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Optimizing Industrial Operations with PLCs: A Deep Dive into Data Exchange

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This study examines the critical role that Programmable Logic Controllers (PLCs) play in enabling data sharing in the context of Industry 4.0, a paradigm-shifting technology. The paper examines the advantages and difficulties of PLC-based data interchange through a thorough case study of a project using PLC for real-time energy parameter display on a dashboard. The scope of Industry 4.0 is covered in this paper, which also looks at important technologies and the advantages and disadvantages of smooth data flow. The study concludes by highlighting the importance of PLC technology as a fundamental tenet for efficient data interchange.
Keywords: Remote Patient Monitoring, Data Analytics, Personalized Healthcare, Internet of Things.

1. Introduction

The history of industrial revolutions highlights significant milestones in technological and production advancements. The first revolution, which began in the late 18th century, introduced steam and water-powered machinery, leading to mechanized production. The second revolution, starting in the late 19th century, harnessed electrical energy to enable mass production. The third revolution, emerging in the 1970s, utilized electronics and internet technologies to drive automation and digitalization in manufacturing [1-9].

Currently, the fourth Industrial Revolution is underway, focusing on transformative objectives [1, 2, 3, 5], [10-20]:

- Implementing human-machine interaction (HMI) paradigms.
- Optimizing production in smart factories through IoT technologies.
- Introducing innovative services and business models within the value chain.

- Enabling tracking and monitoring of parts and products.
- Facilitating automatic and flexible adaptations in production chains.
- Enhancing communication among parts, products, and machines.

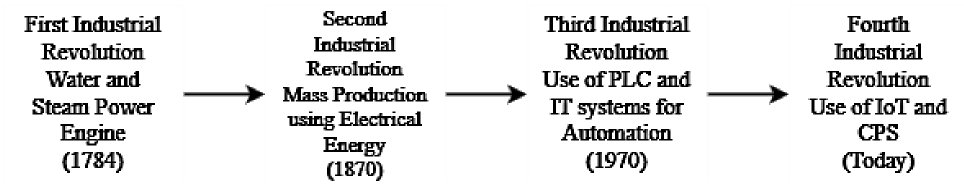

Fig. 1 The Four Industrial Revolutions

PLCs, which were initially intended to replace electromechanical components like relays, have developed into fully functional standalone computers capable of carrying out intricate computations and mathematical tasks as industries have changed. Driven by Industry 4.0 or IIoT, digital enterprises, and platforms for data-driven decision-making have proliferated manufacturing. [21-35]

This paper explores the critical function that PLCs play in Industry 4.0 data exchange. We start by going over the fundamental ideas and technological advancements that are fuelling this industrial renaissance, emphasizing the importance of smooth data flow. We then go into the features and functionalities of PLCs, describing how they interact with other systems and devices, link to sensors and actuators, and eventually serve as data gateways to higher-level platforms.

Based on an extensive case study of a project that uses PLCs for an Energy Dashboard that updates in real time, we examine the specific advantages and difficulties of PLC-based data sharing. To close the gap between theoretical ideas and practical application, we will look at the practical application of PLCs in a particular setting.

Lastly, we move the conversation past the case study and examine the larger potential and problems that Industry 4.0's data sharing presents. We discuss important issues related to labour skills, security, and interoperability while highlighting the promising possibilities for new applications, better decision-making, and environmentally friendly manufacturing techniques.

Our goal with this paper is to shed light on the transformative potential of PLC technology for the future of industrial automation, as well as its critical role in Industry 4.0 data interchange.

2 2. Industry 4.0 and Data exchange

Industry 4.0 emphasizes transforming conventional machines into intelligent, self-aware, and self-learning systems to improve their functionality and streamline maintenance management based on external interactions. The vision of Industry 4.0 is to create an open and intelligent manufacturing platform that supports industrially networked information applications.

Key requirements for achieving Industry 4.0 include real-time data monitoring, tracking the status and position of products, and storing operational instructions for controlling manufacturing processes. Consequently, seamless communication and efficient data exchange are critical components of next-generation industries.

