# Virtual testing lab for digital substation

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## SUMMARY

In the current age of digitalization where almost every aspect of current industry is moving towards digital and cloud-based operations and monitoring. On top of digitalization trend, we have also got challenge to limit human social interaction for non and less essential operations. We had task to complete engineering for relay configuration for our newly planned a major substation upgrade with station bus at Louise Creek (Louise creek is a major 240kV transmission hub in north of Alberta) and pilot digital substation with IEC61850 process bus at 72kV Sullivan Lake substation. This covers Line, transformer, Feeder, and reactive power compensation protection.

All this was planned in middle of pandemic COVID-19 where restrictions were implied for public safety, no organization wants their most asset, their workforce, in reduced safety to complete the project.

First phase of any project is design and engineering where most of the work can be executed online with computer / laptops at remote but testing of relays can be done at the lab only because of requirement of different type of relays, testing kits and safety. Here we came across the concept to have the testing lab in virtual environment. This became reality by application of digital twin technology. Digital twin allows users to make virtual copy of the relay with customized configuration. This virtual copy of 'relay to be' in the field can be verified for correct configuration for below topics or more…

a) By injecting current and voltage for calculated fault level to compare with protection coordination simulation software to ensure relay performance matching with theoretical calculation.

b) Testing and debugging of customized logics and interlock as well as IEC61850 GOOSE.

c) Verify relay front panel indications and control functions like device operation for Display, LED, menu navigation etc.

d) Training of workforce from remote and in person as well with less logistics.

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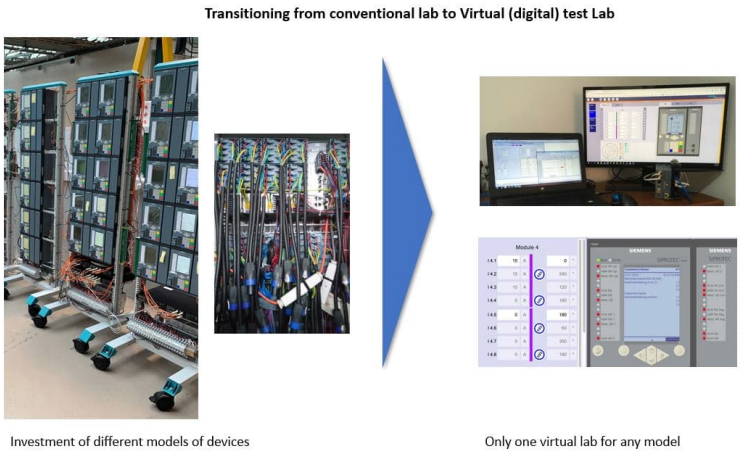



*Figure 1 conventionnel protection relay lab. to virtual*

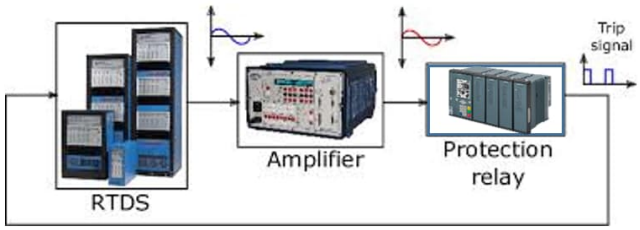
In addition to the engineering of the project, Digital twin supported during commissioning phase particularly for issues identified during field testing. It has greatly improved the productivity and time consumed in replicating site issues and providing the solution. In the past without digital twin technology, engineer used to spend a lot of effort just to identify the issue from the field. Not only time could be saved in identifying the problem, but engineers can test the solution even before applying it to the fields.

