Development the Digital Twin of Thyristor Electric Power Converter using Real-Time hardware

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Relevance of work:

- The use of a digital twin allows you to identify faults in a controlled object at an early stage, which allows you to operate equipment with minimal downtime, schedule repair times, and order spare parts for repairs in advance

- The use of simulation allows for the initial debugging of the fault detection algorithm, which reduces the time of work with physical equipment and energy costs

- Using a real-time machine reduces development time because the stages of controller programming and hardware development are excluded

Scope of work:

- Development of a method for determining faults in a AC / DC 6-pulse bridge (B6) electrical power rectifier

- Development of a model of a physical object of electric power converter in Matlab/Simulink

- Development the Digital Twin of electric power converter in Matlab/Simulink

- Simulate a physical model with the Digital Twin, test modes with faults

- Preparing test equipment

- Run Speedgoat Performance real time target machine in Digital Twin mode with AC / DC 6-pulse bridge (B6) electrical power rectifier 50A, 440V and 26kW DC motor

Digital Twin

The concept of the “Digital Twin" is in line with the European direction for the development of industrial technologies "Industry 4.0".

The main purpose of the “Digital Twin" is to determine the deviation of parameters from the norm by comparing the parameters of the physical part of the object with the calculated ones obtained from the reference model of the “Digital Twin". This allows you to identify a malfunction long before a critical event occurs, as well as predict the timing of the equipment removal for repair, and make a preliminary order of consumables by the estimated completion date of their service.

The purpose of using the Speedgoat Performance real time machine was to test the Fault detection algorithm, indicating the location and cause of the failure.

Detected faults with Digital Twin

- Failure to turn on / off the thyristor:

  - switching on the thyristor at the point of natural commutation (with firing angle $\alpha = 0$ electrical deg.);
  - switching on the thyristor with an firing angle $\alpha < \alpha nom$;
  - switching on the thyristor with firing angle $\alpha > \alpha nom$;
  - not switching on the thyristor.

- Undervoltage / overvoltage control

Software

The main control software was developed and simulation was provided using Matlab / Simulink software.

Physical Object Models of electric power converter and its Digital Twin were developed in Simscape Electrical / Specialized Power Systems library.

Fault detection algorithm was developed in Simulink.

The Digital Twin run on Speedgoat Performance real time machine with 100 μs sample time.

Results from Speedgoat real time machine was received using Simulink Data Inspector.

Work description

The model consists of two thyristor converters:

- the first simulates the operation of a physical converter with faults,
- the second converter runs as a Digital Twin.

The digital twin model accepts the following signals:

1. Instantaneous values of the phases of the supply voltage. The measured voltages at the bridge input take into account switching dips and other distortions of the supply voltage of a real converter and are set at the input of the digital twin bridge. This eliminates the need for a detailed calculation of network reactances.
2. Firing angle.
3. The instantaneous value of the rectified current. Instead of an equivalent circuit for the parameters of a direct current circuit, a controlled current source is used in the twin model, which repeats the rectified current of a real converter. This makes it possible to avoid the development of a detailed equivalent circuit of the rectified current circuit and algorithms for accounting for parameter variations.

