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Using the Megger Digital Twin for FREJA and SMRT relay test sets

Objective: This application note will help users to understand this innovative and pioneering concept of digital twins in power system protection testing applications.

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Introduction to digital twins in power system protection testing applications

Digital twins are a functional copy of physical devices like protection relays and relay test sets.
This technology can be used to perform relay protection testing virtually, without the need to be physically present at a specific location or wait between commissioning project stages. In order for digital twins of protection relays and relay protection test sets to function effectively, they must share the same data, for example through their software tools. This means that the digital twins must be able to exchange information seamlessly and accurately.

To achieve this, the software files generated by the protection device tool and the user interface of the relay test set can be reused to test the physical devices, which are also known as physical twins when they have a corresponding digital twin. The software files allow the digital twins to simulate the behavior of the physical devices, and the physical twins can be tested using the same files. The Figure 1 shows that by using the test tools of the relay twins and test set twins (RTMS), the digital twins can share the same data.
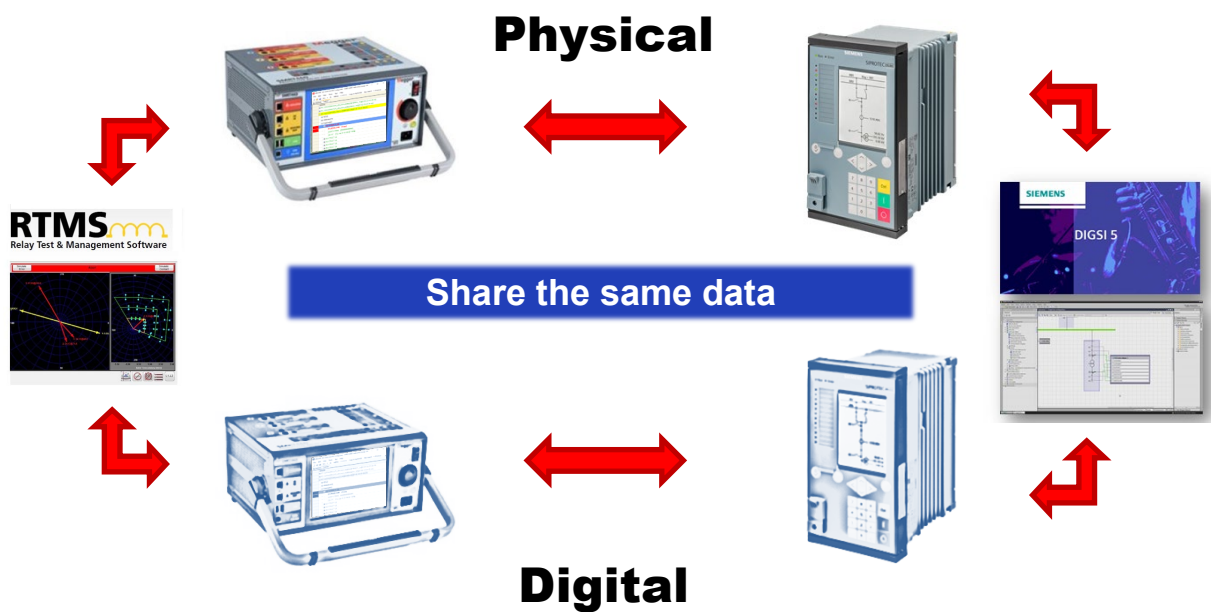
Figure 1: By utilising the test tools of the relay twins and test set twins, it is possible to ensure that the digital twins share the same data (picture from [1]).

This approach enables commissioning tests to be done virtually, making on-site commissioning tests a subset of virtual commissioning tests. It also makes it possible to repeat some of the virtual tests in the physical substation to verify that the system is functioning correctly.

Factory acceptance testing (FAT) can be considered part of commissioning tests, as it involves testing the system to ensure that it meets the specified requirements before it is deployed. By using digital twin technology to perform these tests, it is possible to reduce the need for physical testing, which will save time and resources, while also providing a more accurate and efficient testing process.

Important note

As of January 2023, to the best of our knowledge, there are only two digital twin products available in the power system protection field. These are the digital twin for relay protection devices from Siemens, and the digital twin for relay protection testing devices (FREJA and SMRT series) from Megger. Therefore, in this document, we refer specifically to the Siemens digital twin ([2]) protection relay, not only in the text but also in several illustrations.

In 2019, the digital twin for protection relay was launched ([2]), while the relay test-set was launched in a limited release in 2021 in Sweden ([3]).

A practical application: virtual relay protection testing

Currently, relay protection tests are conducted in real-time by connecting one or more protection test-sets to a protection device, as illustrated in Figure 2, where the FREJA test set (or SMRT- D) is shown to be connected to the protection relay (Siemens SIPROTEC 5) in the usual way.

Figure 2: Simplified diagram of a relay test set physically connected to a protection device for performing protection tests.

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In order to perform these tests virtually, a digital twin is required to serve as the real-time digital counterpart of the related physical objects. Specifically, a digital twin is needed for both the relay test set and the protection device, as mentioned in the previous paragraphs.

To perform the virtual relay protection tests, you need the Megger digital twin, and you need the access to the Siemens SIPROTEC DigitalTwin (https://siprotec- digitaltwin.siemens.com/#/digital-twin-splash-screen) shown in Figure 3. Please contact your local Siemens representative for the details.

Note: When this document was created the Siemens DigitalTwin was not released in all countries.

Figure 3 The SIPROTEC DigitalTwin, from Siemens website in January 2023.

In virtual testing today, the digital twin test set conducts the test sequence without the reaction of the digital twin relay, which is known as open loop testing. With reference to Figure 2, the test's analogue quantities are simulated, along with the connection of the digital twin test set to the analogue inputs of the digital twin relay, and the behaviour of the digital twin relay towards the test quantities. However, the trip from the digital twin protection relay is not connected to a Binary Input (BI) of the digital twin test set. The test results are validated from the digital twin relay through its human machine interface (HMI), event recorder, or the data available in the disturbance recorder.

Open loop testing allows for evaluation and verification of many aspects of relay performance and operation, even if there is no interaction between the digital twin relay binary outputs and the digital twin test set binary inputs.

Furthermore, virtual tests provide an opportunity for the engineer on-site to have validated test files and protection relay files since the test file saved by RTMS can be run from the physical twin (FREJA or SMRT).

Instead of utilising real analogue signals, the virtual relay inputs receive digital signals, which are stored in a COMTRADE file format. This format is widely used in power system tools and is also a normative IEC 61850 requirement for disturbance recorders installed in protection devices standardised. The COMTRADE file is then passed to the digital twin relay and monitoring the digital twin relay HMI. Again, with open loop testing, there is no interaction between the DT relay and the DT test set, but many aspects of relay performance and operation can still be evaluated and verified.

The following paragraphs will take you through the simple and straightforward process that leads to the creation of the COMTRADE file that can be passed to the digital twin relay. Additionally, we will discuss how the test file can be easily saved and reused with a physical test set, following the same saving procedure you would use when performing a physical test.

