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Professional paper

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USING DIGITAL TWIN TECHNOLOGY FOR ELECTRICAL PROTECTION SETTINGS

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Abstract: This is the paper writing about a digital twin technology and its usage in power engineering. DIGITAL TWIN is a digital representation of a physical object, process or service that behaves and looks like its real-life counterpart. The application of digital twin technology is wide and it is closely related to artificial intelligence and the latest trends in technology development (Industry 4.0). This paper describes the use of digital twin technology in one segment of power engineering, the protection of elements of the power system.

Keywords: Digital Twin, relay protection, motor protection, Motor Restart Inhibit

INTRODUCTION

The idea of this work is to bring Digital Twin (DT) technology and its application closer to wider audience. DT is used in almost all areas of our life. This paper will present the application of DT in the power system, more precisely in the setting of relay protection. As a theme of the paper is used the advantage of DT that a certain situation can be repeated several times without wearing out the equipment that was used. The paper is organised in several sections.
The first part gives the basic definitions of DT. In that section are given the types of DT, as well as: where, when and how each of these types are used. A special subsection is devoted to the possibility of using those types in the field of protection and control.

Since the topic of the paper is motor protection, the second section presents the basic principles of setting up motor protection. Which protections and how they are set depends a lot on the power of the protected motors. This paper describes the protection of medium power asynchronous motors with direct starting. One picture shows all the protections which we use to protect these motors. Separate description and verification with DT of all protections would require a lot of space. Therefore, only one protection is described in the paper, namely the protection against overload heating of the rotor during several consecutive starts - Motor Restart Inhibit (ANSI 66).
A detailed description of the use of DT in the setting of one motor protection, protection against excessive heating of the rotor, is described in the third part. The paper provides a step-by-step description of the entire procedure, with the results obtained using DT. What is needed is data and recordings of starting a “real” motor.

1. DIGITAL TWIN TECHNOLOGY

A Digital Twin is a digital representation of a physical object, process or service that behaves and looks like its real-life counterpart.

DT can be a digital representation of an object in the physical world, such as e.g. a motor or a wind farm, or as in our case a protection and control device. It is used to replicate processes in order to predict their performance.
DT is a computer program that uses real-world data to create simulations that can predict how a particular product or process will behave. The simulation is based on the current state of the process or on the historical data. These programs can integrate the Internet of Things (Industry 4.0), artificial intelligence and software analytics to improve results. The use of digital data allows its transfer from the real world to virtual representations in digital environment.

With the advancement of learning and factors such as the existence and acquisition of large amounts of data, these virtual models have become a major component of modern engineering to drive innovation and improve performance.
Developers who create digital twins ensure that the virtual computer model can receive feedback from sensors that collect data from the existing version in the real world. This allows the digital version to mimic and simulate what is happening with the original version in real time, creating opportunities to gather data based on performance insights and any potential problems.

DT can be as complex or as simple as needed, with varying amounts of data determining how accurately the model simulates the real-world physical version.

DT enables users to explore solutions for product life extension, production and process optimization, as well as

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product development and prototype testing. Therefore, DT can virtually represent the problem so that in those cases the solution can be designed and tested in the program, instead of testing in the real world.

DT can be used to save time and money whenever a product or process needs to be tested, or when it is needed its design, implementation, monitoring or improvement.

The DT design is made by collecting data and creating computer models for testing. This can include an interface between the digital model and the actual physical object, which will provide sending and receiving feedback as well as real-time data.

By integrating technologies such as artificial intelligence, machine learning and software analytics with data, DT creates a simulation model that can be updated simultaneously with or instead of its physical counterpart. This allows companies to evaluate a fully computerized development cycle from design to deployment and even decommissioning.

By emulating physical assets, frameworks, and operations to produce continuous data, DT enables the industry to anticipate downtime, respond to changing circumstances, test design improvements, and more.

DT is key to the development of Industry 4.0 to ensure automation, data exchange and joint production processes, as well as reducing the risk of product introduction. Industry employees can monitor operations in real-time, providing early warning of potential future failures and enabling real-time performance optimization and assessment with minimal loss of productivity.

1.1. Types of Digital Twin

DT can be divided into three types, which are used in different stages of the process:

Digital Twin Prototype (DTP) – Digital twin is used before the physical product is created, and in this phase the future operation of the product is simulated virtually. Ideally, DTP should remain connected to its physical original throughout its life cycle.

Digital Twin Instance (DTI) – This type is applied when the product is manufactured, to perform additional tests in different usage scenarios. In this way, the “wear and tear” of the physical product is prevented.

Digital Twin Aggregate (DTA) – This phase of DTI data collection is used to make a forecast, test operating parameters, and determine overall product functionality. It should be noted that DTA is a collection of numerous DTI data and is simulated to understand group behaviour rather than individual behaviour (e.g. groups of relays in one substation (SS) and not just one relay in SS).