The core concepts of Industry 4.0 are:

- Industrial Internet of Things (IIoT)
- Cyber-Physical Systems
- Cloud Computing
- Big Data Analytics

2.1 Industrial Internet of Things (IIoT)

To put it simply, the Internet of Things is made up of digital devices with particular software that allows connectivity and physical objects embedded with electrical sensors and actuators.[7] They are all linked to a global networked environment, usually via the Internet. These devices can include almost any kind of acceptable household item, such light switches and kettles, as well as industrial machinery, like pumps and motors. In 2018, the research firm Gartner reported that there were over eleven billion linked items globally [36]. By 2020, this figure approaches 20.8 billion [37]. A significant component of this industrial transformation is the industry Internet [38, 39].

Numerous applications of the Internet of Things have already been implemented, such as monitoring in the domains of transportation, industry, environment, and healthcare [40, 41, 42, 43, 44]. However, we observe that in the new era of Industry 4.0, all participants must adhere to certain standard protocols in order to connect billions of devices. This may give rise to fresh problems with proprietary ownership, security, and privacy. Therefore, creative multidisciplinary research is always essential to solving current issues with fresh perspectives.

2.2 Cyber-Physical Systems

Cyber-physical systems are a type of system in which software and hardware are integrated intimately and enable several modes of communication between the various components. This kind of view is sometimes referred to as "horizontal and vertical integration." Three fundamental integrations are listed in [4, 45] as part of the Industry 4.0 paradigm: (a) end-to-end engineering throughout the whole product life cycle; (b) vertical integration and networked manufacturing systems; and (c) horizontal integration throughout the full value creation network. Manufacturing process automation would result from a fully digitalized and integrated process in both the horizontal and vertical dimensions [46]. The so-called embedded system is one illustration. It can facilitate highly coordinated tasks by establishing a close connection between the computational components and the physical devices [47].

2.3 Cloud Computing

The phrase "cloud" or "cloud computing" refers to a broad category of computational services that provide scalable resources for a range of online tasks. [48, 49] It is regarded as "the fifth utility" in some literature, along with electricity, gas, water, and telephone [7, 50]. Its high performance and low cost make it ideal for storing information, and in recent years, its influence on our daily lives has grown due to its rapid resource sharing, dynamic allocation, and flexible extension capabilities.

The concept of cloud manufacturing, which enables modularization and service-orientation, has emerged as a result of the growing usage of cloud computing [6]. For instance, cloud manufacturing design allows many players from every step of the production process to participate. As a result, the design phase can incorporate both engineer concerns and client suggestions, significantly cutting down on turnaround time. Cloud manufacturing includes features including software as a service, CRM, data analytics platforms, business planning, collaboration, and platforms for data analytics in addition to design [36].

2.4 Benefits of Data exchange in Industry 4.0

The benefits of Data exchange in Industry 4.0 are:

- Enhanced productivity and efficiency: Real-time data insights allow for enhanced production operations that reduce waste and downtime.
- Predictive maintenance: By using data analysis to anticipate probable equipment malfunctions, proactive maintenance can be carried out to avoid expensive disruptions.
- Improved quality control: Constant data collection guarantees uniform product quality and spots flaws early in the manufacturing cycle.
- Enhanced adaptability and personalization Production lines can quickly adjust to shifting demands and unique client preferences thanks to data-driven insights.
- Novel services and business models: Performance-based contracts, data-driven services, and maintenance options are made possible by data analytics.

3 Industry 4.0 and Data exchange

PLCs were first intended to replace electromechanical components found in cabinets, like as relays, which carried out basic control logic. Though they still have certain unique characteristics when compared to other control system architectures, PLCs have developed into standardized computers. The development of these characteristics was largely complete in the late 1980s. Driven by an extensive programming and configuration framework, the hardware offers a broad range of essentially standardized connection choices (see part 5 of [21]). Increased intelligence and decentralized control are expected to be used, according to trends like Industry 4.0 [28, 29, 30, 31]. With the exception of provided and consumed values, all linked devices are thought of as I/O type devices. Their underlying complexity and behaviours are not understood. PLCs' primary function is to communicate with actuators and sensors.

