Leasing of Production Control Processes – PLC as a Service in Industry 4.0

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Abstract: Programmable Logic Controllers (PLCs) represent a settled technology that is well established and ubiquitous within the automation of industrial processes. This technology is a significant automation foundation, and PLCs are expected to be needed in the future, even in the era of Industry 4.0. However, these controllers have to satisfy a variety of requirements in new era production paradigms. This manuscript gives a brief overview of the current state of the practice, explaining the main reasons for the persistence of PLC technology, while further examining the possibility of the shift towards the direction of their replacement by a cloud service. Thereby, the introduction of the service paradigm could also play an important role in future industrial automation. This paper discusses such a concept of production control as a service substitution of the traditional PLCs. Its application would significantly increase flexibility by fulfilling Industry 4.0 requirements such as autonomy, interchangeability and reconfigurability, and would allow the creation of new business models that would lease production control processes.

1. INTRODUCTION

From the industrial era, economic laws encouraged producers towards mass production, and later, towards automation of production processes, as a condition for achieving competitiveness of their products in the market. Nowadays, automation is faced with an ever-increasing demand for ensuring the adaptability of manufacturing facilities in context of Industry 4.0 (Legat & Vogel-Heuser, 2017). Field level automation software is, indeed, dominant in making manufacturing resources flexible, and as Legat and Vogel-Heuser (2017) argue, classical programming approaches based typically on signal-oriented languages result in disproportionate effort for ensuring necessary flexibility. The well-established basis for the automation of industrial processes are Programmable Logical Controllers (PLCs). A PLC is essentially a microprocessor device that uses programmable memory to store commands that require the performance of specific functions, such as logic functions, sequencing, counting, timing, computing, to control different types of machines and processes via digital and analogue input-output modules. The key to their success lay in their programming method. PLC programming is conducted by the ladder logic diagram language (Wang, 2021), already present in the industry for projecting logical and sequential relay devices. This language uses graphical notation, visually quite similar to the electrical diagram, thus, it is comprehensible to industrial engineers. In other words, industrial engineers do not have to be programming experts to use PLC controllers in their systems. However, creating ladder diagrams for highly complex processes such as welding of complex parts, loading-unloading, painting, etc. may be possible, as Iskandar, Rameli & Ramadhan (2018) argue, with heuristic methods, but the success of those methods depends greatly on the experience of the programmer. This leads to an ever-increasing level of professional speciali-

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sation, combined with also increased demand for narrow specialised employees (Bogoviz, Gulyaeva, Semenova & Lobova, 2018). Furthermore, in today’s Industry 4.0 paradigm, many new challenges for industries have been raised. Exponentially accelerated technology development and customer habits have led to significantly reduced product life-cycles, increased demand for highly customised products while, at the same time, allowing for reduced development and manufacturing costs. This also, as Sallati, Bertazzi & Schützer (2019) argue, require product engineers, as well as engineering students in universities (Tepe, Aslan & Eminoğlu, 2020), to develop new skills in order to meet these new market requirements. Therefore, several issues have to be targeted such as the reduction in the local demand for specialized manpower able to program PLC ladder logic, reduction in the production of physical devices, and increased flexibility without the reduction of functionality, while at the same time obtaining the ever-present total cost reduction. Based on the literature review, we argue that leasing of production control processes, more specifically outsourcing them as a cloud service, tackles all of these issues and represents a natural step further towards Industry 4.0.

2. PROGRAMMABLE LOGIC CONTROLLERS

PLC is a microprocessor device, or computer, designed for multiple input and output arrangements, extended temperature ranges, immunity to electrical noises, and resistance to vibration and impacts (Budha, Thapa, Park & Wang, 2008). Many different types of PLCs vary in size, appearance and processing power, from small units with small and limited inputs and outputs to large, modular units that can be configured to work with hundreds or even thousands of inputs/outputs. Block diagram of a typical PLC is given in Figure 1. They were developed with the goal of overcoming numerous problems specific for the electromechanical control system based on relays while increasing the scope of their functions, and reliability. Decrease in PLC price, and simultaneously, their increased reliability, made them ubiquitous in industry. Compared to relay technic, PLCs are more compact, cost less, more reliable. Moreover, they allow for relatively easy control logic change. Program ladder diagrams are typically developed on a PC with the help of specialised software with an intuitive graphical interface that, in addition, allows you to check and test ladder programs. The ladder diagram is written to the PLC controller with the help of a programmer, and the registration process itself does not take more than a few minutes. The possibility of fast reprogramming is important because the production process, with minimal downtime, can be easily adapted to new requirements.

