Low-Cost Remote Supervisory Control System for an Industrial Process using Profibus and Profinet

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***Abstract*— In this paper we demonstrate two applications of a low-cost remote supervisory control and data acquisition system in two models. The first model is demonstrated with a Profibus-DP protocol based system in which a master Programmable Logic Controller (PLC) unit with control inputs and display outputs controls the speed and monitors the overload condition of a DC motor that is connected to a slave PLC in real time. In the upgraded model, a Profinet protocol is used to connect PLCs, and a power-line communication link is used to remotely connect the control HMI to the network. In both models, remote Supervisory control is achieved using user-defined control functions that act altogether as a block-oriented function library or toolbox. High levels of performance are achieved in real time control and data acquisition in both models.**

Keywords—SCADA; Profibus; Profinet; Programmable Logic Controller

I. INTRODUCTION (*HEADING 1*)

Supervisory Control and Data Acquisition Systems (SCADA) are commonly used in factory settings to provide a centralized control and monitoring of processes in industrial plants [1-6]. These systems originate from the Visicode system which was developed in the 1950's by Westinghouse and North Electric Company and was based on telephone wires [1]. Since the 1960's, SCADA systems have been widely used in industrial plants to remotely monitor and control the different processes [2]. The start of the 2000's saw a trend in SCADA systems that are based on portable computers, in which the systems consisted of a master computer unit that may be connected to Programmable Logic Controllers (PLCs), and field devices such as actuators, motors, CNC machines, and sensors. The master control unit is equipped with a sophisticated software such as Matlab [3] and LabVIEW [4] to perform the control functions as well as a capability to be interfaced to the PLC devices. However, due to the improvements in processing capability, recent years saw an increase in PLC-based SCADA systems [5] [6] [7].

Although SCADA systems evolved as a result of implementing the decades-old Computer Integrated Manufacturing paradigm, these supervisory control systems have adapted to the recently developed technologies that constitute what came to be known as Industry 4.0 and the Smart Manufacturing paradigm such as Internet of Things (IoT) and Cyber-Physical Systems (CPS) [8] [9]. SCADA systems are also used in a wide range of applications from simple DC motor control to water and gas distribution systems [5] [6].

However, for a typical SCADA system, the initial cost can be remarkably high (tens of thousands of dollars) due to the use of high level software and interfacing equipment [10]. SCADA software packages can range in price from $9,950 up to $21,895 [11]. In addition to that, the system requirements for the central computer operating the SCADA system could require external packages and hardware upgrades which increase the total cost of the system [11].

Due to the progress in fieldbus networks, the 1990's saw a shift in process control systems towards interconnecting field devices and controllers in multi-point networks from the older models that used simple point-to-point connections [12]. The deterministic response time, reliability, and effectiveness in real time response of fieldbus networks made them a preferred choice for distributed process control systems [12] [13]. The first decade of the 21st century however, saw a gradual increase in the use of ethernet-based network technologies that are based on TCP/IP protocols in field level communications, the delayed introduction of ethernet TCP/IP technology in the field level was particularly due to lack of deterministic response time [14].

In this paper we present an application in two constructed experimental systems that demonstrates a low-cost supervisory control and data acquisition system in which only PLCs are used, and demonstrated the method in two different models that are Profibus-based and Profinet-based. In the first model, we demonstrate the method on speed control of a dc motor with the capability of overload sensing and protection. In the second model, we demonstrate the method on a complex process that includes multiple PLCs of which each is equipped with its own sensory elements and actuators, a vision system that is used for quality check, a Human machine interface (HMI) panel at the field site, and a HMI panel for control at a remote site. A high-level of Performance of the supervisory control and data acquisition is verified for the two systems in real time.

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II. DEVELOPED MODELS

A. Profibus-Based Model for Real Time DC Motor Control with Overload Current Monitoring Capability

In this model a Profibus network is setup as the means for deterministic communication between the PLC devices. Initially came to public attention by the Department of Education and Research in Germany in 1989, Profibus quickly became one of the standard IEC 61158 fieldbus communication protocols.

With the Profibus standard, a master-slave model is used for communication between the master PLC and the slave devices through a Profibus-Decentralized Peripheral (DP) network. In the Profibus-DP network, communication is established using a standard 2-core screened cable at a speed of 1.2 Mbps and using RS-485 ports. The developed process control and data acquisition model was tested on a DC motor for speed control and overload sensory and protection using a Siemens S7-315 PLC as the master PLC and equipped with the proper digital and analog input and output modules, and a S7-314 PLC as the slave station. This model is illustrated in fig. 1.