Therefore, in CPS and IoT, PLCs are situated at the border of the cyber and the physical and the Internet and the Things. Therefore, physical dynamics plays a role in their design in addition to computing and algorithms. Timing becomes essential to proper operation and goes well beyond being just a performance metric. The main functions of a PLC are:

- Sensors and actuators: Collecting real-time data on various parameters like temperature, pressure, and power consumption.

- Other devices and systems: Interacting with robots, human-machine interfaces (HMIs), and other PLCs on the network.

- Higher-level platforms: Transferring collected data to cloud-based platforms for storage, analysis, and visualization.

3.1 Communication Protocols

PLCs can communicate using various communication languages to ensure data exchange within the industrial network. Common protocols include:

- Ethernet/IP: This protocol enables dependable and real-time communication between controllers, sensors, actuators, and other devices by adapting the Common Industrial Protocol (CIP) to conventional Ethernet. One of the most popular industrial protocols, Ethernet/IP is utilized extensively in the process, hybrid, and production sectors. In addition to connectivity with Profibus devices using an IO-Proxy, it enables discovery, on-demand, subscription, event, and method services.

- Modbus: In the application layer of the OSI model, this protocol is a client/server data communications protocol that was first released by Modicon in 1979 for use with their programmable logic controllers (PLCs). A de facto standard for industrial electronic device communication, Modbus is an open, royalty-free protocol. It can read and write discrete and numeric values, and it can communicate via Ethernet and serial. Modbus is straightforward, versatile for a range of data types, and simple to install.

- PROFINET: This protocol, an industry technical standard for data communication over Industrial Ethernet, is specifically made to convey data under time limits. It is intended to be used for equipment control and data collection in industrial systems. PROFINET supports the cascading real-time notion and is built on the provider-consumer architecture. PROFINET specifies parameter setting, diagnostics, and the whole data flow between controllers and devices. Four compliance classes for PROFINET exist, based on the network infrastructure and application requirements.

- OPC UA: This protocol combines all of the features of the OPC Classic protocols into a single, expandable framework. It is a platform-independent service-oriented architecture. OPC UA facilitates the interchange of data and information between different hardware and operating systems by providing functional equivalency, platform independence, security, extensibility, and thorough information modelling. Encryption, authentication, auditing, address space, on-demand, subscription, event, and method services are all supported by OPC UA. OPC UA is a key technology for Industry 4.0 and the IoT.

4 Case Study: Energy Dashboard

In this section, we look further into the implementation of an Energy Dashboard and Database using Selec MFM 383a, MODBUS RS 485, Siemens S7 1215 PLC, MQTT and AWS.

4.1 Components of the System

Energy Meters: Selec MFM 383a are one of Selec’s Multifunction meters that come equipped with MODBUS Communication. These meters help us acquire data like Voltage, Current, Active and Reactive Power, Power Factor and Energy Consumption (lifetime).

PLC: For this system we are using a Siemens 1215 PLC. For communication with the energy meters, RS 485 MODBUS has been used. The PLC acts as a Master and the energy meter(s) acts as slave.

For communication with cloud, we are using MQTT (Message Queueing Telemetry Transport). MQTT stands out for its lightweight design, ideal for resource constrained IoT devices, minimizing bandwidth usage and power consumption due to its small packet size. MQTT ensures secure data transmission through options like TLS/SSL, authentication protocols, and access control. The data is formatted into a JSON object as such.


```
{
  "V1": 2.334100E+2,
  "I1": 1.666200E+0,
  "PF1": 9.868000E-1,
  "kW1": 3.838127E-1,
  "kWh1": 3.600000E+0,
  "kVA1": 3.889077E-1,
  "kVAr1": 6.274569E-2
}
```


Cloud Service: Amazon Web Services was the choice of Cloud platform, because of its ecosystem and availability of tools like Grafana. Grafana is open-source analytics & monitoring solution. The data upon arrival to the AWS IoT core, is routed to a Timestream database. It is a time-series database that helps our dashboard work and update in real time. The system also has functionality to generate alerts and send mails/messages to preconfigured addresses when the power factor becomes very poor.