![Figure 1. Block diagram of a typical Programmable Logic Controller](image-url)
The first PLC controllers were simple on/off control devices and were used to replace outdated relay technology. However, such PLC controllers could not provide more complex control, such as temperature, pressure, position control. Meanwhile, PLC controller manufacturers have developed and incorporated a number of enhancements and functional enhancements into PLC controllers. Modern PLC controllers have the ability to perform extremely complex tasks such as managing precise positioning and managing complex technological processes. Also, the speed of the PLC controller is significantly increased, as well as the ease of programming. Numerous special-purpose modules have been developed for applications such as radio communication, vision or even voice command recognition. However, PLC operating system is always projected for the specific purpose. It is assumed that, in its basic form, PLC will be used for the realisation of logic functions that translate sensors’ signals to actuator signals. Hence, the PLC is expected to periodically read (input) signals from the sensor, perform a number of arithmetic-logic operations (in accordance with the given function) whose results are transmitted to the executive bodies or some other indicator devices. In addition, with the same or some other frequency, the PLC should maintain communication (exchange data) with some other computer systems in the network. Still, as the need of automation increases significantly, the PLC control system must follow in the footsteps allowing for flexibility, meaning to be easily programmable, but still, robust and cost effective (Alphonsus & Abdullah, 2016). Nevertheless, the complexity and difficulties of programming in adapting to very complex processes remain (Iskandar, Rameli & Ramadhan, 2018). In other words, plants require very skilled ladder logic developers to be constantly available.

3. PLC AS A CLOUD SERVICE

In 1997, author Rullán already discussed personal computers (PCs) as effective devices for the same applications as PLCs (Rullán, 1997). As Rullán (1997) observes, this relationship is established in most cases in Boolean logic. As modern PLCs are computer-like, computer-based devices designed to control processes, PCs also can provide a totally integrated solution that incorporates all of the functions of the PLC, such as the man-machine interface, and the programming terminal, while also providing process simulation/emulation so that complete software development can be done independent of the hardware (Rullán, 1997). However, as Rullán correctly observed at the time, commercial-grade PCs were not designed to withstand harsh conditions frequent in the production facilities i.e., to tolerate the shock, vibration, temperature, and electrical noise (Rullán, 1997). Still, computer technology has advanced significantly in the past decades. More importantly, telecommunication technology has also advanced to the level where SCADA systems can be controlled and managed from remote locations (Bjelica & Lale, 2014; Sajid, Abbas & Saleem, 2016). The past few decades have brought several cellular network generations, e.g., namely from 0G to 5G (Saad, Mehdi & Mingzhe, 2020). Each generation represented an incremental leap in connection speed from Kbps for starting generations, up to 100+ Mbps for 5G. In the relatively near future, further leaps are expected such as 6G and 7G. Sixth generation is aimed to be a ubiquitous ultra-broadband mobile network with ultra-high rate, ultra-high data density and, the most importantly, ultra-low latency (Baiqing et al., 2019). 6G architecture will shrink cells from small to “tiny cells”, but with denser deployment where mesh network and Device-to-Device (D2D) connectivity should become a norm (Saad et al., 2020; Bhat & Alqahtani, 2021; Hoschek, 2021). As Sajid, Abbas & Saleem (2016) also realised, one such solution to fulfil the current needs of industrial systems is the concept of IoT, which involves cloud computing. Still, performance bottlenecks of today’s common Internet of things (IoT) devices such as latency, computing power and storage have to, and should be mitigated by increasing connections to other nodes (Sodhro et al., 2021). These steps to improve the Internet and network communication speed are very important in order
to create a foundation on which to build adequate protocols that should further regulate communication between sensors in production and Cloud service, and vice versa, from Cloud service to actuators or production machines. If this foundation existed, it would be possible to further develop communication protocols in order to, not only ensure timely communication, but also secure it. The final goal is to transfer the whole PLC functionality to the Cloud (Table 1), but along with the imperative of keeping production safe. As Table 1 shows, one of the main concerns for keeping control programs locally is safety and security of production processes. Certain research and development efforts have been invested in virtualisation of complete PLC controllers to outsource them into the cloud, such as a scalable control platform for cyber-physical systems in industrial productions (Langmann & Rojas-Pena, 2016), and a cloud-based controller, which also uses a virtual control system in an Infrastructure as a Service (IaaS) cloud (Langmann & Stiller, 2019).