1.2. Digital Twin in protection and control

The usage of DT is wide. One of the areas where DT is used is in the electrical energy systems. The application in the electrical energy systems is wide, ranging from the use of Digital Twin for the operation of switches, simulation of the state in the network, all the way to application in protection and control.

This paper will deal with the topic of using DT in protection and control. Any protection device is ideal for use in Digital Twin because it is made with the latest technology.

The use of DT in protection and control can be applied in three processes:
Digital Twin Prototype (DTP) – DTP can be used in two ways: creating a new device type and configuring an existing device type in a new plant.

When a company develops a new device or a new function of an existing device, it is not necessary to have a physical device for all the tests, because all of them can be carried out on a virtual device.

The most common case of DTP application is starting the construction of a new energy facility. We usually have several types of devices in the facility. By forming virtual type devices, all required functions, as well as all the inputs and outputs, can be virtually checked. Finally, with DT, the mutual connection of type fields can be examined. An example of such a test is checking simplified busbar protection.

Digital Twin Instance (DTI) – The goal of this process is to verify the manufactured product with various tests in different usage scenarios.

In our case, the product is installed on the building, and we have various situations that happened. All these situations are recorded on the devices. In most cases, we had expected correct reaction of devices, but in some cases, there were also wrong reactions of the device. By using this data, we can improve the correct response of the device (by adding some signalling, a small presetting of the protection, presetting the recording signal etc.) or prevent future incorrect protection responses. Of course, all this can be done without physically “wearing” the device. It is also important to note that for this, it is not necessary to work with test devices, which means that the procedure itself is much faster.

Digital Twin Aggregate (DTA) – By its basic definition, DTA is a set of many DTIs, used to get the group behaviour of the device. In our case, based on the behaviour of the device on one SS, we can simulate and predict the behaviour and operation of the device in a future SS of similar or the same voltage level with different network parameters.

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2. MOTOR PROTECTION

In this paper, an example of using DTI for setting and resetting the motor protection will be presented. Depending on the motor power and what they are used for, we have different protections and their settings. Motor protection setting recommendations are provided by both motor manufacturers and manufacturers of protection devices. Many users, besides these recommendations, also use their own experience and practice.

For setting the motor protection, the most critical case is the moment of putting the motor into operation, due to large starting currents, and that data is used for setting the motor protection. Figure 1 shows a proposal for the coordination of all protections for one motor with direct release. Three segments can be recognized there: the initial moment when the current reaches a value over 10xIn, starting the motor with a current of 5 – 7xIn and a time from a few seconds to tens or more of seconds (depending on the power of the motor and what initiates it) and normal operation with current of In (nominal current). In Figure 1, it can be seen that for the adjustment of all protections, it is preferable to have the curve of the "real" motor starting and based on that curve to perform the adjustment of all protections. The manufacturers motor data are usually used for the first setting. After the initial start-up, the microprocessor relays make a record of that start (Figure 2) based on which any reset of the protection is carried out.

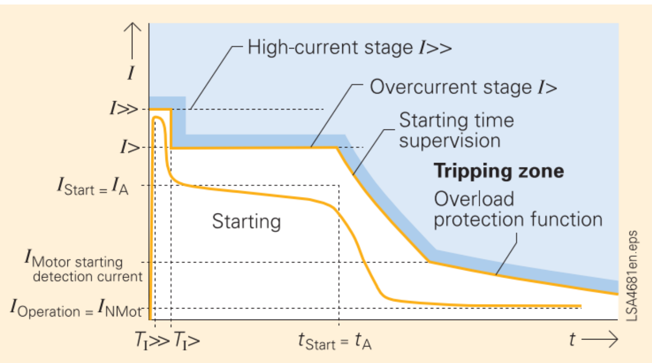

Figure 1: Example of image marking

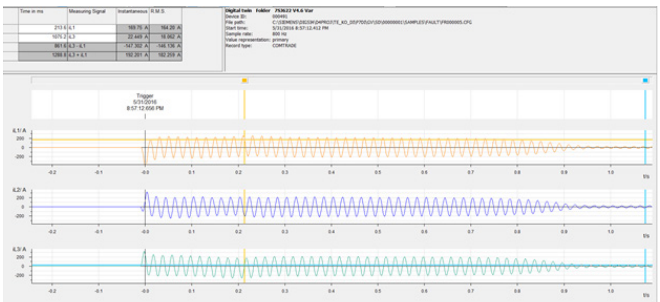

Figure 2: Current record of one motor starting

In addition to the protections presented in Figure 1, the critical condition of all motors also depends on the number of consecutive starts. Namely, during each motor start, value of the motor currents is sometimes greater than nominal current of the stator and rotor. As we know, energy of the motor is heating it up. Due to a greater number of starts, stator or rotor may burn out. Each motor manufacturer prescribes the number of "cold" and "warm" consecutive starts. Figure 3 shows how the rotor temperature increases during several consecutive motor starts.