System Design: The Siemens 1215 PLC uses a CB 1241 RS 485 module. For data acquisition from the energy meter, the proposed work involves two primary blocks: the measuring block and the communication block. In the measuring block, energy meters are employed to measure various properties of the distribution system network, such as voltage, current, power factor, frequency, and power at both transmitting and receiving ends. Each parameter corresponds to specific Modbus Register Addresses (e.g., Voltage corresponds to Address 30000, current to Address 30016). The communication block utilizes RS485 communication as a physical layer for gathering data from energy meters, primarily employing the Modbus protocol to operate control systems. The system employs a Master-Slave configuration, allowing only the Master device to initiate requests, with the slaves responding by providing the requested data or performing actions. RS485 is chosen due to its advantages, including two-way communication using a single pair of wires, support for multiple transceivers on the same line, long distance communication capability, and high-speed transmission. The communication parameters include a start bit of 1, stop bit of 1, no parity bit, and a baud rate of 19200 bits/s. The data bits are all converted into Strings and then a concatenated string that contains all the relevant data is passed into the LMQTT Block. A timer was generated to make sure that the data was sent after certain time intervals. The data is sent to AWS IoT core and then using Timestream database and Grafana, a dashboard is created to monitor the energy KPIs (key performance indicators).

Figure 2 Current as on the Dashboard

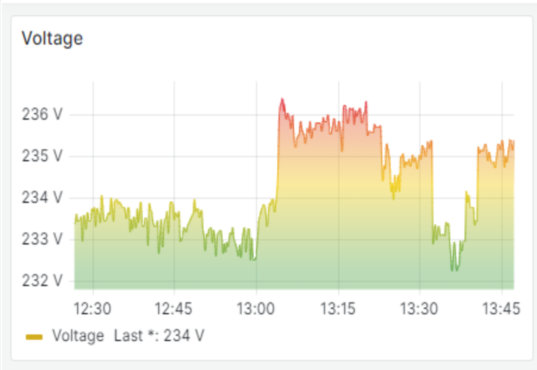

Figure 3 Voltage as on the Dashboard

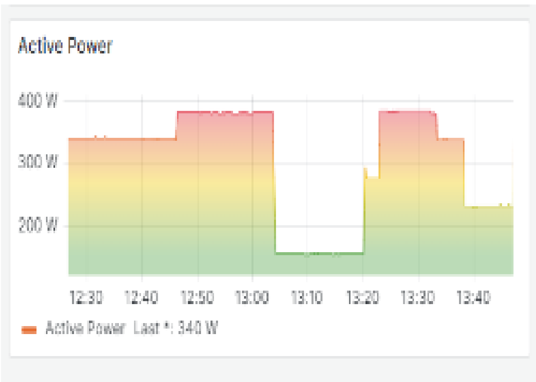

Figure 4 Active Power as on the Dashboard

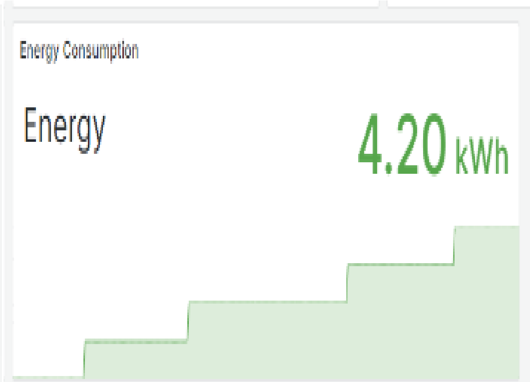

Figure 5 Energy Consumption as on the Dashboard

5. Conclusion

Security and Privacy concerns: Data exchange in Industry 4.0 exposes sensitive information and raises the possibility of cyber-attacks, raising security and privacy issues. Large volumes of data are gathered, transmitted, stored, and processed from a variety of sources and devices as part of data exchange. Personal, proprietary, and sensitive information that must be shielded from unwanted access, alteration, and exposure may be included in this data. Furthermore, data interchange may expose industrial processes and systems to malicious attacks that could jeopardize their dependability, security, or functioning. To guarantee data integrity, confidentiality, and availability, Industry 4.0 data interchange needs strong security and privacy measures.