In this model, a “toolbox” of control and data acquisition functions is developed. A potentiometer that is connected to the master PLC is used to control the speed of a dc motor that, in turn, is connected via a dc drive to the slave plc. Speed and load current data that are obtained from the slave PLC is displayed on a LCD display that is connected to the master PLC. In the case when an overload current is detected by the slave PLC, the master PLC initiates the motor turn-off procedure, with a time constraint that is controlled by the user. A block-oriented approach is used in which program blocks are developed to achieve different functionalities, that altogether constitute a toolbox of functions as shown in Fig. 2. Organizing functionalities in a ”toolbox” of function blocks is commonly used to facilitate programming and control for end-users [15] [16]. The deterministic response feature of the Profibus standard ensures that response to the overload current is executed within a time constraint after initiation of the response by the user. Furthermore, the different control and data acquisition functionalities are created in separate functional blocks, and arranged in a toolbox (similar to a library) of functions that can be used for easier programming, in what can be a called a Function-Oriented Programming method.

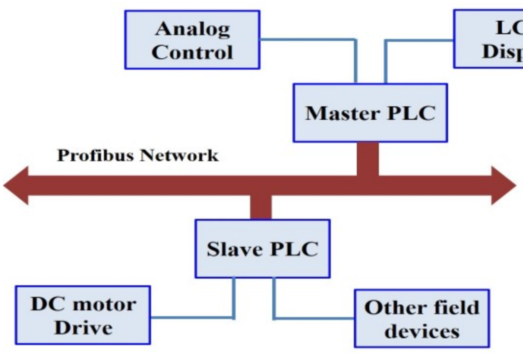

Fig. 1: In the first model, a Profibus-based SCADA system is developed for remote real time speed control and over current protection of a DC motor and acquisition of current data, in a Master-Slave model.

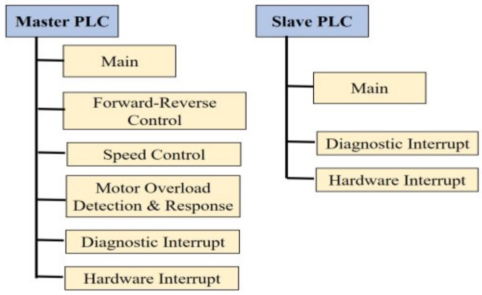

Fig. 2: The control functionalities are organized in a “toolbox” of function blocks that can be used for supervisory control of motors and machines connected to slave PLCs over the network.

The results show a high-level of performance in achieving real time control and data acquisition over the network. This model is illustrated in the Youtube video titled: Speed Control of a DC Motor by a Supervisory Control PLC connected over Profibus Network, the video is available at: https://www.youtube.com/watch?v=GcjU6tpsR9c&t=28s

B. Ethernet-Based Model for Remote Real Time Supervidory Control and Quality Check with a Vision System

This model is an upgrade of the previous one. In this model, the physical layer is an ethernet port and transmission speed is significantly higher than the profibus-based model (100 Mbps compared to only 1.2 Mbps in the Profibus-based model). While network collisions are avoided in Profibus-based models using the Master-Slave protocol, in the Profinet-based model, collisions are avoided using switches. In addition to these features, Profinet uses standard ethernet, and thus can be easily setup to incorporate standard wireless transmitters and receivers.

The HMIs used are Simatic KTP700, and the PLCs were of the S7-1200 family of PLCs manufactured by Siemens. The remote HMI is connected to the network switch via 100 kHz power line communication [17] modules. The remote and the field HMIs have the same functionality, i.e. control of the process and data acquisition from the field devices. All the three S7-1214 PLCs and HMI devices are connected to the network through the switch. The network setup is shown in **Fig. 3**.

III. EXPERIMENTAL SETUP

To demonstrate the capability of the system to achieve real-time remote-control and data acquisition, we developed a process with an added complexity, in which bearing balls of different colors are packaged and controlled using the second model.

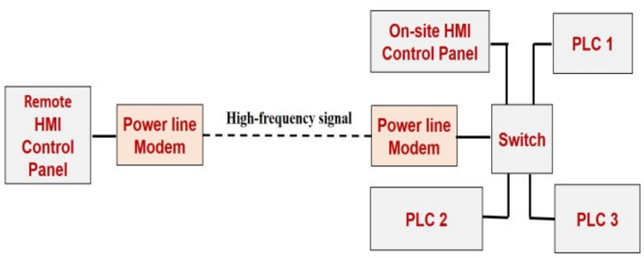

Fig. 3: In this model, a Profinet-based SCADA system is developed in which remote control and data acquisition is performed via an HMI panel that is connected in the Profinet network and a remote HMI connected through a Pwer-line communication link.

In the demonstration process, field devices are connected to each of the three PLCs to simulate a complex assembly process and include solenoids, control relays, limit switches, push buttons, photoelectric and different sensors. In addition to that, the process includes a vision system (Keyence CV-X202 system) for quality check; and was performed over three steps. The NEMA Electrical schematics of the system are shown in **Fig. 4**.

In the first step a cap is dispensed by means of a lab-built motor-driven slider-crank mechanism, and transported to an assembly station over a conveyer belt. A container is also dispensed concurrently from another station controlled by another PLC. A third PLC performs the assembly and quality check, in which the rolling element is placed in the container, the vision system is used to process the color and shape of the rolling element, followed by placing the cap over the container. Finally, the assembly is placed is classified based on bearing color by means of a solenoid-driven accept/reject mechanism.

