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Methods of data streaming from IEC 61499 applications to Cloud storages

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Abstract—**This paper presents and discusses two methods for collecting data from decentralised control applications designed in IEC 61499 architecture. The topic is justified by the growing use of Cloud-based storage and presentation services in the Internet-of-Things systems. Enabling IEC 61499 devices with the capabilities of storing data in the Cloud and using web-based data presentation and data analytics is of great practical importance. Moreover, what is the most elegant way to configure such data streaming in IEC 61499 is an open question, to solving which this paper aims to provide state-of-the-art information.**

Keywords: **IEC61499, data streaming, OPC UA, Cloud services.**

I. Introduction

Data is the new blood of the industry, and collecting and analysing data is a necessary part of modern industrial automation applications.

IEC 61499 is an international standard for the design and implementation of PLC-based distributed control systems [1] quickly gaining supporters in industry. It extends the popular standard IEC 61131-3 [2] with provisions of distributed systems design. One of the key advantages of IEC 61499 is that it supports the development of modular and flexible control systems. This standard effectively bridges the gap between IOT and automation worlds, providing a software architecture for distributed networked systems combining devices of various scales - from smart sensors and actuators, to programmable logic controllers (PLC) and edge and cloud based services. Naturally, the users of IEC 61499 are interested in design guidance for efficient use of external storage and data visualisation services. By leveraging cloud storage and data visualization services, IEC 61499 users can improve scalability of the distributed control systems, make more informed decisions based on data analysis and support integration with monitoring and analytics tools, providing a comprehensive view of the system's behavior. This approach aligns well with the Industry 4.0 vision, which emphasizes digitalization, interconnectivity, and data-driven decision-making. At the moment there are no universal approaches to data streaming from IEC 61499 applications, no narrative approach is offered by the standard, and often users are forced to resort to developing their own specialized solutions.

On the other hand, OPC UA is an established technology for data exchange in automation systems. OPC UA is used to provide access to PLC data for various clients, e.g. SCADA and HMI systems. Initially based on client-server architecture, it is being extended to cover peer-to-peer topologies, and also could possibly be used for delivering PLC data to the Cloud.

In this paper, two methods are presented for collecting data from decentralised control applications designed in IEC 61499 architecture. The purpose of this paper is to provide design guidance for the implementation of data streaming from IEC 61499 applications, which can be used as a starting point for proposing a native approach within the IEC 61499 framework.

The paper is structured as follows. In Section II a brief overview of most relevant publications is given. Section III elaborates on basic concepts of IEC 61499 and OPC UA. Sections IV and V present cases studies, one based on the communication features of IEC 61499 and the other of OPC UA. The paper is concluded with discussion in Section VI.

II. Related works

Industry 4.0 offers a digital transformation of industrial processes and imposes strong requirements for flexibility and optimization of automated systems. One of the necessities to achieve the Industry 4.0 goals is the development of unification technologies and adaptation of common protocols and standards for safe, seamless, and interoperable communication of devices and systems.

Currently, the efforts of many researchers are focused on overcoming the heterogeneity of industrial protocols, devices, and systems. Garcia *et al.* [3] discuss the use of IEC 61499 in combination with OPC standards. The paper describes ways that can provide digital transformation of the oil and gas industry to achieve the benefits of adopting Industry 4.0 approach. The authors elaborate set of IEC 61499 Service Interface Function Blocks (SIFBs) for the encapsulation of functionality supported by OPC UA services. SITBs allow the configuration and operation of an OPC UA server in static and dynamic modes, as well as the implementation of an OPC UA client for reading and writing data from an OPC UA server.

To avoid manual configuration of OPC UA connectors, the associated drawbacks like the lack of flexibility and time and safety loss, Lyu *et al.* [4], [5] proposed an algorithm and software for automatic generation, complementing IEC 61499 applications with OPC UA server interaction.

The next level of unification has been achieved in Seilonen *et al.* [6] and Dai *et al.* [7] publications, where authors developed OPC UA information models for IEC 61499 applications. The OPC UA information model describes the IEC 61499 concepts within the capabilities of the OPC UA address space model. The model encapsulates a model of function blocks, a model of devices, and a model of resources. The developed OPC UA wrapper is an implementation of IEC 61499 informational model and allows the IEC 61499 runtime to be integrated into an OPC UA system.