## KEYWORDS


- Protection and Automation (B5)
- Manufacturing process, design, modelling, materials, degradation mechanisms, experimental science, signal processing, on-board measurement system (OBM), digital twins

**Testing, validation and training of relay configuration- the conventional method**

After engineering is completed for any project or even during the engineering phase when relay configuration is concerned, we need to have a lab setup to test relay parameter. Testing of protection setting, logics, interlocks, display, SCADA signals etc. are required to make sure the relay config files being released for site is reliable and minimum of no error left. To accomplish the testing of relays during engineering we need to perform below exercise as an example



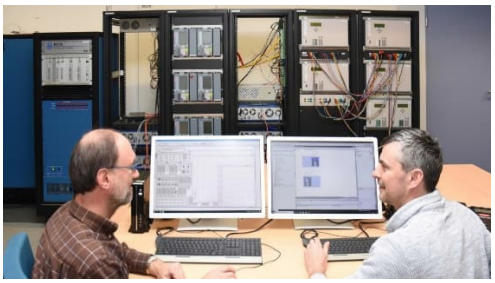



*Figure 2 Conventionnel Relay Lab.*

Different required type of required relays needs to be arranged with testing kits. Testing kits inclueds secondary or primary injection with time measurement, CB or disconnector simulation and relay configuration softwrae to record the waveforms/logs and results. Below are main types of test to be performed in conventional testing.

a) Current and voltage injection for each protection function and monitor operation of correct function on relay display, LED, logs, BOs, and automation.

b) Interlocking/inter-tripping and logics testing of relays by applying voltage on binary input and injecting current and voltage if necessary. It requires multiple relays and switching devices of switching sequence logic with relay testing kit (i. e. Omicron CMC 356 with state sequencer).

Training with conventional setup requires to have setup of relays of various protection and control features training and participants to travel to the training lab location. By depending upon a physical lab only for training it is sometimes difficult for organization (specially Utility) to conduct training other than a centralized location. Site crew and various project technicians and engineers are location to far distant locations and it is mostly not feasible to shift lab equipment's to remote locations for few days of trainings.

**Testing and validation of relay configuration, with virtual testing lab of digital substation (using Digital Twin)**

**What is a Digital Twin?**

A digital twin is a virtual replica of a product, a machine, a process or of a complete production facility. It contains all the data and simulation models relevant to its original. Digital twins not only enable products to be conceived, simulated, and manufactured faster

than in the past, but also to be designed with a view to improve economy, performance, robustness, or environmental compatibility. From the perspective of relay testing world, it is a digital functional copy stored in cloud that includes communication interfaces, protection functions, algorithms, and logics.

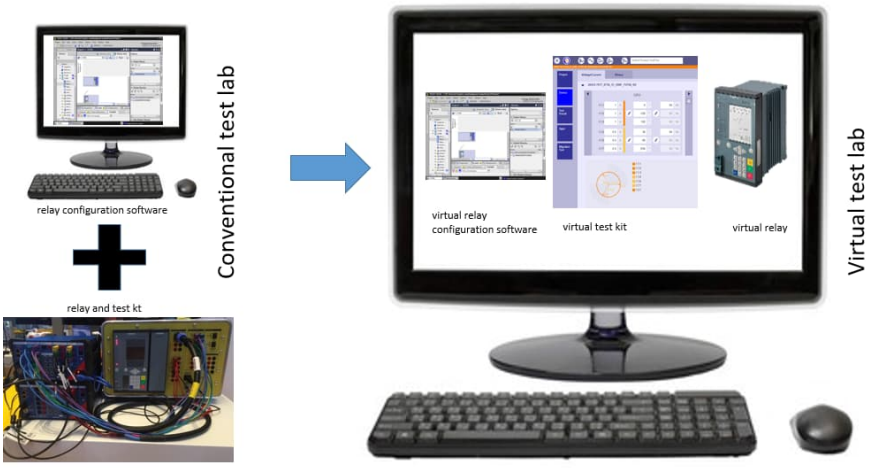



*Figure 3 Relay test setup*

The technology can help substation designers verify substation physical design and layout as well as evaluate the performance of substation assets individually and as a system. One of the key elements of digital twin technology is the sharing of data amongst other twins. Digital twin of a relay test equipment and digital twin of a protective relay can be designed in a way that they share the same data through software tools, enabling efficient virtual and physical commissioning tests.