We will slightly enter in the mechanisms of the Siemens SIPROTEC DigitalTwin, to enhance the comprehension, but to learn more about the use of the SIPROTEC DigitalTwin, we encourage you to refer to Siemens literature or explore the many references provided with this application note. We are confident that with these resources, you will be able to make the most of the digital twin technology and achieve exceptional results.

A detailed video on the process of virtual testing for a distance protection function is available for viewing at this location: 01-Testing Distance Protection with Digital Twin - Megger.mov

Starting your digital twin test set (SMRT 46)

Start your RTMS in the same way you would start it when preparing tests or to test with a physical Megger test set of the FREJA or SMRT series.
To activate the digital twin, click the "Megger Licensing" button (Figure 4) in the configuration pages. For information about the required license, please contact Megger directly.
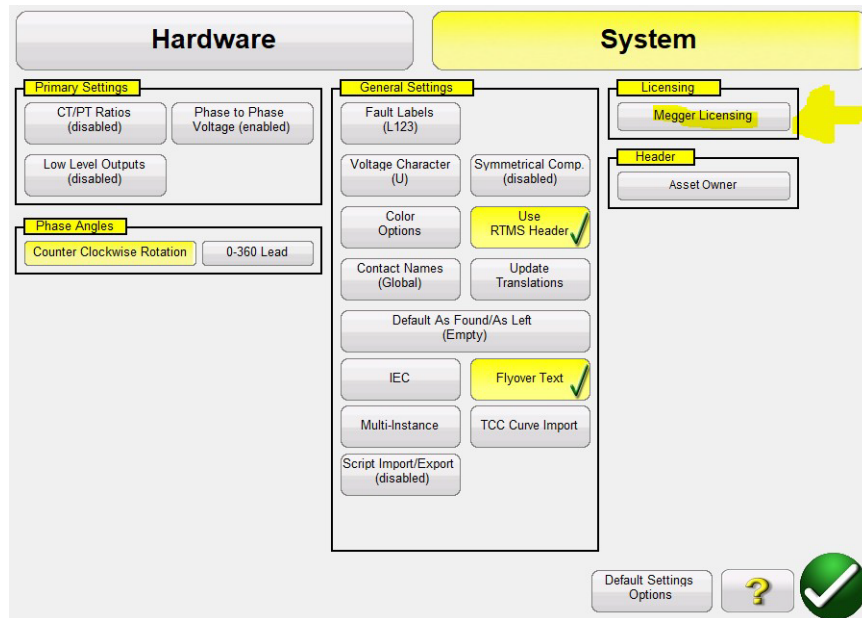
Figure 4: The "Megger Licensing" button to activate your digital twin, in case it is not already activated

Once your digital twin is activated, by when you start up the RTMS Software, you will get the following additional option appear in the dialogue box:
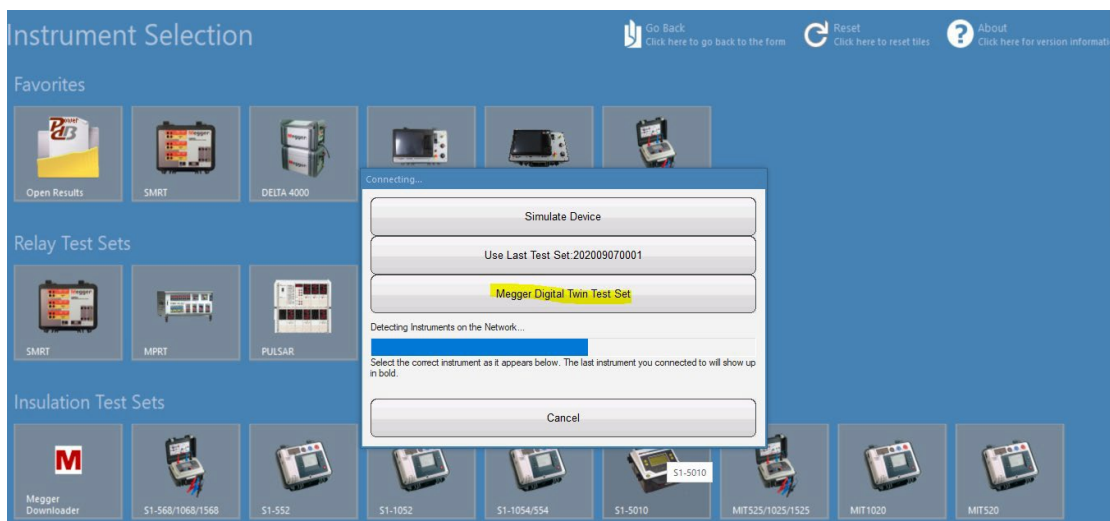
Figure 5: The new "Digital Twin Test Set" button becomes available in the RTMS Software once the license is activated

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By clicking on the "Digital Twin Test Set" button, you enter in the Megger digital twin world. While not all Megger relay test sets have currently been implemented as digital twins, Megger is continuing to develop and release more in the future. In Figure 6, the digital twins available from January 2023 are shown.

Figure 6: The available digital twin test sets

Attentive users of Megger relay test sets may have noticed that all the test sets in the list have a physical counterpart, except for the SUPER DT "Super Digital Twin). This is a virtual testing platform designed to accommodate a high number of analogue channels (12 voltages and 12 currents), making it suitable for performing tests that may not be feasible in the field for simple practical reasons. While the Super DT test set does not directly exist as physical device, it can be replicated by daisy-chaining multiple physical test sets to achieve the same number of analogue channels. For details about daisy chaining the Megger test sets please look at reference [4].

From the selection menu in Figure 6, choose one test set that you have, so that the saved test file can be reused with that physical device as well (which is the physical twin). For the purposes of this application note, we will use the SMRT 46 test set. However, the concepts explained in this note can be easily extended to other test sets, taking into account their unique number of available generators and/or binary outputs.

Figure 7 is the front page of the SMRT 46 Digital Twin. It can be understood that it is a digital twin from the new button [⟳], which allows changing the digital twin test set, in case it should be needed.
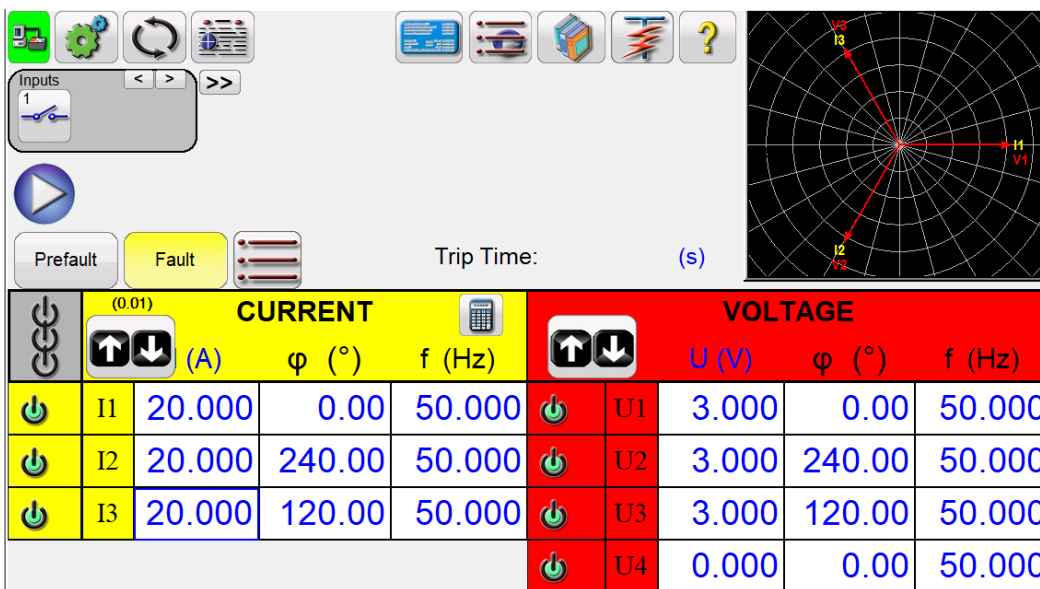