Dai *et al.* [8] discussed two different methods of data acquisition which are OPC UA and OPC UA Pub/Sub. Those two OPC protocols have different architectures where OPC UA is N-to-1 and OPC UA Pub/Sub is N-to-N. Since OPC UA is based the client/server model, the communication connections are always hold between the client and the server, while OPC UA Pub/Sub supports more loosely-coupled connections. Publishers and Subsribers don't need to have consistent communication channels, which makes this protocol more flexible and scalable.

Since cloud architectures play a significant role in Industry 4.0, there is an urgent need to develop modern methods of integration of IEC 61499 technologies into Cloud architectures.

III. Supporting Technologies

A. IEC 61499

IEC 61499 programs are based on an object-oriented approach and consist of a graphical network of Function Blocks (FBs) as exemplified in Fig.1.

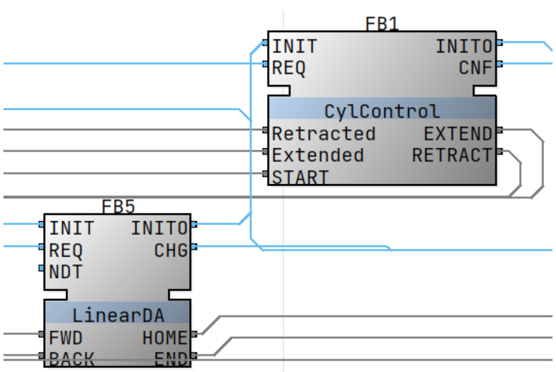

Fig. 1: Example of an IEC 61499 function block network (FBN).

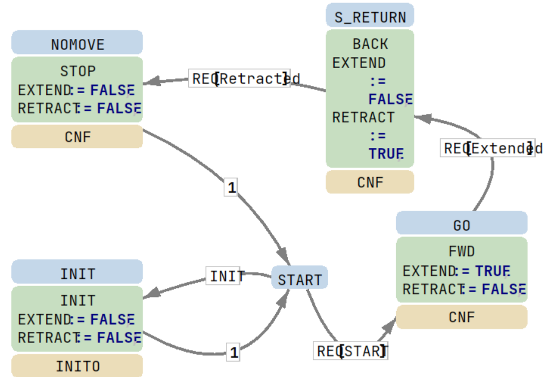

Fig. 2: Example of an IEC 61499 Execution Control Chart (ECC) diagram in the graphical notation of FBME tool [9], [10].

Each type of FBs has an interface that includes input and output data and event ports. Function blocks may be Basic or Composite. Execution control Chat (ECC) defines the inner logic of the basic FB (Fig. 2). ECC is an executable state machine managed by input events and logic conditions. One Composite function blocks consist of a network of basic and other composite blocks. Emerging events manage the order of FBs activation in the network.

B. OPC UA

OPC UA (Open Platform Communications Unified Architecture) is a machine-to-machine communication protocol that is widely used in manufacturing automation and process control systems [11]. OPC UA provides a unified interface for exchanging data between different devices, platforms, and applications. OPC UA is based on Client-Server architecture. OPC UA hierarchical data model allows for easier interoperability between different systems and devices. It is a structured and standardized way to organize and access data in an OPC UA server for modeling data and methods. The data model is stored as a tree-like structure, where each node corresponds to objects and attributes that are used to describe the controlled system.

OPC UA provides scalability - it can cover a wide range of devices, from small embedded devices to more complex ones. OPC UA architecture consists of several layers, including the transport layer, session layer, presentation layer, and application layer. Also, OPC UA achieves scalability through support for various communication protocols. Since OPC UA is designed to provide security in every aspect of its architecture, it embeds encryption, fault tolerance, access control, etc.

C. LEAP

La Trobe Energy Analytics Platform, or LEAP as it will be referred to from this point onward, is a technology platform which supports the monitoring and analysis of the energy usage of 50 buildings across all of La Trobe's campus. LEAP was conceptualized for the purpose of decarbonizing the La Trobe university campus by 2029 as part of its net-zero emissions target. LEAP brings together disparate data sources (such as energy consumption, climate conditions, work schedules and heating/cooling aggregates etc) and utilizes Artificial Intelligence (AI) techniques such as deep learning, machine reasoning and optimisation algorithms to provide actionable insight into the energy usage, usage predictions and performance Key Performance Index (KPIs).

