Virtual testing with a Digital Twin of protection devices in the Cloud

Abstract:

Designing and commissioning a complex energy automation system are time consuming processes and often can only be done after plants and systems have actually been set-up and connected to each other. This used to take days and sometimes even weeks. With digital twins for protection devices, tests can be carried out before or while setting up the hardware. This significantly shortens the time to system operation. Project data can be simulated and tested individually in a cloud in just minutes, with no hardware or additional effort.
This paper introduces the concept of a Digital Twin as virtual copy of a physical asset, including all interfaces, functions, and algorithms of a protection device. This can be extended to further substation devices such as bay controllers, fault recorder or even later as Remote Terminal Units.
This paper then shows where and how a Digital Twin for protection devices saves time and increases quality throughout the entire lifecycle of the system. Examples of various application scenarios, starting from protection testing, substation integration with communication protocols, to cyber security, illustrate the value of a digital twin. Those scenarios cover both single devices testing as well as distributed applications, like differential protection or IEC 61850 GOOSE. The benefits of use at all the stages are mentioned from the design to the commissioning, training and operation, targeting as audience the whole protection community.
Finally, an outlook for this recent innovative approach is given. This includes the cloud potential for future scaling digital twins up to a full virtual substation, as well as a vision of an ecosystem with many digital twins, where network models, test equipment or 3rd party IED could interact to bring the substations to the next level of digitalization.

Introduction

With the IEC 61850 digitalization of substations, IED products and system engineering have been significantly further developed. Testing functionalities during the operation have been supported, but initial commissioning of substations remained quite similar to the early days with the exception of virtual wirings via GOOSE or SMV. A significant amount of time is still commonly spent on site at the factory acceptance test (FAT) or site acceptance test (SAT). With a digital twin, a virtual copy of a physical asset with its interfaces, functions and algorithms, testing can be done virtually. This paper shows why an industry trend has the potential to overcome that limitation and bring the digitalization further into the protection and substation automation domain, not only over commissioning but during the full lifecycle of the devices.

Application scenarios

A protection digital twin can address all testing application scenarios to validate a protection and control application in advance, without having hardware, without being at a specific location, and without having waiting times between the different stages of the project:

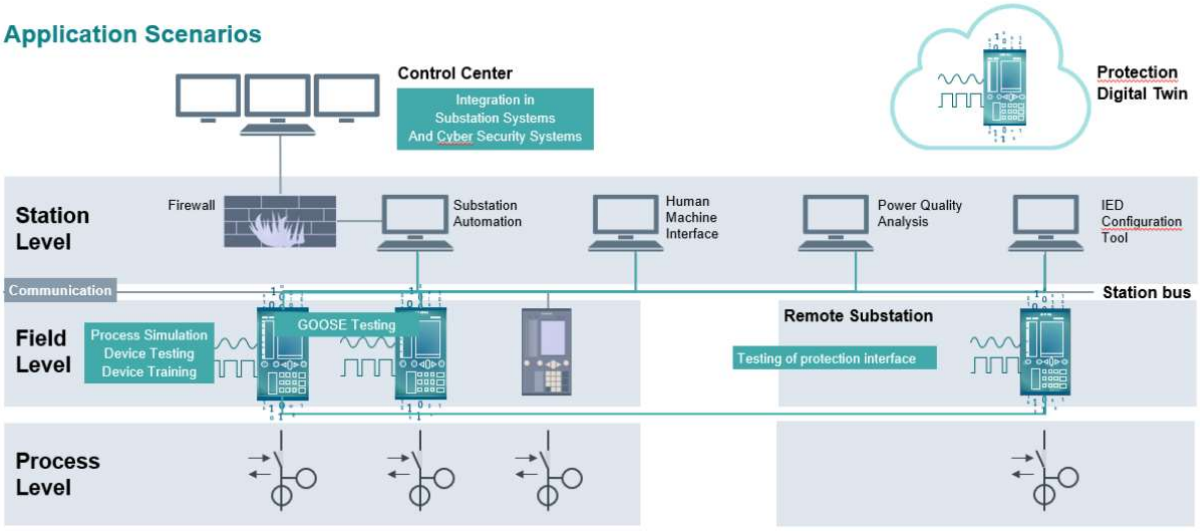
- Validate an application with single or multiple devices, communicating via IEC 61850 GOOSE - such as interlocking or tripping – or via a protection data interface for tele-protection or differential protection applications. Specially for distributed applications where devices might be located far away from each other and where the impact in case of wrong or suboptimal configuration might be even higher, it is even more convenient to pre-test it at the office without hardware setup.

- Validate the capabilities and the configuration for the integration into a substation automation system, including gateways, local HMI, fault record collector, communicating via IEC 61850 MMS or via other Ethernet protocols such as DNP3.

- Validate the capabilities and the configuration of cyber security functionalities, such as Syslog, RADIUS or RBAC.

- Validate or simply use the software functionalities of the IED configuration tool during online interactions with the IED, such as data retrieval, configuration update, online debugging of the programmable logic or advanced test features

- Validate the operation of the device front display, including the single line to control the bay, the measurements, the operational logs, the LEDs, the function keys and the menu navigation



For the use of a protection digital twin, not only the IED behavior is required, but also the process simulation to provide the test inputs. This includes the virtual injection of both analog inputs such as currents and voltages, as well as of binary inputs. This process simulation may provide static inputs or more dynamic ones such as a COMTRADE replay.

Many tests can then be prepared without secondary injection test set and without any wiring.
The outputs of the digital twin are similar to the ones from the real IED. They include then the status of the binary outputs and the telegrams sent via communication protocols.