Figure 7: The Main Screen for the SMRT 46 digital twin

When working with digital twins, it is important to keep the following in mind. Analogue quantities should be in secondary values, even if RTMS would allow tests in primary values, as the COMTRADE file for exchanging data with the Siemens digital twin strictly contains analogue values expressed in secondary quantities.

Tests that require feedback from the protection relay contacts or published IEC 61850 GOOSE cannot be performed as open-loop tests, and are therefore deactivated (such as distance protection and differential protection). Only tests that allow serious methods for virtual relay testing are currently activated, including the main screen (pre-fault and fault) and the sequencer.

The digital twin relay used in this application note is the distance protection Siemens 75A86.

Preparing a simple zone1 trip test

From the main screen, prepare the following test:

Pre-fault: nominal voltages, zero currents (according to IEC 60255-121 test methods for impedance characteristic tests). Pre-fault duration: 1000 ms.

Fault: Three phase fault in forward direction, at the approximate line angle of 80 degrees, very close to the origin of the impedance plane.
Fault duration: 100 ms.

The "fault duration" refers to the time-out time used by the test set to determine if the protection relay has tripped or not. For the SMRT 46 Digital Twin, there will be no tripping detected, since there is no feedback from the protection relay. The duration has been selected to be shorter than the timer of distance protection zone 2 (300 ms). To avoid that, zone 2 will also trip. If zone 1 does not trip, there will be no report from the digital twin relay HMI.

There are several conditions that may cause a non-trip from the instantaneous zone 1, particularly during the commissioning or engineering tests of the protection relay, such as incorrect CT direction settings in the protection relay or test set, or incorrect zone 1 settings. These tests are necessary to identify and address such issues, to allow their correction usually by modifying the digital twin relay settings or its configuration.

Note: Even for the Siemens digital twin relays, the twins share the same data, so the saved DIGSI 5 file by the DIGSI 5 software communicating to the Siemens digital twin relay, can be easily loaded into the physical twin relay.

The pre-fault and fault test is also prepared to receive a trip at binary input 1, so that the saved test file can be used by another user with a physical test set without any modification.
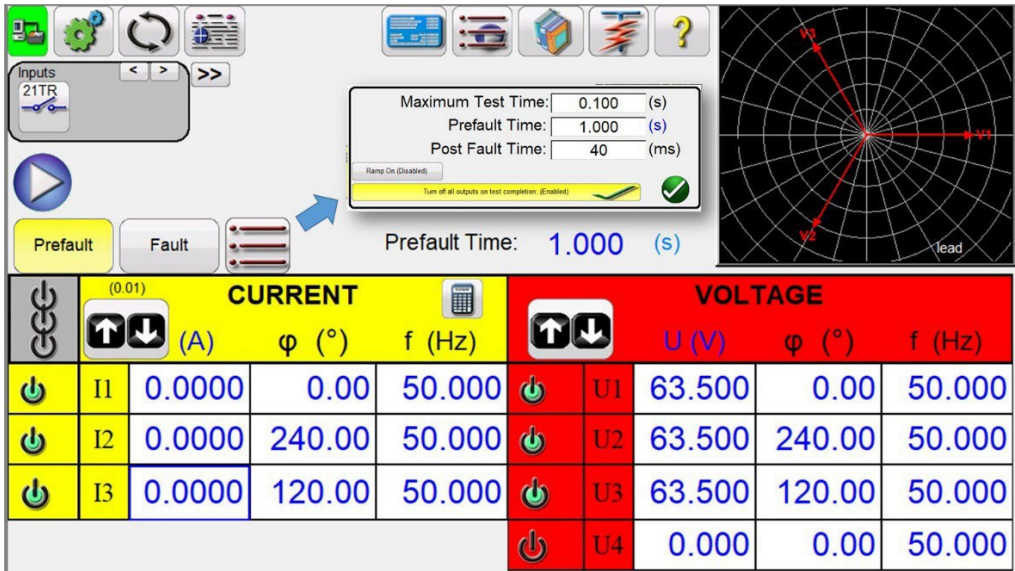
The pre-fault

The pre-fault is shown in Figure 8:

Figure 8: Pre-fault quantities and time durations for the test

The fault

Figure 9 shows the three-phase fault very close to the origin (at the beginning of the protected line). It shows a fault in a forward direction at the approximate line angle, considering the secondary current entering the protection relay by the CT in phase with the primary fault current:
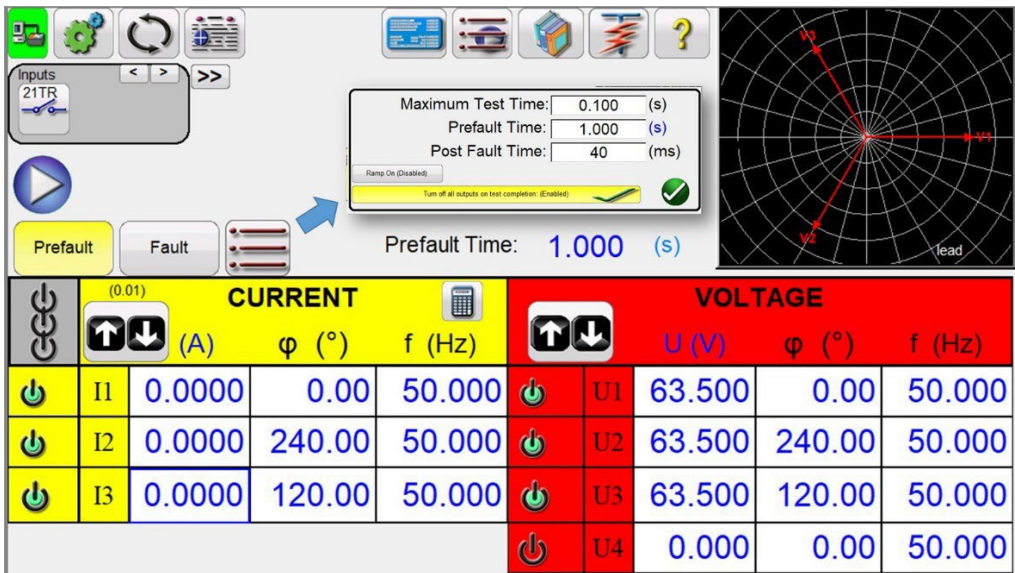

Figure 9: Fault quantities and time-out duration for the fault (Maximum Test Time) of 100 ms

The post-fault

The Post Fault Time has no meaning for the virtual test, as it depends on the feedback from the trip contact, and this information is not available to the SMRT 46 digital Twin. It will be anyway used for the physical test, so it is necessary to set it reasonably, and 40 ms is a reasonable operating time for a high voltage circuit breaker.