IV. Use case 1: Data streaming with communication function block

The system shown in Fig.3 is a laboratory scale model of a building management system (BMS), called BMS wall. This wall is built to demonstrate opportunities for flexible networked control in building automation systems with IEC 61499. The wall includes a number of sensors (illumination, proximity), switches, lamps and curtains, which simulate the "smart house" system behaviour. It also includes two smart electric meters.

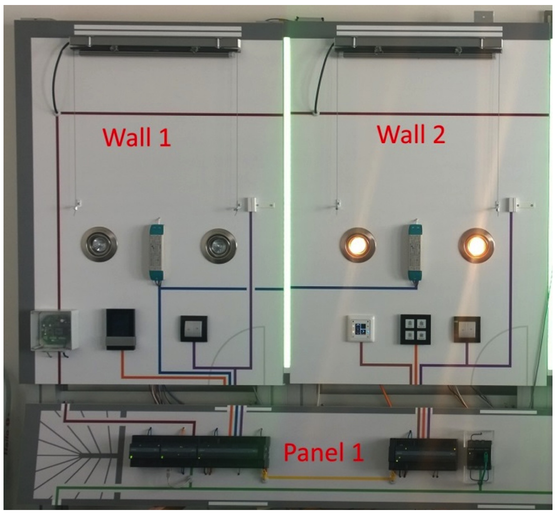

Fig. 3: Building automation model BMS Wall.

The control of the wall is implemented with an IEC 61499 application which is deployed into four control devices seen in the lower part of the photo. The distributed control and information processing infrastructure of the wall is depicted in Fig.4.

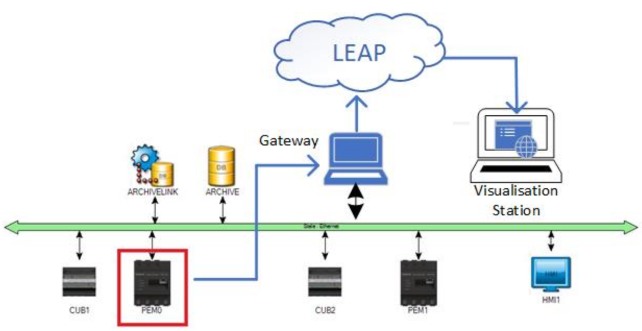

Fig. 4: Structure of the control network.

The device PEM0 encircled with the red rectangle is a smart meter. In addition to the IEC 61499 compliant devices, there is a gateway device added and a visualization device. The gateway is needed to re-transmit the data received from an IEC61499-compliant device to the Cloud in HTTP format. The visualization device is a computer with a web browser, where the data of interest can be visually presented.

The IEC 61499 application executed in this device is shown in Fig.5[1]. The measured active power and active energy are available as software variables, outputs of the function block EnergyVis, executed in PEM0. Suppose the active power measured by the smart meter is of interest to be observed through an external web-based visualisation application. This value is the output "activePower" of the function block EnergyVis.

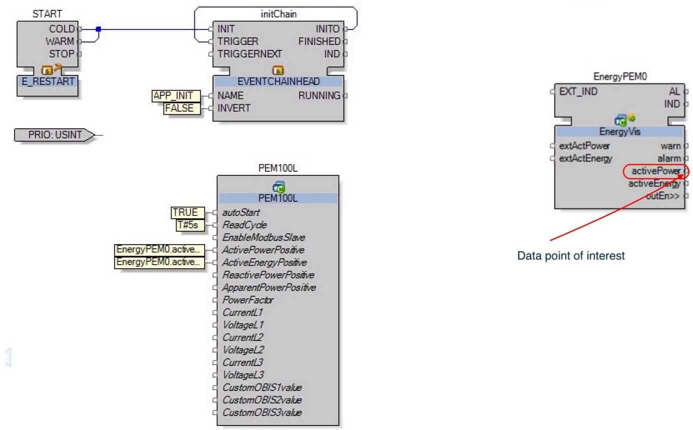

Fig. 5: Function block application executed in the smart meter device.

Fig.6 shows the application augmented with the function blocks for data transfer. The key role here is played by the NETIO function block that communicates the data assigned to its parameter SD over the network. The address of the receiving party is specified by the parameter ENDPOINT, which is assigned to the value `"UDP:8080;10.135.109.92"`, specifying the IP address of the gateway.

The value of interest is connected via the data connector first to the data conversion function block of type ANY2ANY and then to the input SD of the NETIO.

