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## DEVELOPMENT OF MONITORING AND CONTROL SYSTEMS FOR PRIVATE PV PLANTS

Over the past five years, system modeling and automated design have undergone a radical transformation, shifting from the separate design of components to the creation of integrated cyber-physical systems.

The main academic trend has been the introduction of the concept of Digital Twins, which ensure continuous data exchange between a virtual model and a real physical object at all stages of its life cycle. In parallel with this, the MBSE [1] (Model-Based Systems Engineering) approach has gained traction, allowing for the integration of mechanical, electronic, and software components within a single modeling environment, thereby minimizing compatibility risks as early as the architecture development stage.

Modeling principles have been significantly updated thanks to the development of cloud platforms and real-time tools. Platforms such as NVIDIA Omniverse and the updated MATLAB/Simulink [2] and Autodesk Fusion 360 suites have shifted the focus toward multiphysics modeling and photorealistic simulation of robotics.

A key milestone was the widespread adoption of open-source environments and the integration of specialized software into educational and research processes. These tools enable high-precision calculations of semiconductor structures and

digital automata, capabilities previously available only in highly specialized laboratory packages.

Artificial intelligence has become a defining factor in development, evolving from a supporting tool to the core of the design process. The introduction of generative design based on neural networks has made it possible to automatically create optimal part topologies that cannot be developed using traditional methods.

In addition, AI has radically impacted control systems through the use of reinforcement learning, which ensures the adaptability of mechatronic modules to changing environments. New approaches have also extended to the field of Edge AI, where data processing algorithms are integrated directly into microcontrollers, allowing systems to make autonomous decisions in real time without delays caused by data transmission to the cloud.

Let's examine the development of the modeling industry using Siemens as an example [3]. The effect of Siemens monopoly is reinforced by a phenomenon known as vendor lock-in. Thanks to proprietary data exchange standards and unique functional objects (Technology Objects), Siemens modules work perfectly within the ecosystem but require significant adaptation costs when attempting to integrate with third-party systems.

Siemens strategy to dominate the software module market, particularly through the Integrated Development Architecture (IDA) concept and the TIA Portal ecosystem, is viewed as the creation of a closed, self-contained infrastructure. The main mechanism of "monopolization" is based on the principle of vertical integration, where software (PLM, TIA Portal) is inextricably linked to hardware (S7-1500 controllers, drives).

Recently, Siemens has been transforming its dominant position as an Industry 4.0 leader in the field of digital manufacturing through the Xcelerator platform, which is formally positioned as open but effectively cements the company's leadership through control over critical interfaces (APIs).

Academic case studies highlight that the company's strategy has shifted from protecting physical media to dominating the Industrial Edge and cloud computing sectors.

By controlling the software layer where modules are developed and integrated, Siemens dictates automation standards for entire industries, effectively turning its architecture into an industry standard-the highest form of market dominance.

Siemens is acquiring software developers specializing in simulation (such as Altair Engineering, Mentor Graphics, or CD-adapco) to build a complete Digital Twin of a product that bridges the virtual and physical worlds, enabling engineers to design, test, and run a factory or component in a simulation before any materials are used; create a closed-loop cycle (Digital Thread) where the design and production stages are linked (if something changes in the model, the data is automatically transferred to Siemens machines at the factory and vice versa).

Siemens recently acquired Altair, gaining access to the world's best artificial intelligence for simulations, which allows for the prediction of equipment failures as early as the design phase.

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