**Where does the Digital Twin fits ?**

Virtual testing lab setup is a computer with login credential on SIPROTEC digital twin with internet connection. Having a virtual lab eliminates the requirements of various physical relays and test kits for most of the requirement and adds flexibility to access from anywhere and shift the lab anywhere. SIPROTEC digital twin is a cloud-based application which can be accessed by most of internet browsers (for example, google chrome), so, user can login to digital twin portal from any computer anywhere in the world. Digital Twin of a protection relay can allow tests to be done before or during the erection and installation of a real substation. Settings of a protection relay and schemes can be validated in advance without any hardware.


*Figure 4 Digital Twin login*

## The testing of transformer protection

## Test setup using Digital Twin

The test setup for digital twin platform involved creating the relay settings in the relay software. The relay settings were exported in the form of SIMulation data format (SIM) file from software tool of the protection relay. This SIM file was then imported to the digital twin platform to simulate the relay under test. Figure below shows the SIM file after it is imported in the digital twin platform. There can be multiple simluation files in the project. The two highlighted files are representing relay for transformer differential and CB simulator to test opening and closing logic.

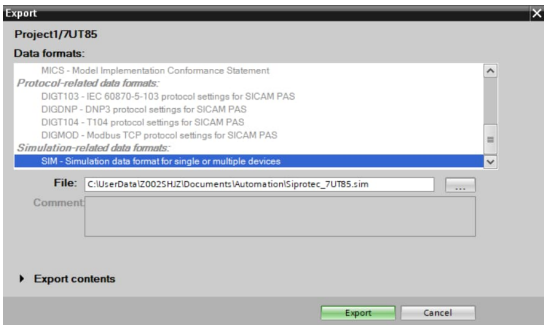



*Figure 5 export simulation file from software*

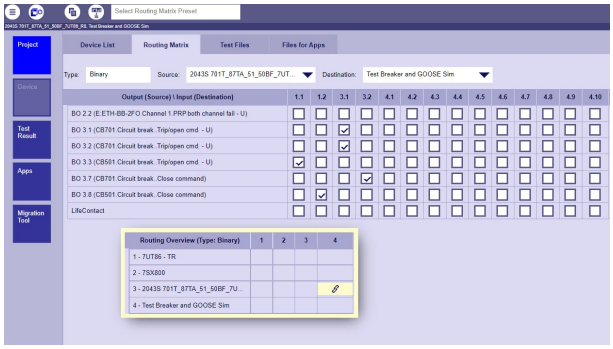



*Figure 6 Connection between relay and CB*

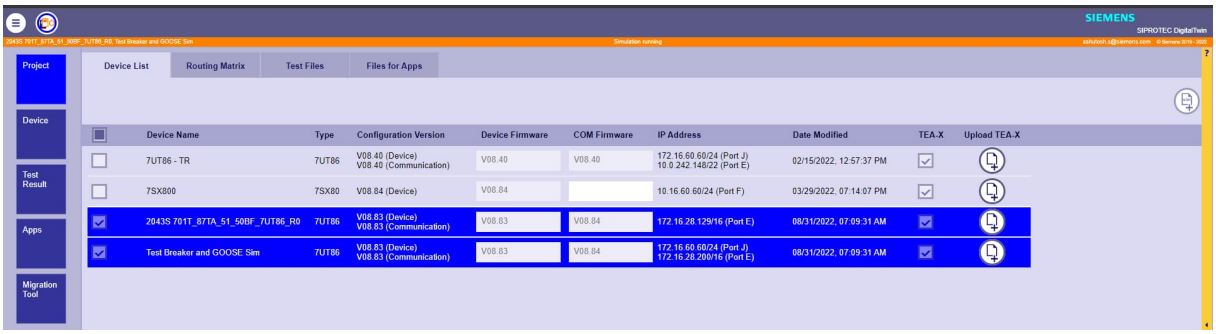