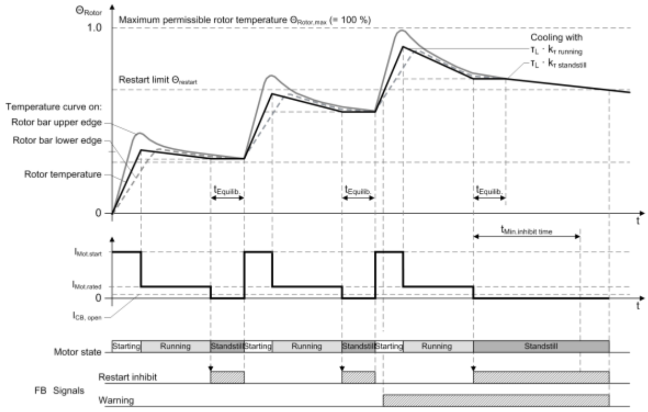

Figure 3: The curve of the rotor temperature increases during several consecutive motor starts

3. USING DIGITAL TWIN TO SET MOTOR PROTECTION

An example of using Digital Twin to set the motor protection will be given through an example of setting the protection for multiple consecutive starts - Motor Restart Inhibit. This setting should be checked during exploitation. That process can be time-consuming because the problem is to do several consecutive starts with real motors. Another way to check this protection is the application of Digital Twin.
In this paper, we have taken the example of one motor with power P_n = 200kW and operating voltage U_n = 6.3 kV. From the protection of this motor, we have a recording of one start shown in Figure 2. From the recording, the values which we need to set the protection can be read. Also, it can be seen that the starting time of the motor is 0.9 sec, the starting current is 160 A, from the diagram from Figure 2. In this case we use only one record of starting this motor. These values depend on the condition during motor starting, value of the voltage, condition of the load, moment of the closing…. For more precisely data it will be better to have more recordings of starting and then use average value of the starting time and the starting current. The operating current In of this motor is about 18 A.

The procedure for working with DT was as follows:

- In the program for setting and parameterizing motor protection, we adjust all protections. In this work, we will pay attention only to the protection of the motor from multiple consecutive starts - Motor Restart Inhibit, i.e. on the thermal protection of the rotor and stator. Data obtained from the recording is used to set these protections. An example of setting protection against multiple consecutive starts is given in Figure 4;

- When the protection setting is made, it is necessary to export this setting in a format (*.sim) accepted by DT;
- Then, in the DT program, it is necessary to import that file (Figure 5);
- In order to be able to simulate the motor start, it is necessary to import a file with a record of the motor start into DT. A file with the standard COMTRADE format is imported, as shown in Figure 6;