The binary input

The setting for the binary input one of the SMRT 46 Digital Twin is also of no importance for the virtual test, but it will be important for the physical test, when the operate (trip) contact of the physical distance protection relay will be connected to the physical SMRT 46. Considering that in the substation the relay contacts will be polarised by the battery voltage, this is the setting for the binary input 1 (Figure 10).
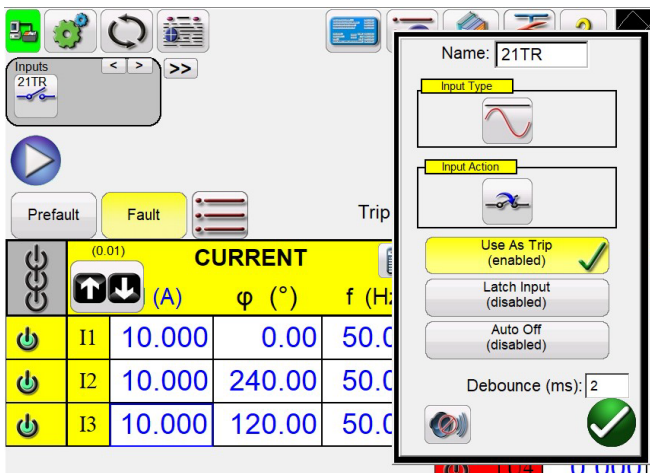

Figure 10: Settings for BI 1 to receive the operate (trip) signal from the distance protection relay

Running the test

At this point the test can be run, by pressing the button. The RTMS software will start the digital twin test set in the same way as it would start the physical twin test set. The test set will perform the requested test. This cannot be shown in pictures, but all screens will behave as in reality. Figure 11 shows one moment of the execution of the test by the SMRT 46 Digital Twin.

Note: That this is NOT the simulation mode implemented in RTMS. This is the digital twin for the SMRT 46 that is executing the test instructions!
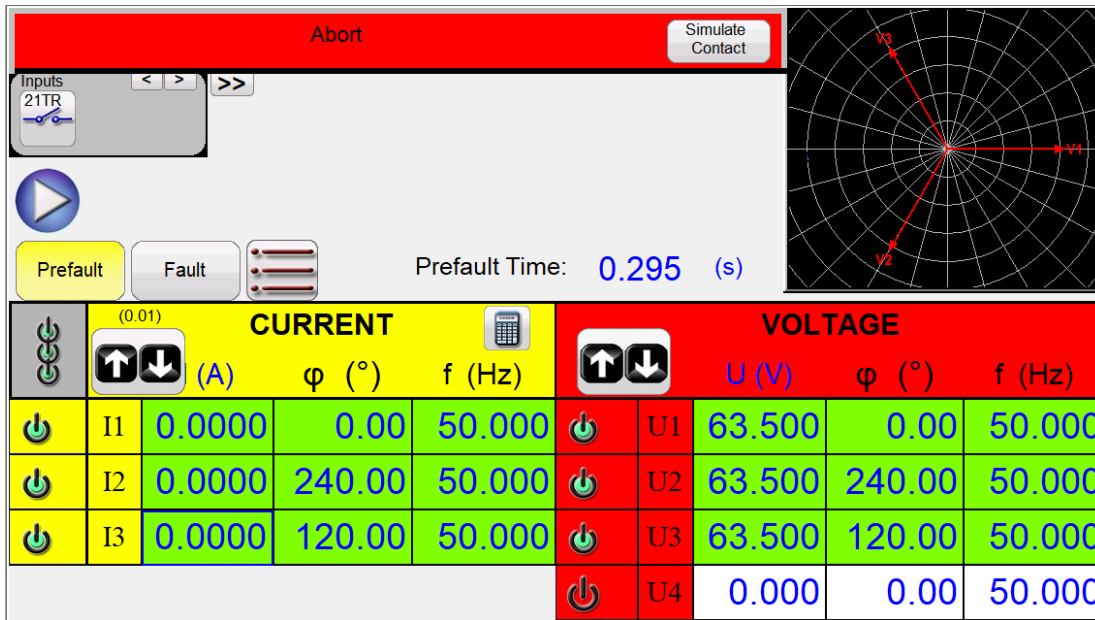
Figure 11: One instant of the execution of the test by the SMRT 46 Digital Twin

Saving the COMTRADE file

At the end of the test, the digital twin will show the following dialogue box, informing you that the test has been executed and that now the digital twin is ready to provide the output of the generators in form of a COMTRADE file (Figure 12):
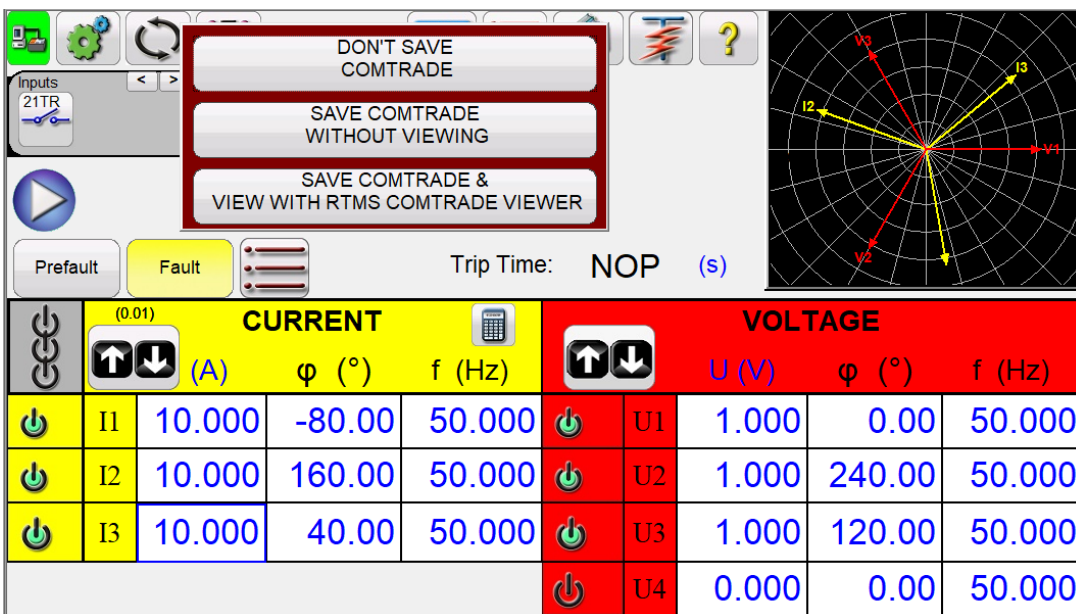

Figure 12: The SMRT 46 Digital Twin is ready to provide the COMTRADE file

It's possible to select to not save any COMTRADE file in case a clear error in setting up the test has been identified and the test needs to be corrected. Alternatively, it's possible to save the COMTRADE file without previewing it if the test is known to be correct, or if there is a need to view the file with more comprehensive viewers such as Siemens SIGRA. The MEGGER RTMS COMTRADE VIEWER can also be used to provide a simple and concise overview of the file.