*Figure 7 starting relay in virtual environment*

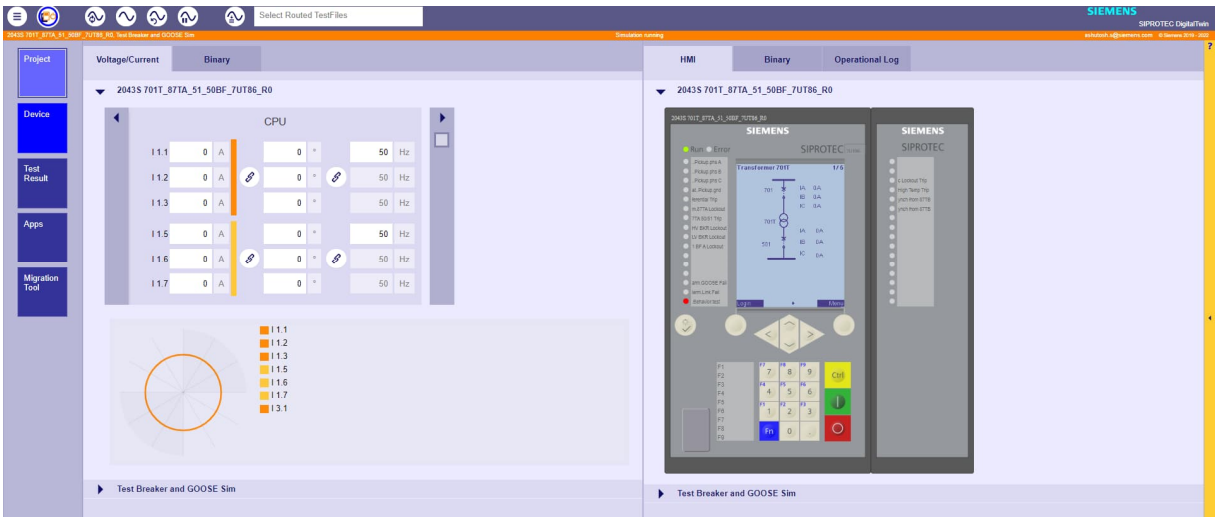



*Figure 8 Complete test setup or relay and CT, VT & BI injection*

SIM files can be updated overwritten also. SIM files include the TEAX-file for displaying texts of binary input-/output and LEDs. Start of simulation easily can be done by selcting multiple device, it is very useful when interlock testing, bus/line differential protection or teleprotection schemes needs to be tested. Once relay is up and running ( simulation started). Portal provides interface like below with representation of relay output on the right side (like display/HMI with LED, Binary O/P and logs) and input of the left side ( like injection of voltage, current and binary input). voltage and current signals from digital twin equipment were mapped to the digital twin relay terminals. Once the mapping was done, the digital twin relay was energized

Injection of process data (I/V) with any binary input if requires, user can select appropriate phase angles. It also gives visualization of vectors like relay testing set. Relay(virtual) processes the injection exactly in the same manner as it would have been operating in real world. Display provides indication on LCD screen and programmable LED as per the configuration.
Correct operation of the protection function can be verified by checking the log displayed on the logs tab and display tab of the relay for LED indication.
Digital twin also contains virtual relay configuration software (DIGSI5) inbuilt. User can use start DIGSI5 to communication with virtual relay. In this way event log and trip log can be retrieved from virtual DIGSI5 to the PC for the future record of performance and operation.