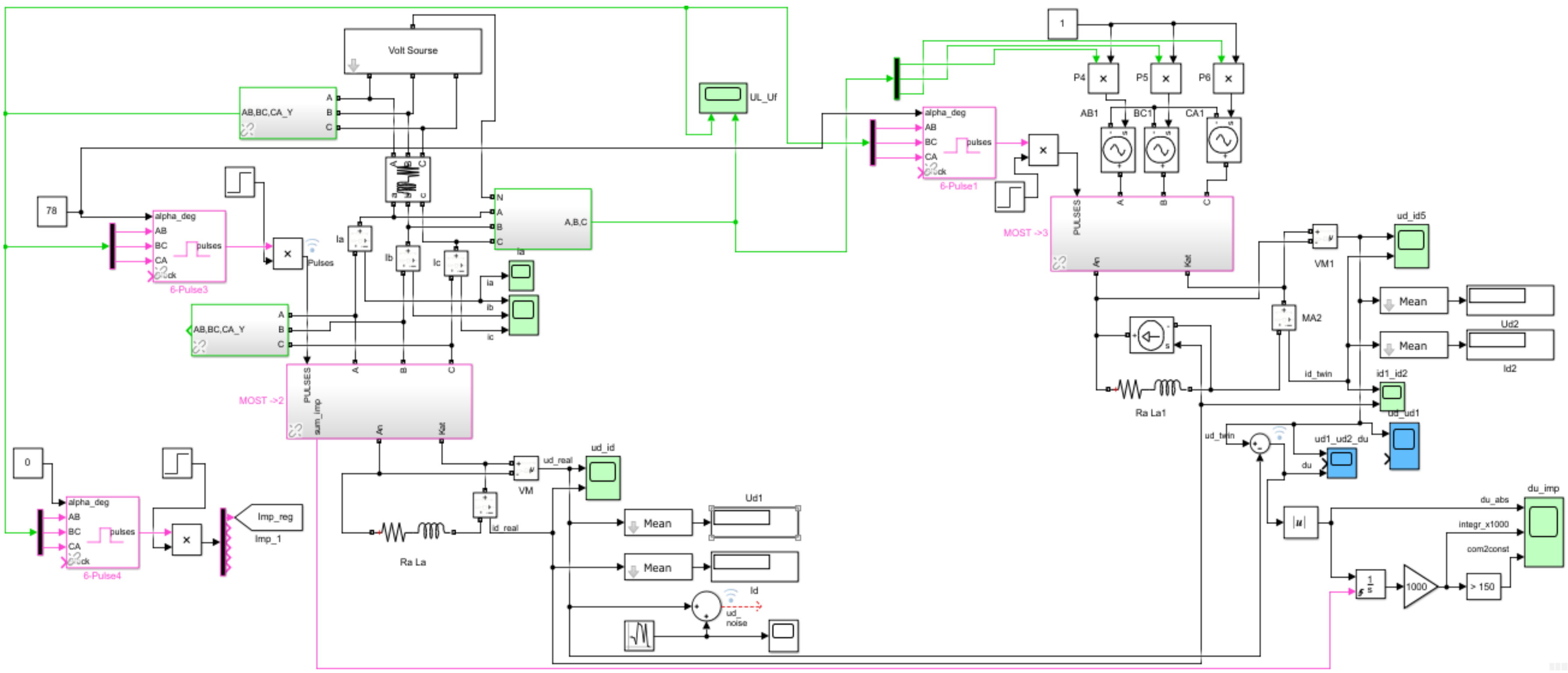
In normal mode, the two models work identically, the instantaneous value of the rectified voltage of the real converter u_dr coincides with the corresponding voltage of the digital twin u_dt. Mismatch error:

$$u\_dr - u\_dt = 0$$

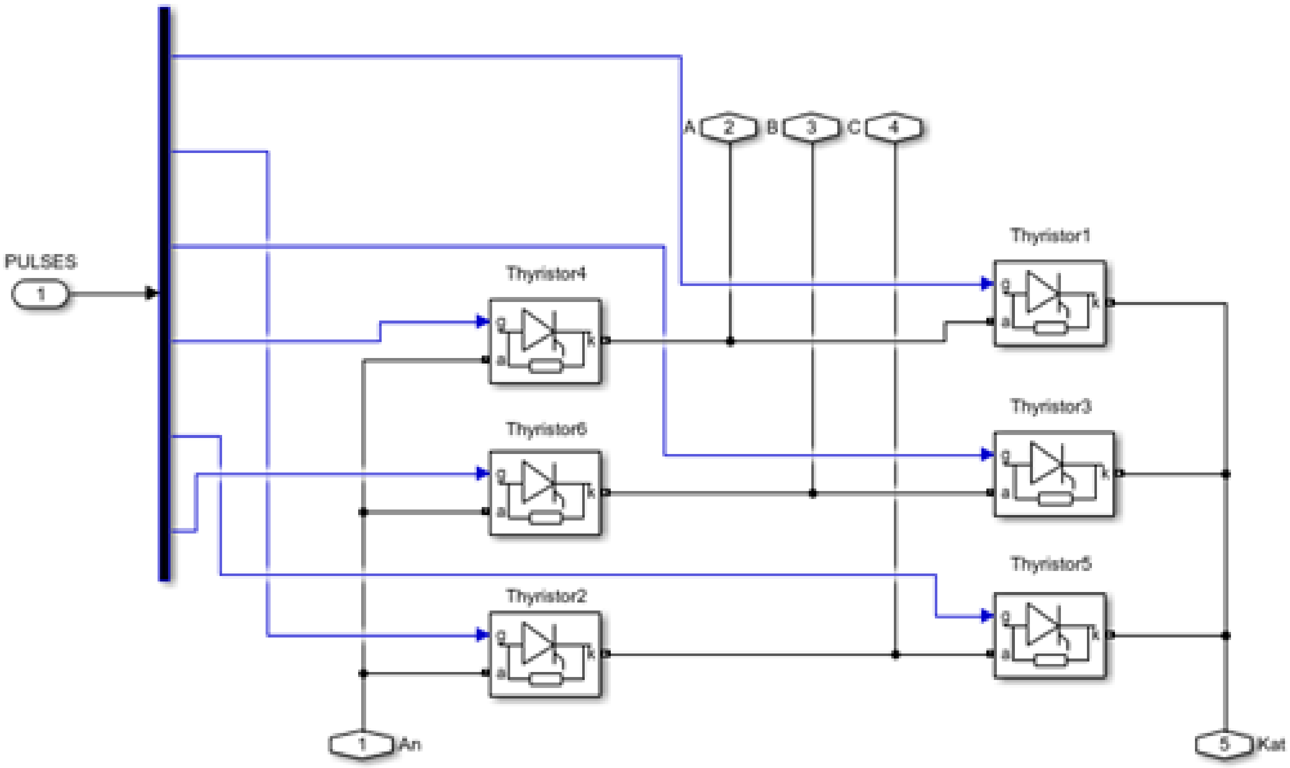
When a malfunction occurs in the operation of thyristors, a mismatch of the instantaneous values of the rectified voltages occurs. This discrepancy is recorded by the system and compared with the thyristor number in operation.

The system implements an algorithm for the integral estimation of the error signal, which provides robustness with respect to noise, impulse noise and the presence of a small constant component in the measured signals of a real converter.

Structural - functional diagram of the electric drive model with Digital Twin for simulation



Model of the 6-pulse bridge scheme of electrical power rectifier (B6 according to power rectifier circuit topologies DIN 41761)



The physical object model of electric power converter consists of:

- electrical grid,
- three-phase chain RL - unit that releases the transformer reagents, reduced to the secondary winding,
- current meters,
- AC / DC 6-pulse bridge (B6) electrical power rectifier,
- load.

The Digital Twin consists of:

- voltage source, which consists of three adjustable voltage generators,
- AC / DC 6-pulse bridge (B6) electrical power rectifier,
- load,
- fault detection algorithm.