In this example, we will choose "SAVE COMTRADE WITHOUT VIEWING", for simplicity, and tit is necessary to give a file name to the COMTRADE file, as shown in Figure 13:
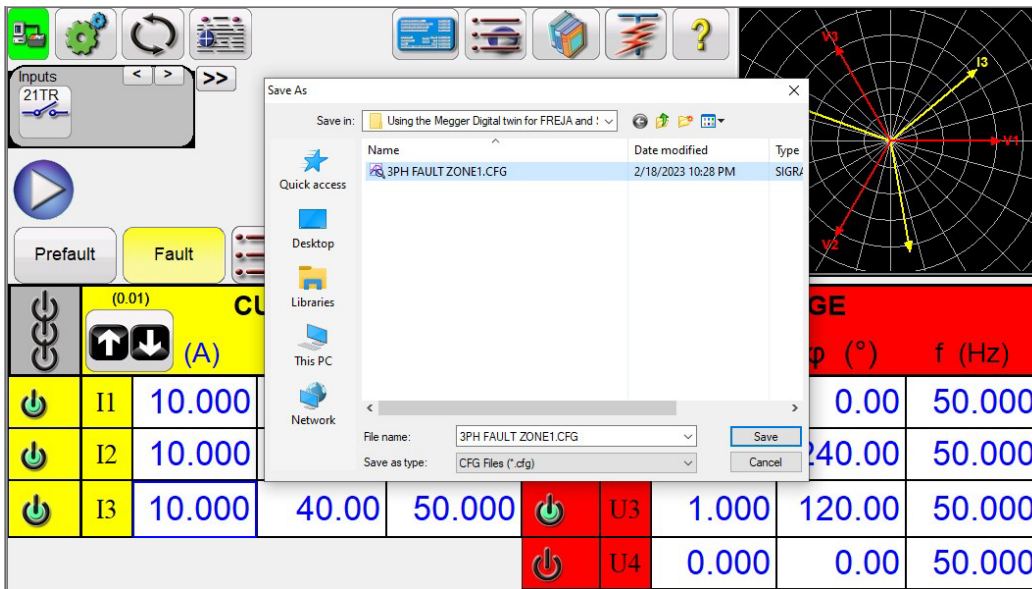

Figure 13: Saving the COMTRADE file for the three-phase forward fault in zone 1

If the test should be repeated, for instance in commissioning, it's possible to save the test in PowerDB format, so that it can be passed to the test engineers that will take care of the physical tests.

Note: It is not necessary to perform all the virtual test as physical tests. The concept of virtual testing is that only a subset of the virtual tests will be performed at site. See references [1] and [5] for details about this important concept that is represented by Figure 14.
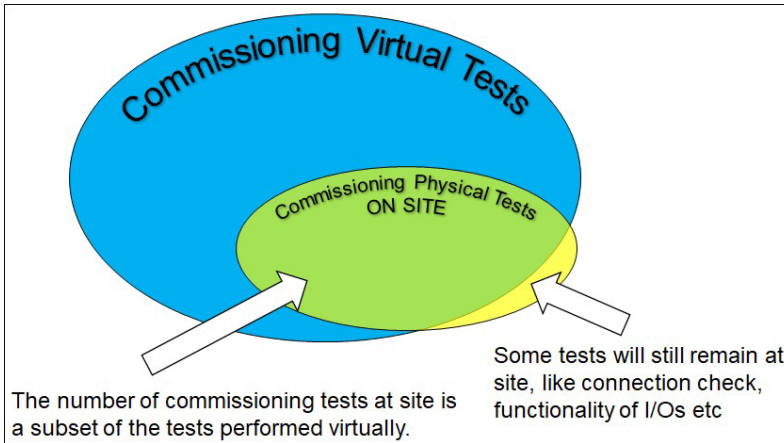
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Figure 14: Commissioning physical tests defined as a subset of the virtual tests

Saving the test in RTMS format (PowerDB xml format)

Saving the test in PowerDB format is done in the usual way by using "SAVE AS", as Figure 15 shows.
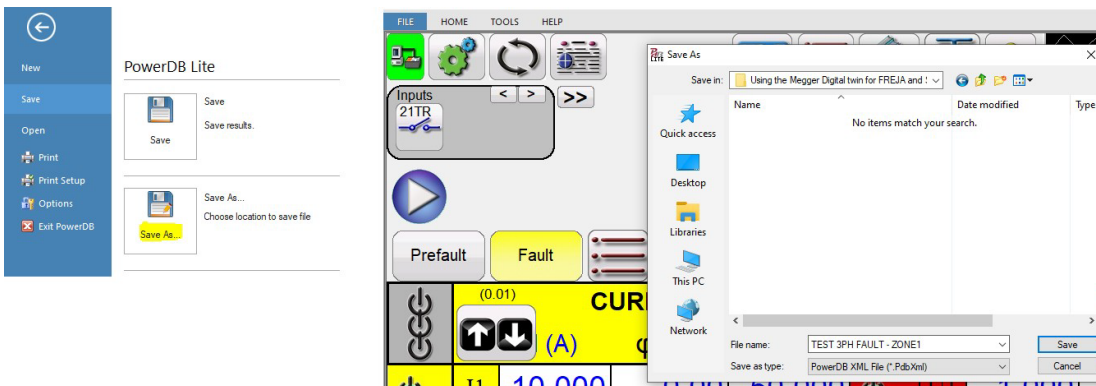

Figure 15: Saving the test as PowerDB file

Transferring the COMTRADE file to the Siemens digital twin relay.

It is now necessary to transfer the file to the Siemens digital twin relay, where the digital twin for the relay has been prepared. We will not go through many details of this procedure as it requires a certain knowledge about the Siemens SIPROTEC DigitalTwin.