The entire process was fully-controlled in real time, remotely and on-site, in both an automated and in a manual mode. In manual mode, control is achieved step-by-step via the remote or the on-site HMI panel, with access to data acquired from the sensory components on each PLC in real time. The simulation process that was built to demonstrate the real-time operation of the model is shown in **Fig. 5**. and a video demonstration is found at: https://youtu.be/ut5_840LgeY

IV. Supervisory Control Library (Toolbox)

A toolbox of functions was then developed in a Block-oriented programming fashion, in which functional blocks are used and organized in a function library or “toolbox”. In the first model, functional blocks are used to attain certain control functionality, such as a Reset function block, Overload shut down procedure function block, Motor Forward-Revers Control, Motor Speed Control block. The function blocks form altogether a toolbox of functions for different motor control actions. In the second model, function blocks were organized to achieve independent control capability for each PLC device. The function blocks are illustrated in **Fig. 6**.

V. Multimedia Demonstration

The reader will find a demonstration video of the first model at: https://www.youtube.com/watch?v=GcjU6tpsR9c&t28s and a demo video of the second model at the address: https://youtu.be/ut5_840LgeY

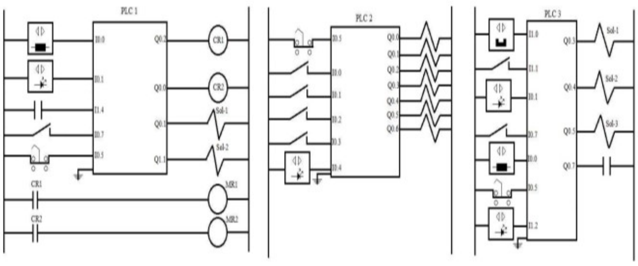

Fig. 4: Electrical schematics of the second model show a complex assembly process that is simulated with different field devices connected to each PLC in the experimental setup to demonstrate Real-time operation of the model.

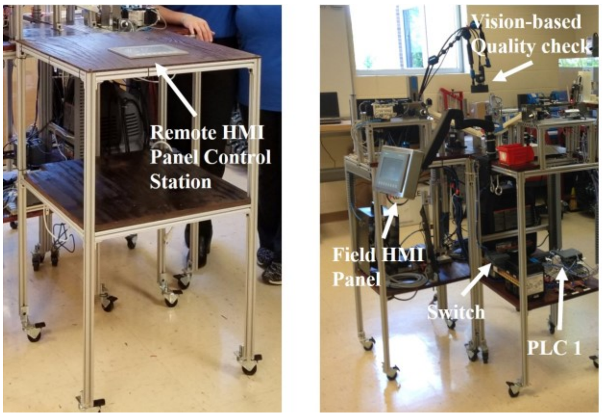

Fig. 5: The experimental Profinet-based model with the remote HMI control panel station (Left). The Remote HMI control station is connected to the network in real time via a power-line communication link.

VI. Conclusion and Discussion

Two models were demonstrated for low-cost supervisory control and data acquisition systems. In the first model, speed and overload monitoring and control of a DC motor in real time are demonstrated using a Master-Slave PLC network over the Profibus standard. In the second model, an experimental process is setup that includes multiple PLCs equipped with recently-introduced quality check systems such as a vision system, and commonly used sensory and actuator equipment that are used for a demonstrative bearing packaging process. Remote supervisory control and data acquisition is achieved by a HMI panel connected to the network via a power-line communication link in real time. An on-site HMI is also connected via the Profinet and achieves the same functions as the remote HMI. It can also be wirelessly connected over the Profinet network.

A toolbox of functions is developed to achieve a high level of programming flexibility by employing the block-oriented programming technique. Tests with the power-line communication link show that real time operation is achievable, however, limitations of utilizing this communication link include low achievable ranges and noise interference, as this communication medium is considered “hostile” for transmitting data, due to the impedance changes, attenuation, and noise resulting from voltage and current spikes from equipment and machines [17].

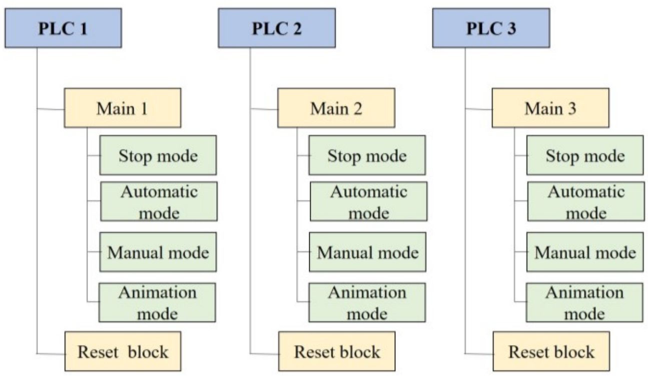

Fig. 6: Block-oriented programming is employed with functional blocks to facilitate troubleshooting and controllability.

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