Besides covering the use case of virtual commissioning, additional aspects of the IED lifecycle are covered:

- Present new IED capabilities with live demo, without carrying hardware devices nor ordering newly introduced hardware modules. This also enables to show preview firmware functionalities and get earlier feedbacks for agile development process
- Design a specific user-defined application and evaluate its performance in advance. It provides a higher certainty by confirming that the selected IEDs will also support non-standard applications in dedicated substations.
- Prepare and support protection approvals. Demanding customer-specific requirements or new product platforms may need clarifications between remote experts on both customer and manufacturer side. Digital technology supports a more efficient collaboration via a balance of virtual and on-site meetings to achieve a better common understanding and faster approvals.
- Understand deeper the IED algorithms, besides the documentation in the manual. This allows to avoid confusions
- and increase further the autonomy of the protection engineer via a training-on-the-job.

- Improve further the quality of planning phase by using the real protection algorithms and not the simplified mathematical models. More optimal protection settings can be easily tested and defined, opening the door for co-simulation with power system models.

- Validate an application with single or multiple devices. The validation can be carried out partly without a test equipment for secondary injection and physical wirings, which allows a reduction of efforts, operational times and errors. Furthermore, in case of using standardized engineering and configurations for all projects, the validation is done for the first project and it is valid for the rest of the projects without the need to do further validation tests and with the guarantee of having zero errors.

- Validate the integration of the device into the substation automation system in advance, without having the need to wait until the physical device is installed. IED protocols such as IEC 61850, DNP3 or Modbus TCP can be simulated with the application data, which also facilitates the split of work between protection and automation engineers within the same company or also when coordinating the integration with various interoperable manufacturers.

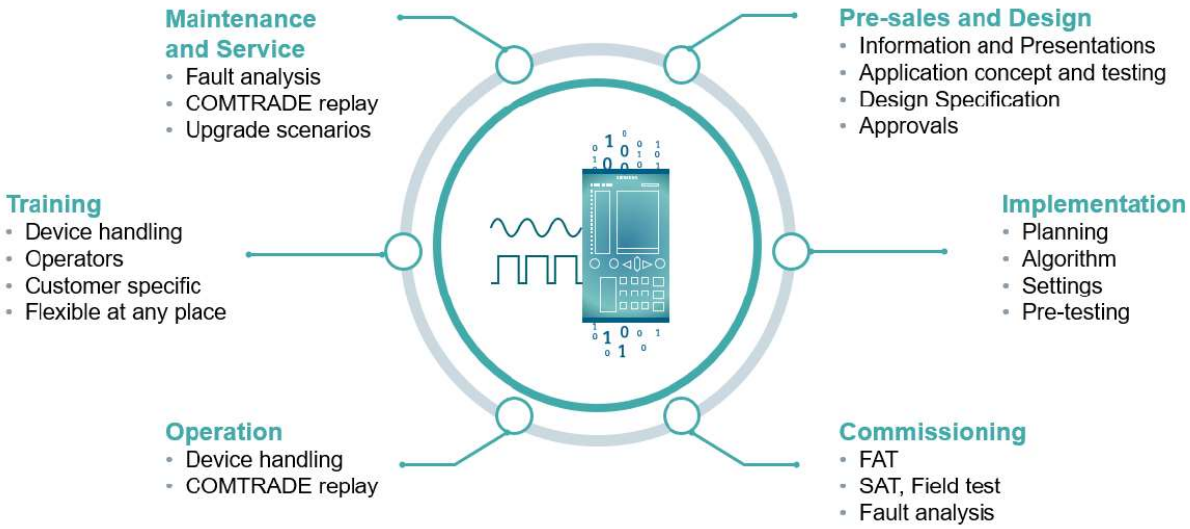
- Validate the integration of the device into the monitoring and system (automatic fault record extraction, automatic logs extraction, automatic fault location, …), without having the need to wait

up to the physical device is installed. This reduces site intervention time and the amount of people from various departments that might else attend the test on site.

- Validate the integration of the device into a Cyber Security environment, using Syslog, RADIUS, RBAC. This makes users more confident with the implementation and verification of mandatory security regulations such as NERC CIP, and therefore contributes of making the power system more secure

- Reduce human errors due to missing knowledge via efficient and scalable trainings on the job, both for commissioning and operational team. More employees can be easily trained based on their exact needs, remotely or on site, without a dedicated room with many test devices.
- Investigate real power faults, by virtually replaying COMTRADE files. If needed, configuration parameters can be adapted, and test result improvements can be documented and deployed faster on substation site.

- Support patch management activities, both for security patches and functional upgrades, by verifying virtually the improvements before deploying them on site.



A digital twin not only support the virtual commissioning and training but also bring benefits:

- Faster energization of new protection and control systems thanks to shorter project lifetimes.
- Reduced OPEX thanks to better pre-testing.
- Fast and realistic fault analysis by easily reproducing the behavior of the products and systems.
- Faster and more efficient technical support.
- High efficiency, performance, security and availability 24/7 from everywhere without any hardware.
- Reduced dependencies between different departments and work parallelization

Future activities and outlook

From testing several devices in a bay or in a small application to a full digital substation, the scope of a virtual system under test is expected to increase further. A research project is aiming to cover later a full power network with hundreds of substations. This brings not only the aspect of the scalability into the game - where a Cloud solution has excellent pre-requisites - but also the integration of multiple Digital Twins into an ecosystem, the so-called Co-simulation. Various partners from utilities and industries to secondary test equipment providers, power network simulator, IoT platform, other IED manufacturers, or communication protocol simulators have already raised their interest.

The potential of digital twin of the IED lifecycle will disrupt the way the protection ecosystem is organized. First benefits are available on the market, will continue to be increased to address unexplored chances of the digitalization. Challenges for the complete twin of a digital substation still exist, such as interfacing 3rd party devices or solutions, but market interest is there, and activities have been initiated.