Import the COMTRADE file into the SIPROTEC DigitalTwin

The COMTRADE file generated in Figure 13 is imported in the SIPROTEC DigitalTwin environment, and the imported file will appear among other imported test files.
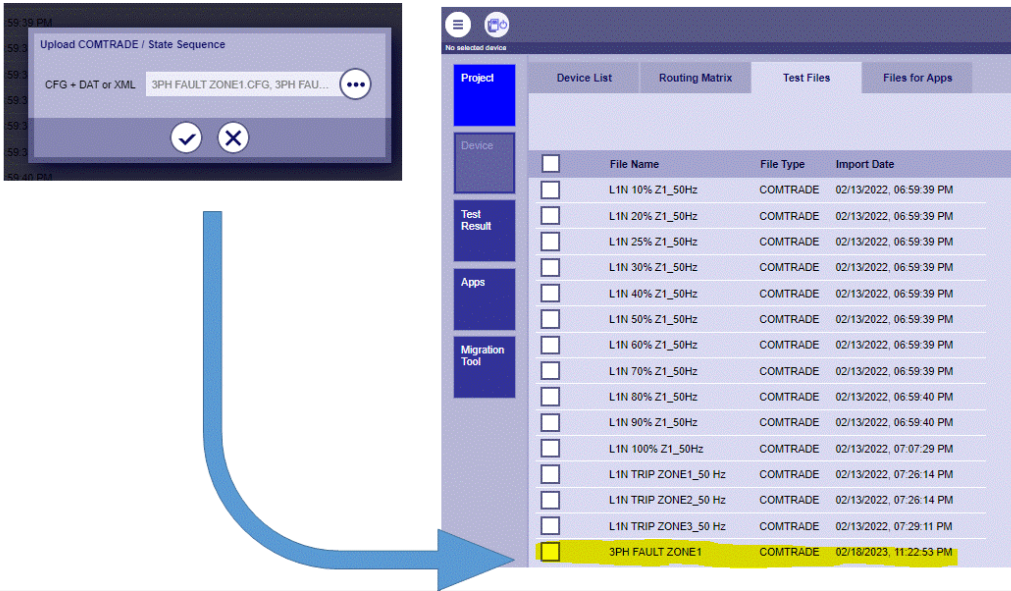
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Figure 16: Importing the COMTRADE file as a test file in the SIPROTEC DigitalTwin environment. In the figure above, the SMRT 46 Digital Twin generated file is selected. This imported file is added to the list of previous imported files

Virtual connections between the digital twin relay and the digital twin test set

The analogue outputs of the SMRT 46 Digital Twin must be virtually connected to the digital twin of the 75A86 relay. The analogue signals in the COMTRADE file generated by the relay test set digital twin represent the analogue generators of the SMRT 46 Digital Twin. These COMTRADE analogue signals are then mapped to the analogue inputs of the SIPROTEC DigitalTwin relay for proper association (see Figure 17).
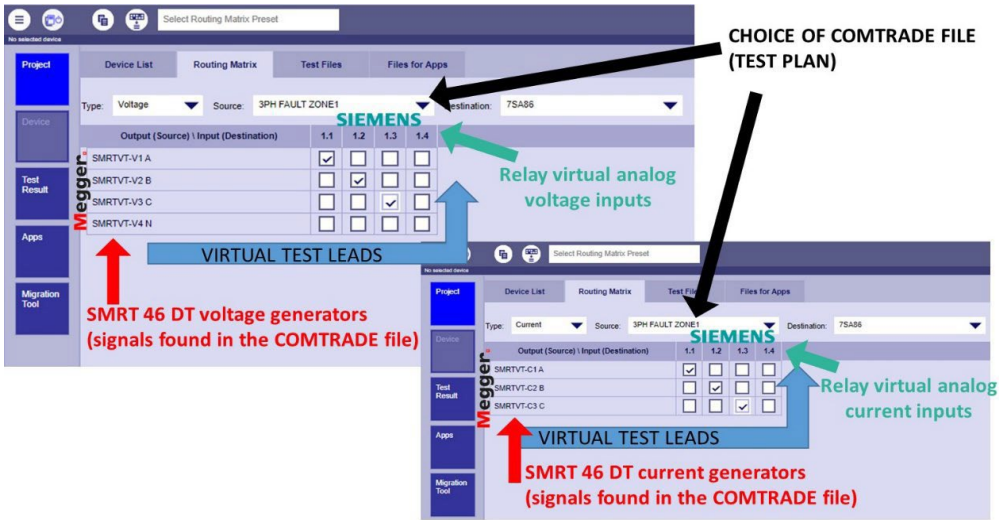

Figure 17: The virtual connection between the virtual test set generators and the analogue inputs of the digital twin relay is done in the Siemens SIPROTEC DigitalTwin environment by means of an intuitive mapping matrix

Note: In this case, the test only generates voltage and current signals. As a result, the COMTRADE file only includes analogue signals. If the test had also involved the activation of the binary outputs of the SMRT 46 digital twins, the resulting signals would have been included in the COMTRADE file and mapped to the binary inputs of the relay's digital twin.

Virtual fault injection into the digital twin relay.

Run the test described in the COMTRADE file means that the waveforms contained in the COMTRADE file are virtually "injected" into the digital twin relay. In the "device" window of the SIPROTEC DigitalTwin environment, it is possible to see the digital twin relay under test, and from there it is possible to choose the test that needs to be performed (see Figure 18).
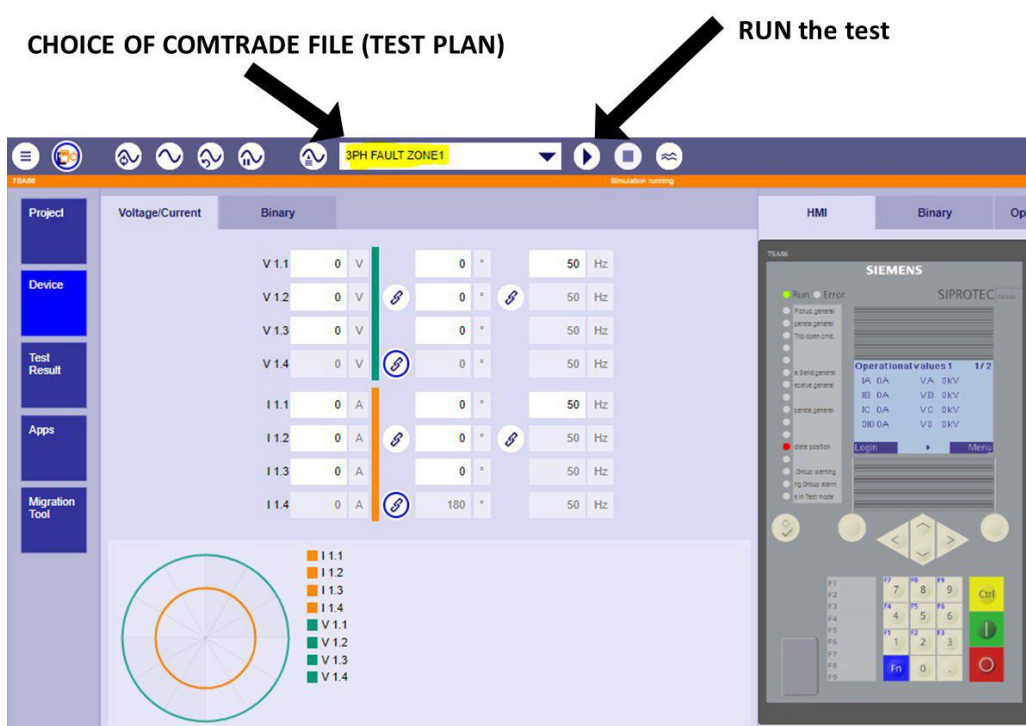
Figure 18: Choosing the test to be "injected" and running the test

Assessing the test results.