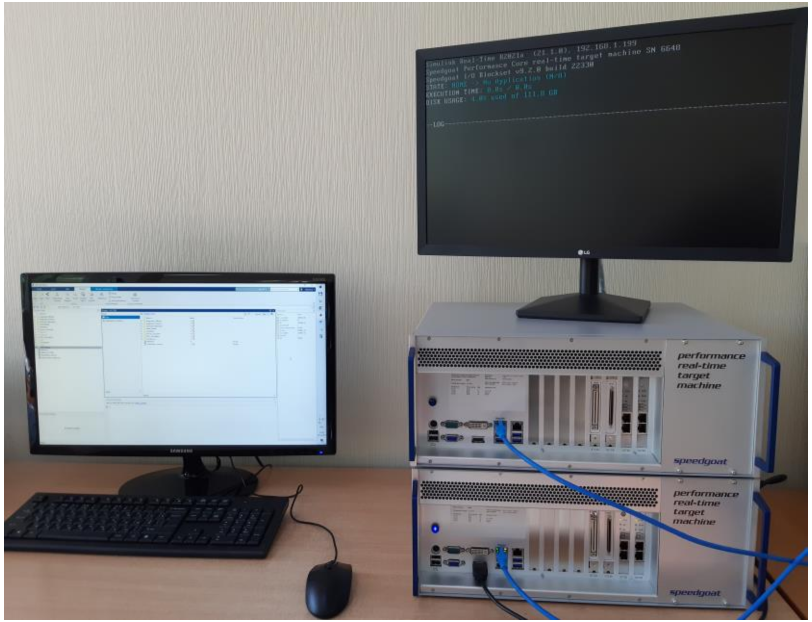
Physical hardware:

- AC/DC 6-pulse 4Q bridge (B6) electrical power rectifier 50ADC, 440VDC,
- DC motor 2ПФ 2001ПГ 26kW, 67A, 440V, 1300/2500 rpm, excitation 5A, 220V,
- Speedgoat Performance real time target machine
- archiving and visualization computer
- set of voltage, currents sensors, galvanic isolation.

Real-Time Hardware

What can be achieved with real time machine (advantages):

- ✓ Development speed
- ✓ No programming and hardware development stages required
- ✓ Possibility of fast correction of the algorithm
- ✓ Ability to test equipment in emergency and abnormal modes