Data standardization and interoperability: Industry 4.0 data sharing needs uniform formats and protocols to guarantee quality and compatibility. Integration and coordination of diverse systems and devices—which may have distinct architectures, communication protocols, or data formats—are required for data sharing. This could lead to inconsistent, erroneous, or incomplete data, which could have an impact on the effectiveness and results of data interchange. Consequently, in order to provide smooth and dependable data interchange across many platforms and domains, Industry 4.0 data exchange demands data interoperability and standardization.

Workforce shortage: Industry 4.0's data exchange necessitates new, expensive, and scarce skills and capabilities. The usage and administration of intricate and advanced technologies and ideas, like cloud computing, big data analytics, IIoT, and CPS, are all part of data interchange. The current industrial workforce lacks the specific knowledge and experience needed for these technologies and concepts, and they are also not readily available. Furthermore, as technology and concepts change and evolve, data interchange also calls for the capacity to adapt and pick up new knowledge and abilities. As a result, Industry 4.0 data interchange need a workforce that is qualified and skilled enough to manage the benefits and problems of data exchange.

5.1 Opportunities

Creation of new services and applications: Industry 4.0's data interchange fosters innovation and uniqueness by generating new markets and value propositions. Access to vast and varied data sets through data interchange can lead to the creation of novel ideas, information, and solutions. In addition, data exchange makes it possible to develop and provide new services and applications that can adapt to the evolving needs and preferences of stakeholders and customers. The creation of new income streams and business models that can boost the profitability and competitiveness of industrial firms is another benefit of data exchange.

Better decision-making and optimization: By offering real-time insights and feedback, data interchange in Industry 4.0 facilitates data-driven decision-making and optimization. The gathering and processing of data from a variety of sources and devices, including machines, sensors, actuators, and goods, is made possible by data interchange. This data can be used to track and assess the operation and condition of industrial systems and processes, as well as to find and fix issues. Data interchange also makes it possible to optimize and improve industrial systems and processes by giving data-driven actions and recommendations that can raise quality, productivity, flexibility, and customisation while also enhancing efficiency.

Sustainable manufacturing practices: Industry 4.0's data sharing reduces waste, energy use, and emissions to support sustainability and social responsibility. The measurement and management of the social and environmental effects of industrial processes and products are made possible via data interchange. Implementing sustainable manufacturing techniques, such as resource efficiency, waste minimization, energy conservation, and emission reduction, is also made possible via data exchange. Reuse, recycling, and product recovery are just a few of the green and circular economy concepts that can be developed and adopted thanks to data interchange.

5.2 Final Remarks

PLCs are an old but tenacious technology. In our experience, we found that the conversion of data into different formats can be a tedious task, and unnecessarily consume resources available in the PLC. This is mainly due to the limited availability of function blocks we experienced in our case study. Also, we found that there was a character limit of 263 characters that the MQTT library could handle for Siemens 1215. Another issue with PLC we encountered were the limits of RS-485. The theoretical limit 256 devices that 1/8th load each, and maximum 32 devices at full load.

In order to achieve determinism, facilitate virtual prototyping, capitalize on multicore architectures, utilize networking developments such as timesensitive networks (TSN), and bolster safety guarantees, we think it's time to reevaluate the fundamental PLC programming model.

PLCs need to adapt and change with the need of the time. We hope that this paper can point academicians and researchers in the right direction.

Conflicts of Interest

The authors declare that there is no competing financial interest or personal relationship that could have appeared to influence the work reported in this paper.

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