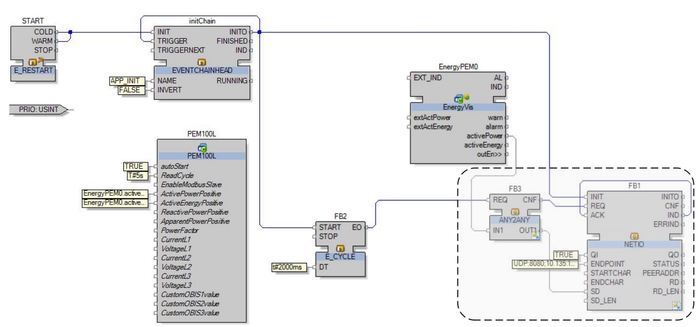

Fig. 6: Function block application augmented with the data streaming function blocks.

The gateway receives the measurement data in STRING format using a UDP socket and sends messages to the LEAP

[1]One should not be confused by the fact of some function blocks are not connected to others, even to the initialisation event of the resource: these are composite blocks and their initialisation is implemented internally. Discussion of their internal content is beyond this paper's scope.

in the format illustrated in Fig.7. It should be noted that the gateway is, in principle, not necessary, its use is explained by the particulars of the IEC 61499 implementation which did not include a function block for the direct sending of HTTP messages from within IEC 61499 applications.

On the LEAP side, the architectural diagram of LEAP is shown in Fig.8. LEAP aggregates disparate data sources through its data lake before it can be processed by the analytic engine. A data lake is a central repository for the storage and processing of disparate data (be it structured, semi-structured or structured data). All the data that is to be processed by the LEAP platform must enter the data lake where it is processed to the correct format before analysis. Since LEAP will be deployed on the Azure cloud services, an Azure IoT hub is used to provide two-way communication between the LEAP platform and any connected IoT devices. In the context of this paper, an UDP connection is created on the IoT hub, where it can directly receive UDP packets sent from the data streaming function block before passing onwards to the data lake. Once the data is uploaded to the data lake, the LEAP platform can carry out its various analytical functionalities and visualize its results in a plethora of visualisation opportunities, as exemplified in Fig.9.

V. Use case 2: based on OPC UA

One can assume that all IEC 61499 compliant devices have an embedded OPC UA server, which can easily configured with the help of an Integrated Development Environment, such as EcoStruxure Automation Environment (EAE). Therefore the problem of streaming data to the Cloud reduces to the problem of streaming data from an existing OPC UA server.

Fig. 10 illustrates the use case where OPC UA Pub/Sub is used for data streaming between the local control system and cloud-based simulation models.

This use case's objective is to create a Simulation-Based Digital Twin (SBDT) utilizing the OPC UA Pub/Sub standard and cloud deployment. The cloud-hosted SBDT is intended to imitate a heat production plant (HPP). Using OPC UA Pub/Sub, the HPP will be able to connect with a local control system controlling a local water heating system.

To guarantee that the SBDT is always in sync with the physical plant, a dynamic estimating procedure is used to follow process data and correct the model accordingly. Based on this method, the SBDT is able to optimize and accurately forecast the performance of the process.

Fig. 10 presents the system architecture of using OPC UA Pub/Sub as the communication standard for streaming data from a local control system to a cloud-based simulation model.

The data is transmitted via an OPC UA Publisher with a broker endpoint. Subscribers are able to subscribe to topic queues and retrieve data that has been published. The Online Simulation Manager (OSM) is a Semantum-developed application used to deliver instructions to the Apros simulation program. A subscriber of the OSM subscribes to the HPP topic queue. The OSM utilizes Apros to simulate the first-principle model. Users are able to observe the current condition of the system via visualization.

This use-case is relevant to this paper's goal because the simulation-based digital twin is running on an Amazon Web Services (AWS) EC2 instance. The SBDT interfaces with the onsite Heat Producing Plant through OPC-UA Pub/Sub. In addition, the SBDT is linked to Apros and InfluxDB for data visualization. Thus, the Heat Production Plant could be remotely monitored, and process activities can be optimized and accurately forecasted. In this use case, OPC UA Pub/Sub proves it capabilities including flexibility in the environment where hybrid computing devices are involved.

VI. Discussion and future work

In this paper, we presented two examples of implementing data streaming to the cloud storage and visualisation services in IEC 61499 applications. The developed approaches allows to stream date which let us compare their pros and contras. Direction for further research - compare different approaches by following metrics:

- Performance overhead.
- The ease of use in terms of engineering effort.