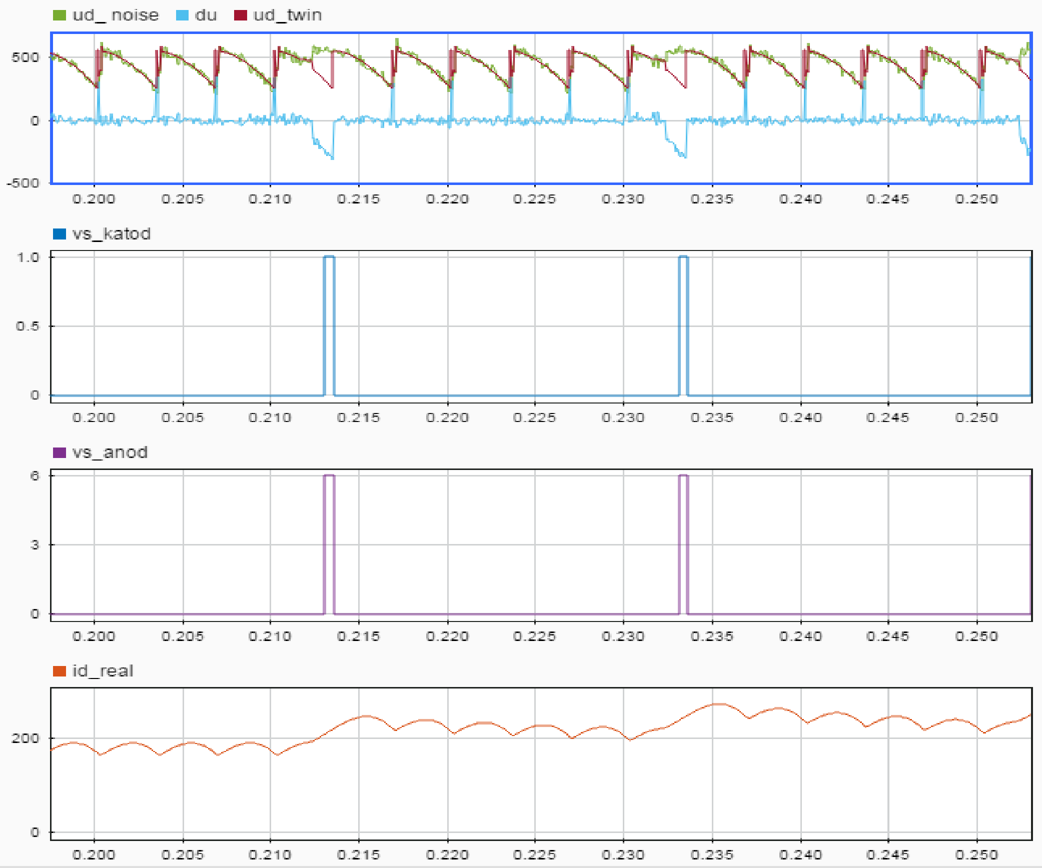


Simulation results

Operating modes with various faults were set on the physical equipment, in certain thyristors.
Speedgoat Performance real time machine was running in Digital Twin mode.
The purpose of using the Speedgoat Performance real time machine was to test the Fault detection algorithm, indicating the location and cause of the failure.
This Fault detection algorithm allows to detect failure in the early stage.

Simulation results

Malfunction: Switching on the thyristor at the point of natural commutation



MODE

The power converter operates with a nominal angle α = 35 electrical degrees, with a malfunction - the thyristor VS1 is switched on with an angle α = 0 electrical degrees.

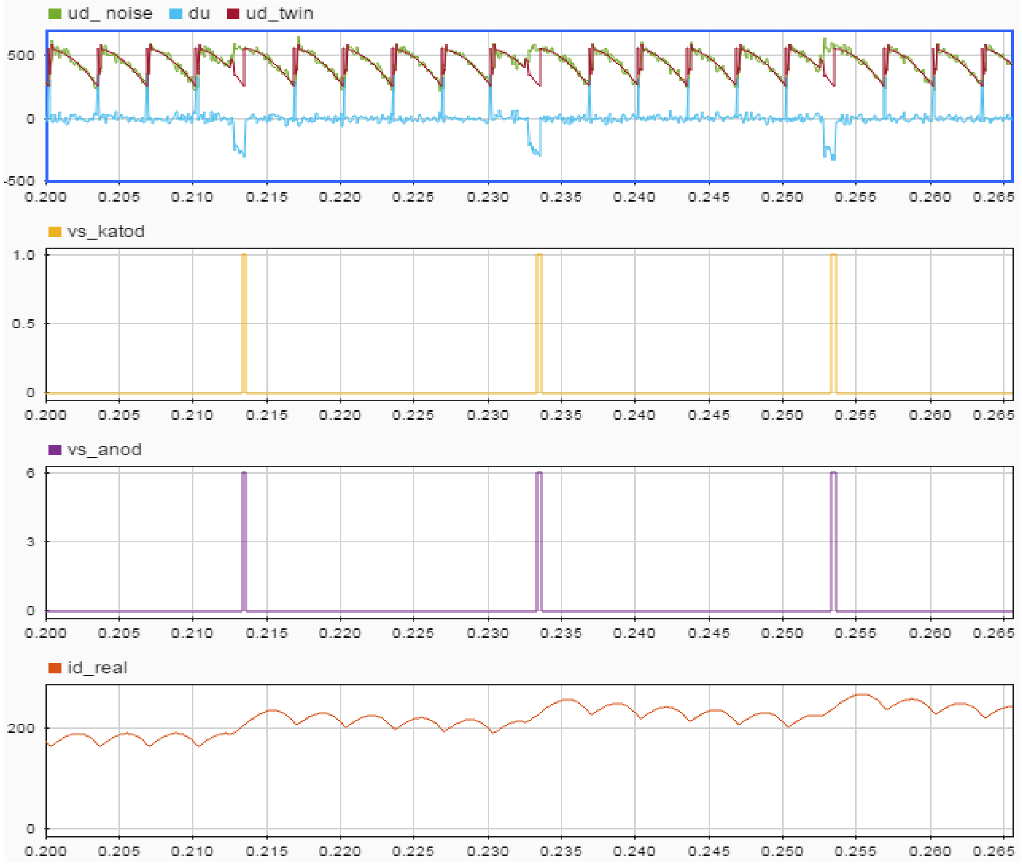
From the figure you can see that the diagnostic system detects VS1 VS6, because a malfunction occurs at the time of their joint conduction, and therefore shows probable faulty thyristors