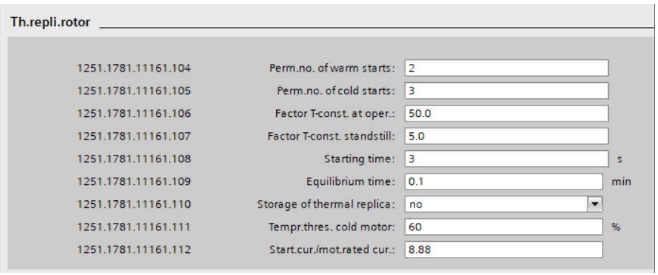

Figure 4: Setting the protection against multiple consecutive starts

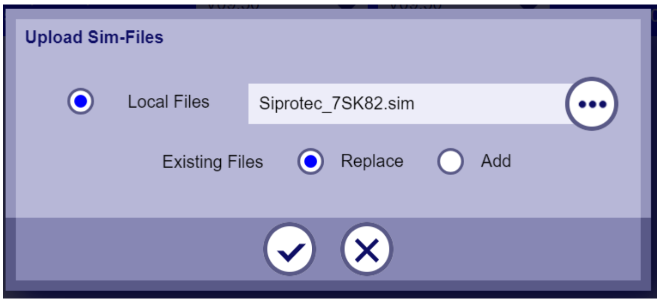

Figure 5: Importing a file for DT simulation

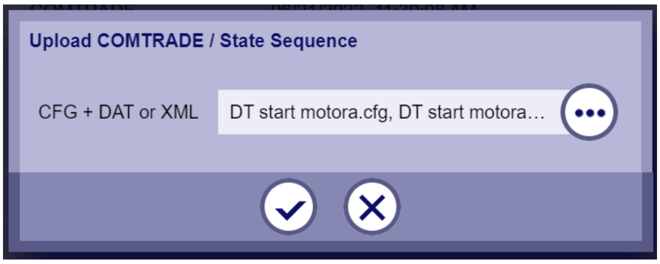

Figure 6: Importing a CFG snapshot of the fault

- The next step is to start the simulation by setting the current and voltage values with which we simulate the actual operation of the motor. In our case, we set the nominal parameters of currents and voltages. This is shown in Figure 7. From the figure we can see that although the motor has some current, the device recognises that it is in standstill mode. The reason for that is the fact that we did not simulate the starting process of motor with higher current. Once we input higher current the device recognises the motor running.
- By running the imported startup record file, we simulate the motor startup. We can see that the start was successful from the screenshot of the protection screen, where you can see the following: excitations in all three phases and the signal that the motor is in the running mode, which can be seen in Figure 8;
- After each motor start, the state of stator and rotor heating is monitored on one of the relay displays, as shown in Figure 9.

Monitoring the heating of the stator and rotor after each motor start serves us to check the protection setting of that motor. We can repeat this procedure several times until we get the desired results.

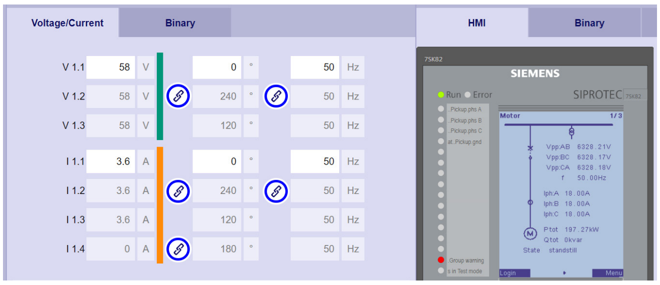

Figure 7: Snapshot with nominal values "before starting the motor "

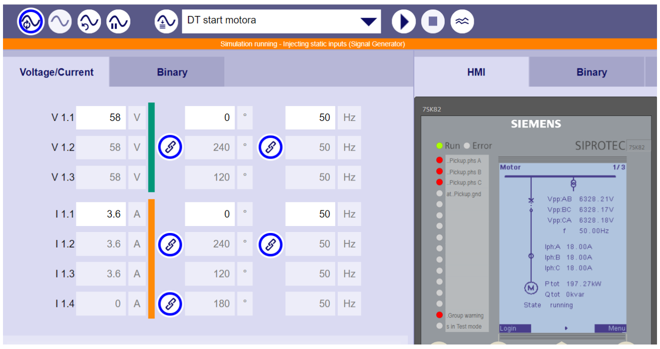

Figure 8: Snapshot with nominal values "after starting the motor"

Figure 9: Display with stator and rotor heating values

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4. CONCLUSION

The procedure presented in this paper has shown that the protection setting, in this case of one motor, can be checked in an easy way, from the office, within couple of hours. On the other hand, this check can also be done on an actual motor, but it would be a time-consuming process. Additionally, bringing the motor to certain heating values would also require physical cooling of the motor. This process, depending on the power of the motor, can last from several hours to a whole day. In the case of DT, this is achieved by simply resetting the relay through DT, up to one minute.

The result of working with a real motor would be identical to the result we obtained using Digital Twin. The advantage of Digital Twin is primarily in the saved time. Another big advantage is that there is no work with real motors and relays i.e. of their excessive work.

In addition to the field of protection, in the power industry DT can be used in the following cases:

- power transformers, generators and other elements of the power system can be simulated in DT and their behaviour can be monitored during various cases of operation.
- by using DT medium-voltage plants, trainings for people that are working with these plants can be carried out;
- the entire switchgear can be presented in DT and then serve as an aid in their maintenance.

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BIOGRAPHY

Born in 1960 in Travnik, Bosnia and Herzegovina. Graduated from “Pomoravski heroji” Gymnasium in Ćuprija. Graduated in 1985 at the Faculty of Electrical Engineering in Belgrade - Department of Energy. Master’s degree in 1993 at the same faculty. First employment at HPP Đerdap 2, then worked at Elektrovojvodina - Novi Sad, Energotehnika “Južna Bačka” Novi Sad. For the last 20 years, he has been employed at Siemens doo Belgrade on tasks related to the relay protection. During work, active member of CIRED Serbia in the committee for protection and control, as well as CIGRE Serbia in committee B5. The main achievements, in addition to the commissioning of many substations, in the working life are:

- project leader of procurement, installation and commissioning of the first substation in Serbia (TS 110/20kV Nova Pazova) with microprocessor protection and control,
- member of the working team for the introduction of the IEC 61850 protocol in the transmission network of Serbia (TS 400/x kV).

Married and has one child. He likes skiing, hiking and working in the garden.