After the test is run, the behavior of the digital twin relay is available through the front HMI, the event list, or the disturbance recorder.
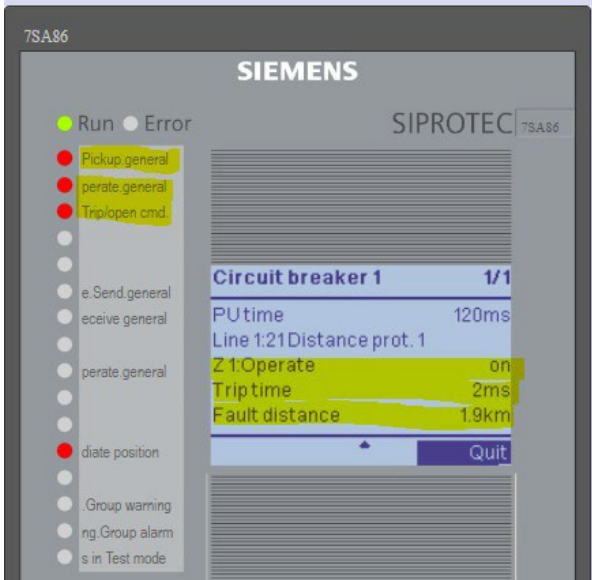
In this particular case, the information from the HMI is sufficient to assess the test result. The digital twin relay showed, with the LED indications, that there was a general start, a general operation occurred, and the trip command to the circuit breaker was issued, which is what was expected.

By reading more in the HMI details, it can be seen that the fault locator saw the fault very close to the beginning of the line (Figure 19).

The test was not done to verify the fault location, but this gives a reasonable hint that things are as they should be. Of course, tests for fault location should also be prepared (as it can be seen in Figure 16, where there are several old tests done to verify the fault location).

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Figure 19: Validation of test results can be performed by observing the virtual LEDs and scrolling through the HMI information on the digital twin relay

Note: In this case the information from the HMI was enough for assessing the test result.

A deeper analysis, if needed, can be performed by analysing the disturbance recorder that the relay has saved because of the trip. There it is possible to measure the time difference between the fault injection and the activation of the internal trip time.

To this time, we need to add the reaction time of the binary output contacts (few ms), if we want to obtain the trip time that would be measured when performing the same test physically.

Such deep investigations is in generally not needed during commissioning tests, unless something goes wrong and it is necessary to investigate for troubleshooting.

The reference [6] details in depth in these more complex tests.

Sharing the same data: run the test with a physical SMRT 46

The SMRT 46 Digital Twin produced a test file called "TEST 3PH FAULT - ZONE1.PdbXml". This file can be run on the physical SMRT 46 twin device using the same steps as opening a test file in RTMS. Instead of selecting the digital twin, the user should choose the connected device, which is one SMRT 46, when asked which test set to use for the test. This is shown in Figure 20.
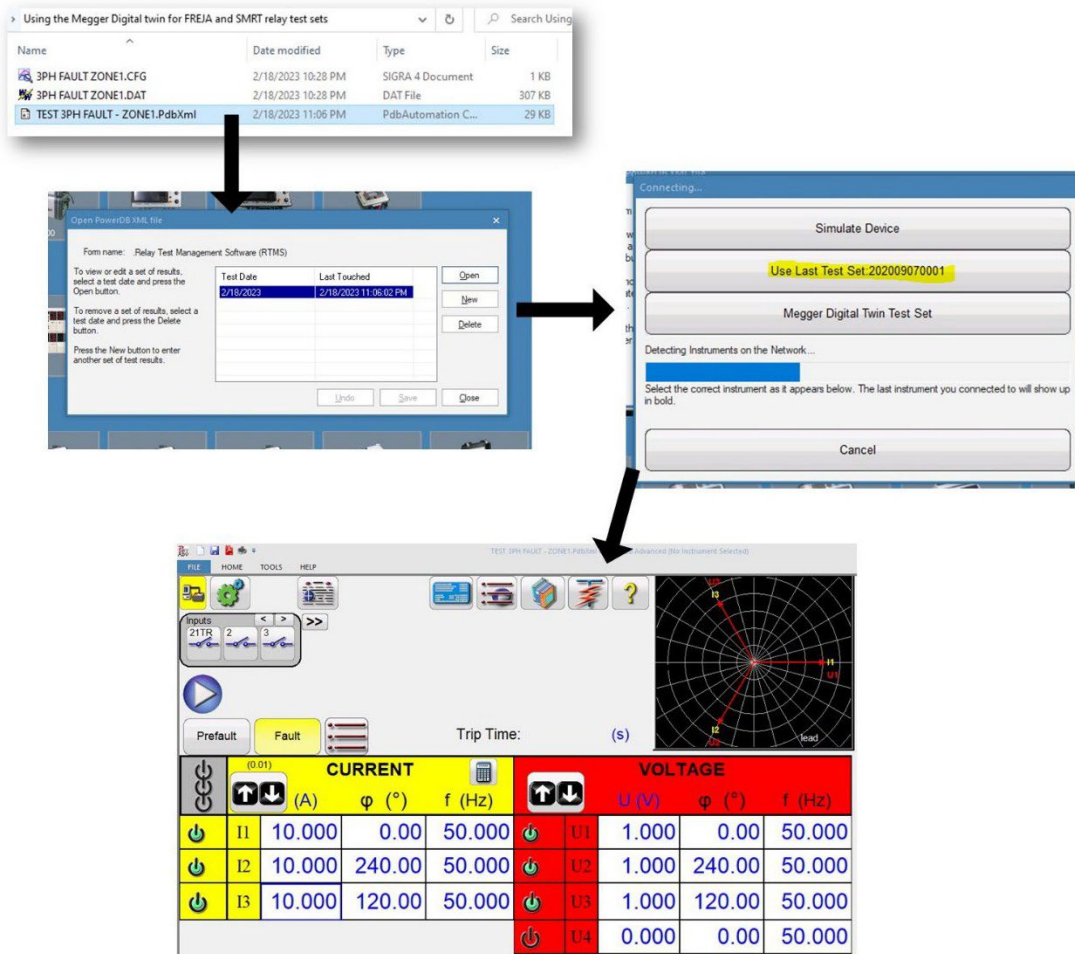
Figure 20: Standard procedure followed when opening a test file from RTMS. The only difference is that the etst file was generated for virtual testing

The RTMS is now ready to perform the test with a physical SMRT 46, which is the physical twin of the digital twin we have just used in this application note.

An overview of the Super digital twin (Super DT)

The Super DT provides users with a virtual test set that offers a large number of analogue signals and binary outputs, including 12 current generators, 12 voltage generators, and 32 binary outputs. This allows for the creation of virtual tests that do not necessarily need to be performed physically. However, if required, a physical super test set can be created by connecting multiple SMRT/FREJA devices as described earlier.