On oscillograms:

- instantaneous values of rectified voltages of a physical converter, Digital Twin and mismatch $u_{dr} - u_{dt}$;
- number of the faulty thyristor of the cathode group, determined by the diagnostic system at the time of the malfunction – VS1;
- number of the faulty thyristor of the anode group, determined by the diagnostic system at the time of the malfunction – VS6;
- instantaneous value of the DC current.

Simulation results

Malfunction: Switching on the thyristor with an firing angle α <αnom



MODE

The power converter operates with a nominal angle α = 35 electrical degrees, with a malfunction - the thyristor VS1 is switched on with an angle α = 15 electrical degrees.

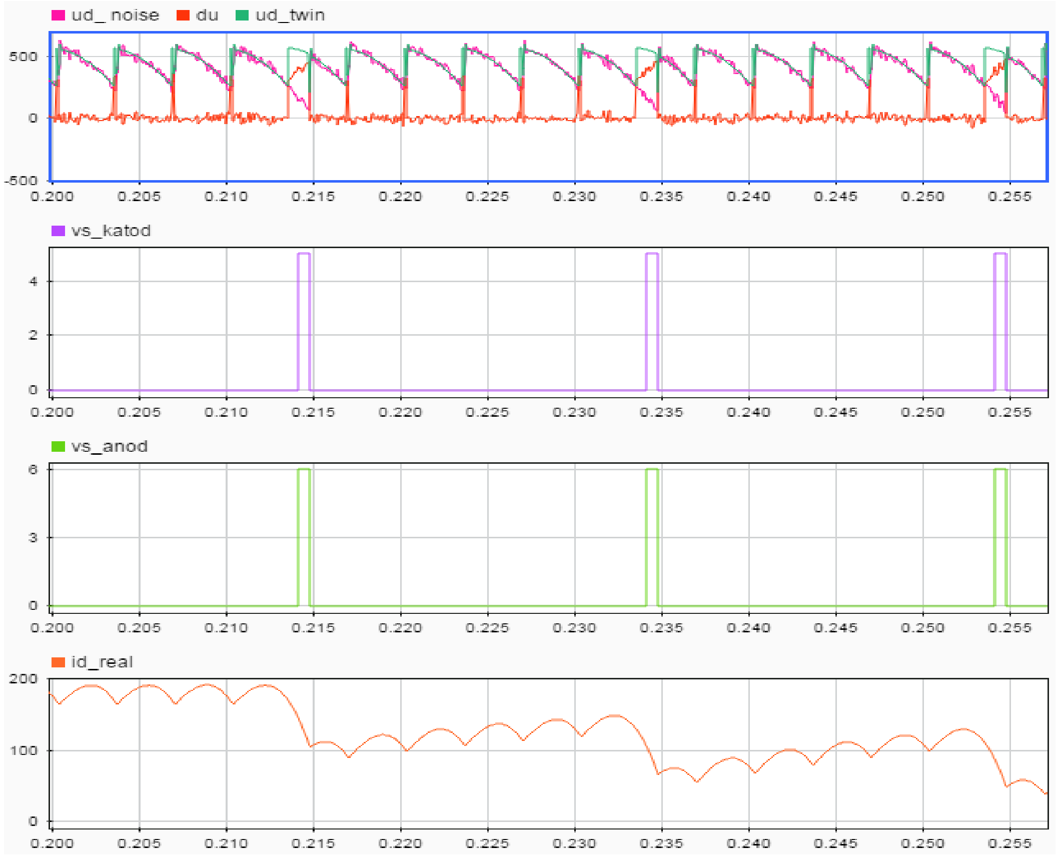
From the figure you can see that the diagnostic system detects VS1 VS6, because a malfunction occurs at the time of their joint conduction, and therefore shows probable faulty thyristors