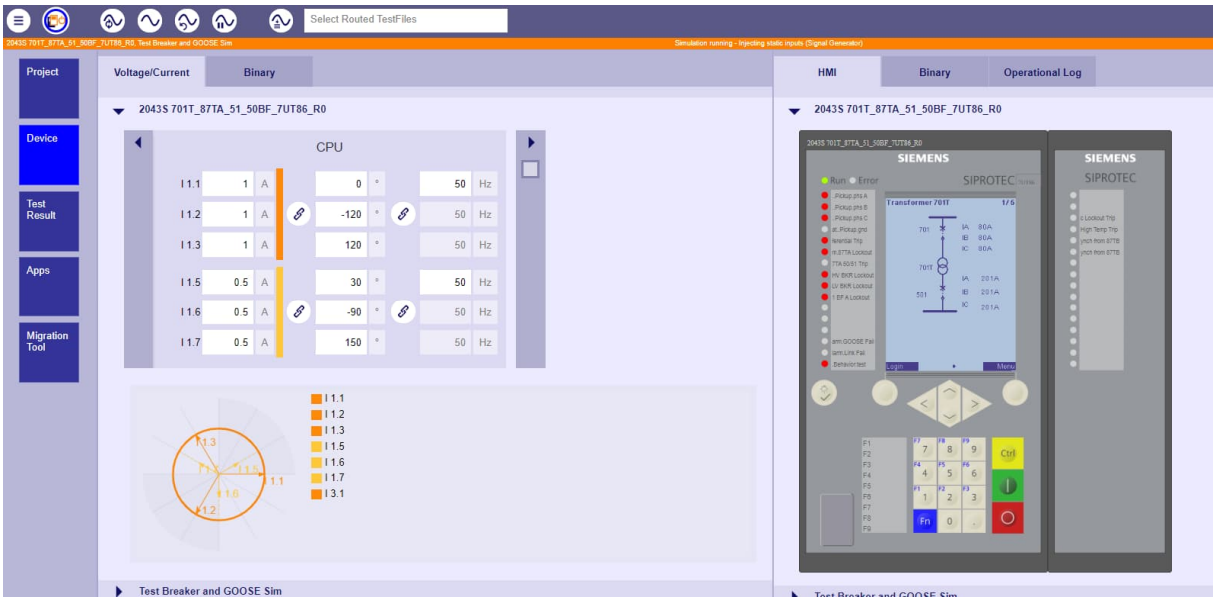


*Figure 9 Relay trip after current injection for differential in-zone fault*

*Figure 10 Test result on digital twin injection unit*

## SIPROTEC DigitalTwin Test Report

User: ashutosh.s@siemens.com
Start time: [redacted]
Stop time:

### Devices

| Name | Product Code | Config Version | Firmware Version | IP Address (Port Name) | Imported On |
|---|---|---|---|---|---|
| 2043S 701T_87TA_51_50BF_7UT86_R0 | 7UT86-DAAA-AA0-0AAAA0-AV0111-23121B-BAA000-000AC0-CC1BA1-CH1 | Device: V08.83<br>COM: V08.83 | Device: V08.83<br>COM: V08.84 | 172.16.28.129/16 (Port E) | [redacted] |
| Test Breaker and GOOSE Sim | 7UT86-DAAA-AA0-0AAAA0-AV0111-33121B-BAA000-000AC0-CC1BA1-CH1CD0 | Device: V08.83<br>COM: V08.83 | Device: V08.83<br>COM: V08.84 | 172.16.60.60/24 (Port J)<br>172.16.28.200/16 (Port E) | [redacted] |

*Figure 11 test result downloaded from Digital Twin injection unit*

This fault record can be downloaded from virtual relay using virtual configuration software (DIGSI5) which is inbuilt in the portal.