Based on comparison of these characteristics, the next step would be to propose a native IEC 61499 solution for implementing the same.

Use case 1 demonstrates an approach how to collect and stream data from IEC 61499 applications to the Cloud. The approach is based on the LEAP cloud platform oriented on analysts and monitoring of energy data. However, strict adherence to one cloud platform can cause problems in the flexibility and reconfigurability of the entire system in the future. In addition, the presence of the intermediate gateway is unnecessary and complicates the architecture of the system. The problem may be solved by the integtation of specialized IEC 61499 function blocks for HTTP communication. There is also a possibility of data discrepancy due to the lack of communicaion between BMS Wall and the information stored in the cloud. In the future, the information model OPC UA can be used to describe the system.

Use case 2 demonstrates how to apply OPC UA Pub/Sub in the development of automation systems. OPC UA Pub/Sub supports flexible and scalable communication among different software components crossing cloud/edge platforms to shop floor. Since data streaming quality crossing hybrid computing platforms is highly relied on network condition, OPC UA Pub/Sub enables micro-service-like IEC 61499 components more robust and reliable compared to OPC UA. However, OPC UA Pub/Sub is not yet natively supported by current IDEs. It requires additional effort and cost to enable OPC UA Pub/Sub in IEC 61499 systems.

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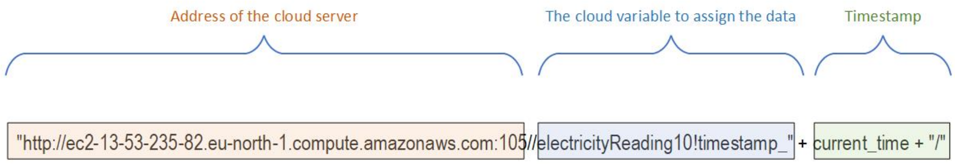

Fig. 7: HTTP message sent from the gateway to the cloud service.

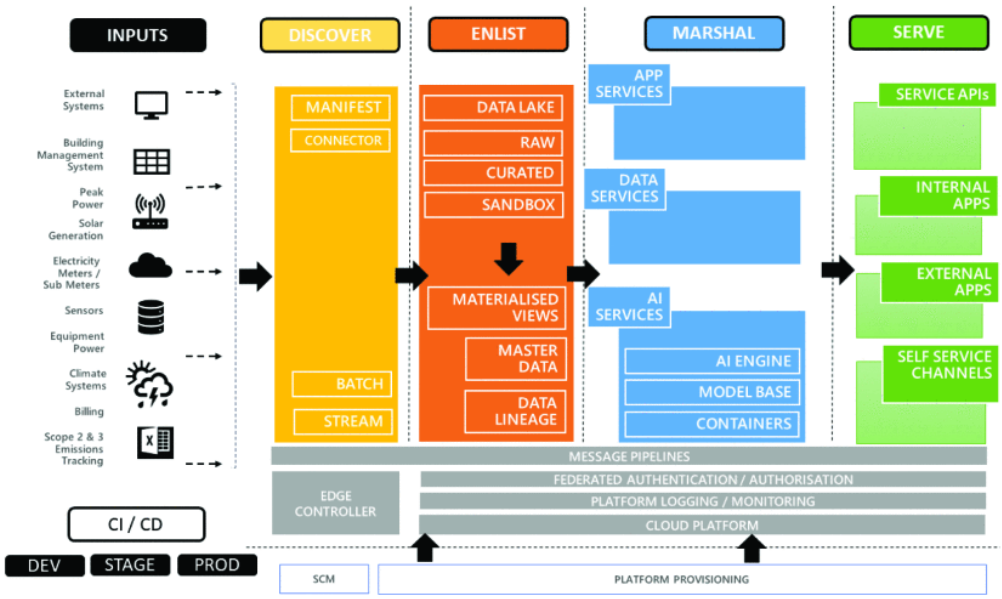

Fig. 8: LEAP platform architecture. [12]

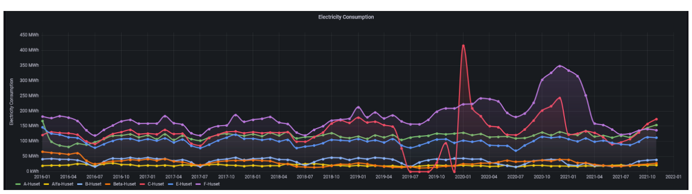

Fig. 9: An example of LEAP visualisation of data.