On oscillograms:

- instantaneous values of rectified voltages of a physical converter, Digital Twin and mismatch $u_{dr} - u_{dt}$;
- number of the faulty thyristor of the cathode group, determined by the diagnostic system at the time of the malfunction – VS1;
- number of the faulty thyristor of the anode group, determined by the diagnostic system at the time of the malfunction – VS6;
- instantaneous value of the DC current.

Simulation results

Malfunction: Switching on the thyristor with an firing angle α >αnom



MODE

The power converter operates with a nominal angle α = 35 electrical degrees, with a malfunction - the thyristor VS1 is switched on with an angle <u>α = 55 electrical degrees</u>.

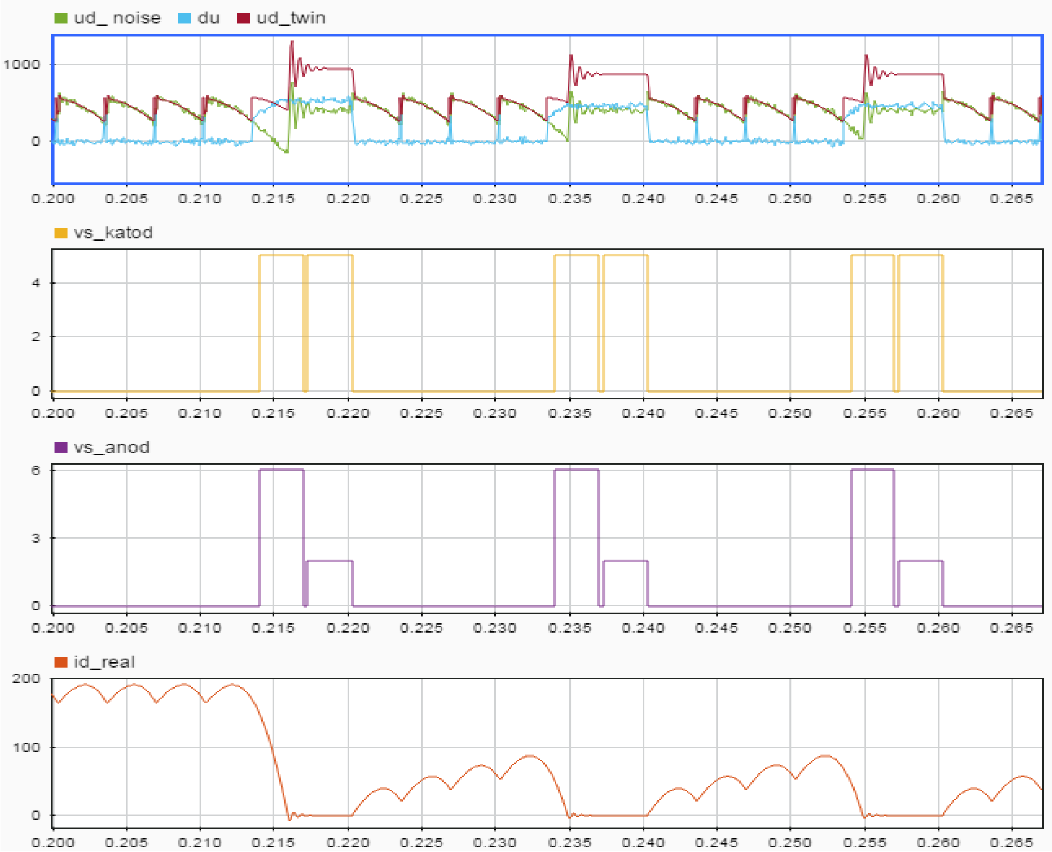
From the figure you can see that the diagnostic system detects VS1 VS6, because a malfunction occurs at the time of their joint conduction, and therefore shows probable faulty thyristors

On oscillograms:

- instantaneous values of rectified voltages of a physical converter, Digital Twin and mismatch $u_{dr} - u_{dt}$;
- number of the faulty thyristor of the cathode group, determined by the diagnostic system at the time of the malfunction – VS1;
- number of the faulty thyristor of the anode group, determined by the diagnostic system at the time of the malfunction – VS6;
- instantaneous value of the DC current.