### Table 1. Industry 4.0 PLC controller capabilities

<table>
<thead>
<tr>
<th>Class</th>
<th>Service Ability (SA)</th>
<th>Control Locality (CL)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>No service</td>
<td>All control programs are encapsulated locally in the PLC hardware.</td>
</tr>
<tr>
<td>1</td>
<td>Services only for non-critical and overarching functionalities</td>
<td>Some control programs that include non-critical and overarching functionalities are not located on the local hardware, but are instead distributed to other systems such as, e.g., in the network.</td>
</tr>
<tr>
<td>2</td>
<td>Services for most functions available</td>
<td>Most control programs are distributed in the network. Control programs that are critical in terms of time and safety remain in the local PLC hardware.</td>
</tr>
<tr>
<td>3</td>
<td>All control functions as services</td>
<td>All control programs are distributed in the network. Third instances can access all the control algorithms in real time.</td>
</tr>
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</table>

**Source:** Langmann & Stiller, 2019.

However, problems with the virtualisation of PLCs result, as Langmann & Stiller (2019) argue, especially from the fact that already available manufacturer-specific PLCs are virtualised. As these authors observe, these controllers, however, are closed systems, which were originally not developed considering the aspects of web technologies (Langmann, & Stiller, 2019). Hence, any eventual modifications of these controllers by third parties would be hardly possible. Cristiani, Demrozi & Tomazzoli (2018) proposed a methodology for converting a plant automation managed by PLCs onto an EFSM control module (EFSM—extended finite state machine) that is driven by single board computers or SoC (system-on-a-chip). Such control module is able use IoT devices, but the control program, as Langmann & Stiller (2019) also observe, cannot be resolved as a cloud service. Summa summarum, different efforts to equip PLC controllers with additional functions, in order to be able to use the controllers in an Industry 4.0 – type IP network, exist. However, deficits also exist, and further research is required in the field of a flexible distribution of the structure and function of the control functionality. Moreover, systematic investigations, architectures, interfaces and demonstration solutions are also lacking.

### 4. CONCLUSION

Production systems, as every business system, always prefer to reduce operational costs. To support such reductions, solutions capable of providing robustness and flexibility are always needed. Cyber-physical integration with the Internet of Things (IoT), and Cloud computing services are the step further. Transformation of PLC towards the service paradigm is, as we see it, inevitable. ICT components are already increasingly present in PLCs, especially when the system is aimed to represent a sub-system of SCADA. Three different approaches emerge as necessary to allow
PLC controllers to be Industry 4.0 compatible and these are the inclusion of the basic web technologies, the global networking of process data and the introduction of service principles. Significant steps in that direction have already been made, primarily on an infrastructural basis. Fast and resilient Internet of extremely low latency is already being widely developed and this should enable real-time communication within the production system and cloud service. The next step is the development of protocols and the physical IoT components themselves in production machines that will be able to use Cloud functionalities. Finally, it is necessary to develop in parallel the entire service environment that will represent a separate business model, and unite experts and developers within clusters who are highly specialized in this field. It is realistic to expect that such a model of production process management will contribute to the overall reduction of production plant costs, eliminating, by outsourcing, specially trained workforce whose presence is now necessary in each complex production system separately.

REFERENCES


ADDITIONAL READING