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This can be useful for virtual testing, for example, a busbar protection that can be tested per phase. The 12 current generators can be used to simulate a single-phase through-load for 12 feeders. This can be more practical than physical testing, especially if the busbar protection is distributed. For example, a through-load can be created for a busbar with 2 feeders in and 10 feeders out, and the behaviour of the protection relay can be observed.

For simplicity, the CT ratios are supposed to be equal for all the feeders (which is not a realistic situation). This way it is possible to have a direct visualisation of the primary currents involved by observing the secondary currents set in the Super DT test set. All CTs are earthed towards the protected busbar, so a phase angle of 0 degrees for the secondary current represents an incoming current, and a phase angle of 180 degrees represents an outgoing current from the busbar.

Once the Super DT test set is started, Figure 21 shows the simulation for the single phase through load. Incoming feeders 1 and 2 are simulated by generators 1 and 2. The other 10 outgoing feeders are simulated by generators from 3 to 12. A fault time of 30 seconds has been chosen in this case to allow the (virtual) observation of measured differential current from the relay's HMI. Of course, different times may be chosen, depending on the purpose of the test.
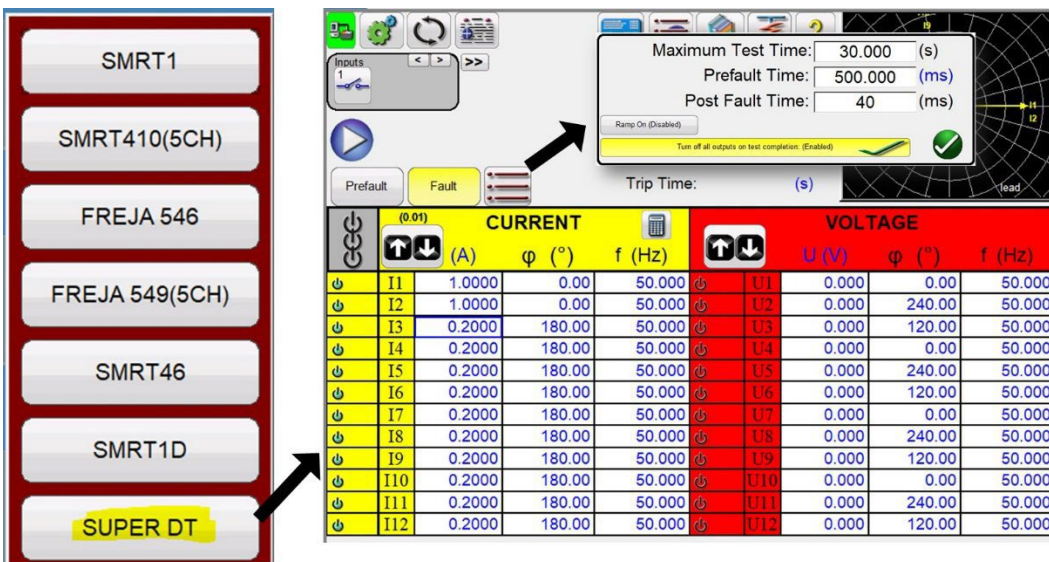

Figure 21: Example of a virtual simulation for a single-phase through-load for 2 incoming feeders and 10 outgoing feeders, using the Super DT test set

By running the test, the Super DT will ask to save the COMTRADE file. This is the same procedure shown in the previous paragraphs.

The test file will also be saved in PowerDB format, in case it needs to be reused, modified, or run against a super physical test set generated with daisy-chained devices.

The COMTRADE file can be passed to the SIPROTEC DigitalTwin to be used for testing the busbar protection but in this case, it will be simply opened with the third-party COMTRADE viewer WaveWin, showing the correct representation of the 12 currents.
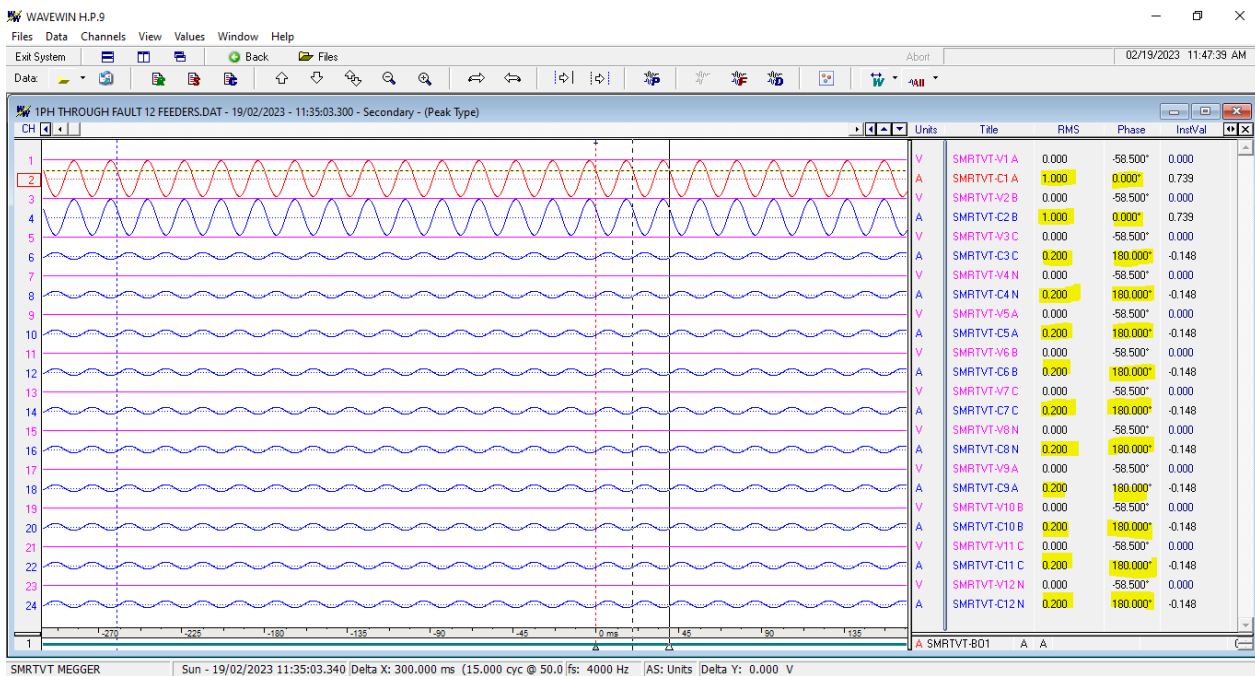
Figure 22: The generated COMTRADE file contains 12 currents and 12 voltages (set to zero in this test), enabling a wide range of virtual tests!

Closing words

Thank you for choosing to be at the forefront of the industry! You will benefit from all advantages that digital twin enables. Digital twin technology in relay protection testing has just taken its first pioneering steps, making it likely that updates will come regularly. Please check for information, updates, enhancements, etc, frequently on the Megger website or with your local Megger representative.

References

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