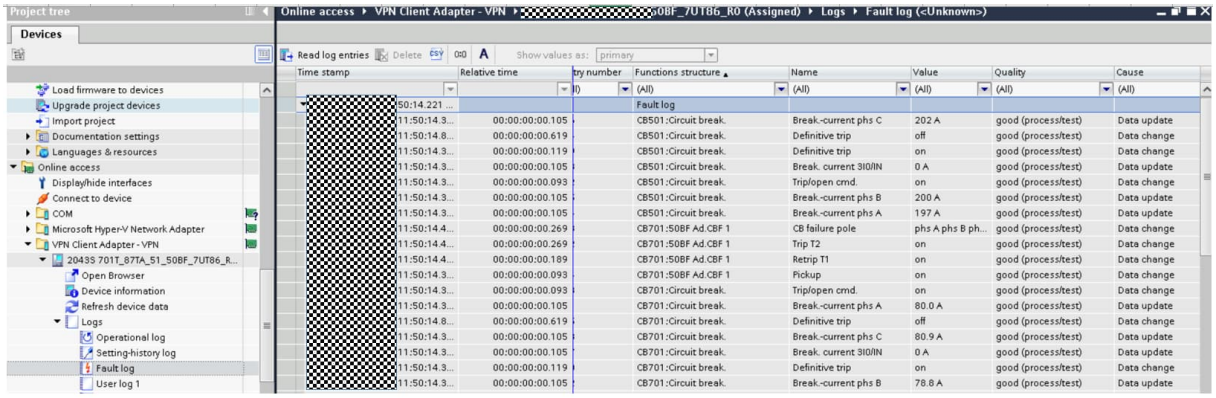



**Figure 12 Fault record from relay software**

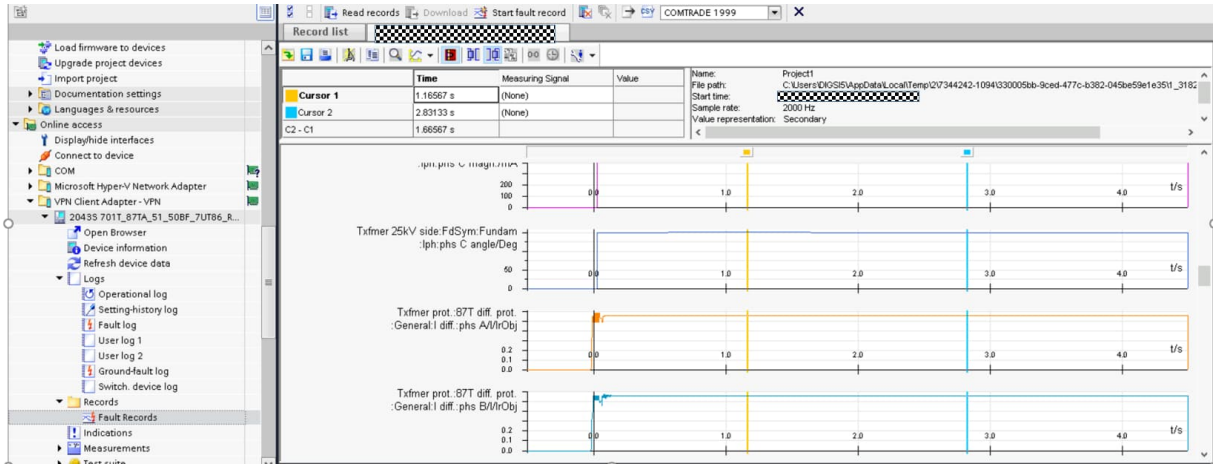



**Figure 13 Ocillographic record**

**Benefits and limitations of using a digital twin in the validation process of protection and control system**

A Digital Twin of an IED, or a set of IEDs, either with protection, control measurement or/and monitoring functions, brings nowadays, as a summary, the next benefits to the users of the current digital protection and control systems:

a) Reduction of dependencies between departments involved in the design, validation, engineering, configuration, commissioning, fault analysis, maintenance and technical support of protection and control systems.
b) Reduction of execution times of the projects. For example, faster energization of new protection and control systems thanks to shorter project lifetimes.
c) Reduction of costs of the projects.
d) Reduced OPEX thanks to better pre-testing.
e) Replica of the same protection and control system in new substations, or consecutive projects, without errors. 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.
f) More efficient trainings.
g) Fast and realistic fault analysis by easily reproducing the behavior of the products and systems.
h) Faster and more efficient technical support.
i) High efficiency, performance, security and availability 24/7 from everywhere without any hardware.
j) Mitigation of humane errors
k) All pages after title page must start from this line, i.e. 1" (2, 5 cm) margin from the top (Times or Helvetica, size 11 or 12). Pages will be automatically numbered.

**Future use**

Please note that any new technology like digital twin, not only helps in solving existing challenge but also opens doors for new technology and methods for future innovations. At last, but not the least there are some of further applications identified with Digital Twin virtual lab which can be used for projects in future.

l) System event analysis, replay and issue mitigation. COMTRADE replay with virtual relay can save significant time for just setting up the test scheme. Support engineer does not need to have all relay models with different firmware and test equipment physically.
m) Multi terminal protection scheme coordination verification. Digital Twin allows user to inject fault quantities in multiple relays simultaneously which is not feasible without extensive lab environment.
n) Communication testing for SCADA protocol and IoT connectivity.

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