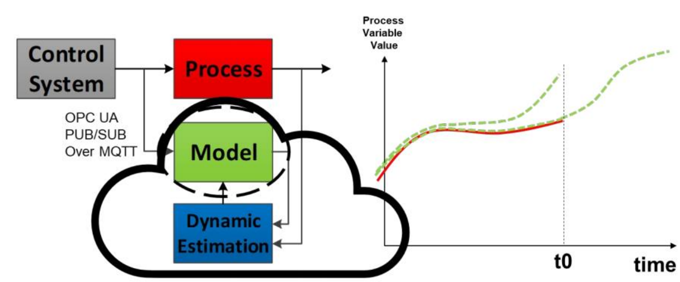

Fig. 10: Illustration of simulation-based digital twin and its ability in predicting process variable value via OPC UA Pub/Sub

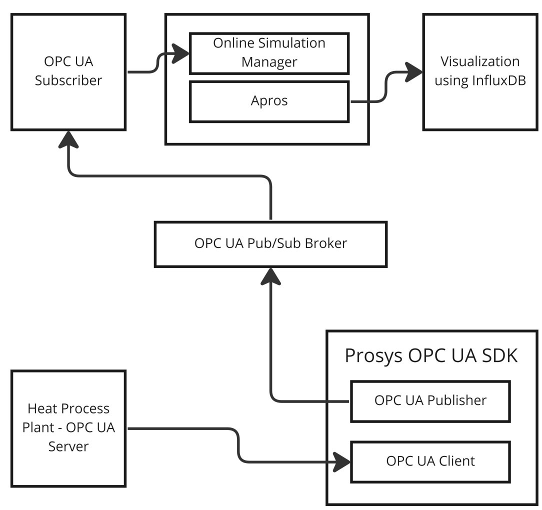

Fig. 11: System architecture and data flow

References

[1] "IEC 61449-1: Function blocks – part 1: Architecture," International Standard, 2012.

[2] "IEC 61131-3: Programmable controllers – part 3: Programming languages," International Standard, 2013.

[3] C. A. Garcia, G. Caiza, and M. V. Garcia, "Oil and gas upstream sector: The use of iec-61499 and opc," in *Handbook of Smart Materials, Technologies, and Devices: Applications of Industry 4.0.* Springer, 2022, pp. 1–32.

[4] T. Lyu, U. D. Atmojo, and V. Vyatkin, "On automatic generation of OPC UA connections in IEC 61499 automation systems," in *2022 IEEE 5th*

International Conference on Industrial Cyber-Physical Systems (ICPS). IEEE, 2022, pp. 1–6.

[5] ——, "On enhancing reconfigurability of i/o connection and access in iec 61499," in *2022 IEEE 31st International Symposium on Industrial Electronics (ISIE)*. IEEE, 2022, pp. 818–823.

[6] I. Seilonen, V. Vyatkin, and U. D. Atmojo, "OPC UA information model and a wrapper for IEC 61499 runtimes," in *2019 IEEE 17th International Conference on Industrial Informatics (INDIN)*, vol. 1. IEEE, 2019, pp. 1008–1013.

[7] W. Dai, Y. Zhang, Y. Zhang, J. Kang, and D. Huang, "Automatic information model generation for industrial edge applications based on IEC 61499 and OPC UA," *IEEE Transactions on Industrial Informatics*, 2022.

[8] W. Huang, W. Dai, P. Wang, and V. Vyatkin, "Real-time data acquisition support for iec 61499 based industrial cyber-physical systems," in *IECON 2017-43rd Annual Conference of the IEEE Industrial Electronics Society*. IEEE, 2017, pp. 6689–6694.

[9] R. Sorokin, S. Patil, and V. Vyatkin, "Novel development tool for iec 61499 based on domain-specific languages," *IFAC-PapersOnLine*, vol. 55, no. 2, pp. 439–444, 2022.

[10] (2020) Function blocks modelling environment (fbme). [Online]. Available: https://github.com/JetBrains/fbme

[11] W. "Mahnke, S. Leither, and M. Damm, *OPC Unified Architecture*. Springer, 2009.

[12] N. Mills, P. Rathnayaka, H. Moraliyage, D. De Silva, and A. Jennings, "Cloud edge architecture leveraging artificial intelligence and analytics for microgrid energy optimisation and net zero carbon emissions," in *2022 15th International Conference on Human System Interaction (HSI)*, 2022, pp. 1–7.