Simulation results

Malfunction: Not switching on the thyristor



MODE

The power converter operates with a nominal angle α = 35 electrical degrees, with a malfunction - the <u>thyristor VS1 is not switching on</u>.

The figure shows that the conductivity of thyristor VS5 is twice normal. And this happens with the work of thyristors VS6 and VS2. This indicates that thyristor VS1 is not switching on.

On oscillograms:

– instantaneous values of rectified voltages of a physical converter, Digital Twin and mismatch $u_{dr} - u_{dt}$;
– number of the faulty thyristor of the cathode group, determined by the diagnostic system at the time of the malfunction – VS5;
– number of the faulty thyristor of the anode group, determined by the diagnostic system at the time of the malfunction – VS2, VS6;
– instantaneous value of the DC current.

Conclusions

- ✓ With the help of digital twin technology, an algorithm for detecting malfunctions was implemented - untimely switching on or off of the thyristor. The simulation results showed the possibility of identifying faults that do not trigger the standard protection of the converter. The fault detection algorithm provides robustness with respect to noise, impulse noise and the presence of a small DC component in the measured signals of a physical converter.
- ✓ The use of the Digital Twin allows you to identify malfunctions in the controlled object at an early stage, which allows you to operate equipment with minimal downtime, plan the repair time, order spare parts for repair in advance.
- ✓ The use of simulation allows for the initial debugging of the fault detection algorithm, which reduces the time of work with physical equipment and energy costs.
- ✓ Using a real-time machine reduces development time because the stages of controller programming and hardware development are excluded.
- ✓ The results of the experiments allow us to determine the requirements for the hardware part of the industrial controller and its performance.
- ✓ In the future, it is possible to convert the algorithm from Simulink to C-code for the target controller using Matlab tools, which reduces development time and errors in implementing the algorithm into code.

About company

M-Works is the industrial branch of IT Master Soft GmbH company.

IT Master Soft GmbH

IT Master Soft company was established in 2012.
Main activity of the company is software development.
Company has offices in Germany, Bulgaria, Ukraine.

M-Works

M-Works offers engineering services using **Matlab/Simulink software**.
Our key strength are **Responsibility, Result oriented, Confidentiality**.
Our experts has been working with Matlab products **since 2004** and keep knowledge up to date.
Our team has engineering background in **Electrical Engineering** and **Control System Design**.
We work closely **with industry** and understand production processes.
We work **with universities** and can extend our team for specific project (not limited to the mentioned engineering).
All this allows us to take a comprehensive approach to solving the problem and find the optimal solution.

We offer services

- Digital Twin Development
- Hardware-in-the-Loop testing
- Model-Based Design
- Control System Design

Engineering background	Electrical Engineering (Power electronics, Electric drives, Energy Production)
	Control System Engineering
	Multiphysical Systems Engineering
Main Industries	Power Electronics
	Energy Production
	Power Systems

Experience with Matlab/Simulink Toolboxes

m-works
IT MASTER Soft GmbH

- Simulink
- Simscape
  - Foundation Library (Electrical, Mechanical, Thermal, Gas…)
  - Driveline
  - Electrical
  - Specialized Power Systems
- Control System Toolbox
- Robust Control Toolbox
- Simulink Control Design
- Simulink Desktop Real-Time
- Simulink Real-Time (Speedgoat hardware)
- Embedded Coder
- DSP for TI C2000
- App Designer (GUI)

Contacts

We look forward to discuss the details of our pilot project

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