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Concept, Design and Implementation of Power System Component Simulator Based on Thyristor Controlled Transformer and Power Converter

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***Abstract*—**This paper presents information on Power System Component Simulator – a device designed for LINTE^2 laboratory owned by Gdansk University of Technology in Poland. In this paper, we first provide an introductory information on the Power System Component Simulator and its capabilities. Then, the concept of the unit is presented. Requirements for the unit are described as well as proposed and introduced functions are listed. Implementation details are given. Hardware structure is presented and described. Information about used communication interface, data maintenance and storage solution, as well as used Simulink real-time features are presented. List and description of all measurements is provided. Potential of laboratory setup modifications is evaluated. Lastly, the results of experiments performed using Power System Component Simulator are presented. This includes simulation of under frequency load shedding, frequency and voltage dependent characteristics of groups of load units, time characteristics of group of different load units in a chosen area.

***Keywords*—**Power converter, Simulink real-time, MATLAB, load, tap controller.

I. Introduction

POWER system component simulator was designed and implemented by Institute of Power Engineering Gdansk Division in Poland. So far three such devices have been manufactured and have been used in laboratory experiments.

Power system component simulator is a device offering wide scope of operation characteristics and therefore provides capability to simulate different types of devices present in modern power systems. The power system component simulator can operate as the following devices:

- load with voltage-dependent voltage characteristics
- load with frequency-dependent characteristics
- electric motor (induction, synchronous)
- compensation reactor
- static var compensator
- statcom.

Power System Component Simulator is based on two IGBT converters with DC link and a thyristor-controlled tap changer as shown in Fig. 1.

This paper is divided into five sections: Section I provides introductory information on the Power System Component Simulator and its capabilities. In Section II, concept of the unit is presented. Requirements for the unit are described as well as proposed and introduced functions are listed. Implementation details are given in Section III. Also, hardware structure is presented and described. Information about used communication interface, data maintenance and storage solution, as well as used Simulink real-time features are presented. List and description of all measurements is provided. Potential of laboratory setup modifications is evaluated. In Section IV, results of experiments performed using Power System Component Simulator are presented. This includes simulation of under frequency load shedding, frequency and voltage dependent characteristics of groups of load units, time characteristics of group of different load units in a chosen area.

II. Concept

The purpose of introducing described power system component simulator in LINTE^2 isolated laboratory grid is to provide flexible device with wide area of operation. Power system component simulator is designed to be used for performing various tests of other compensation and generation devices installed in LINTE^2 laboratory.

Concept diagram of the power system component simulator is shown in Fig. 2 and described in [1].

Among others, it provides the following functions:

- emulation of underfrequency load shedding algorithms including these described in [2],
- experimental tests of underfrequency load shedding algorithms [3]
- emulation of time, frequency and voltage-dependent load types,
- operation in reactive power consumption/generation mode with unity power factor value seen from outside grid (increasing or decreasing lab busbar voltage),
- operation in active power consumption mode with reverse power injection into external stiff grid.

As a static device based on power frequency converter it is capable of reaching high current and power rising steepness values, depending on power converter protection settings. Moreover, it can operate in active power generation mode and simulate many types of generating units.

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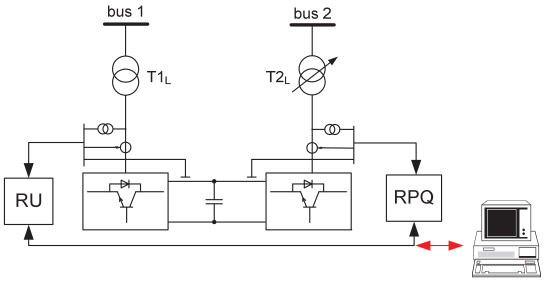


Fig. 1 Electrical diagram of power system component simulator

III. IMPLEMENTATION

In order to enable Rapid Control Prototyping, dedicated software environment (Simulink Real-Time, SRT) is employed in Functional Unit Controller [4]. Simulink Real-Time is used to create real-time applications directly from Simulink models. After compilation, the applications are loaded onto a target computer connected to physical devices by I/O cards. Since the whole process is automatic this approach allows changing high-level control algorithms in a flexible manner.

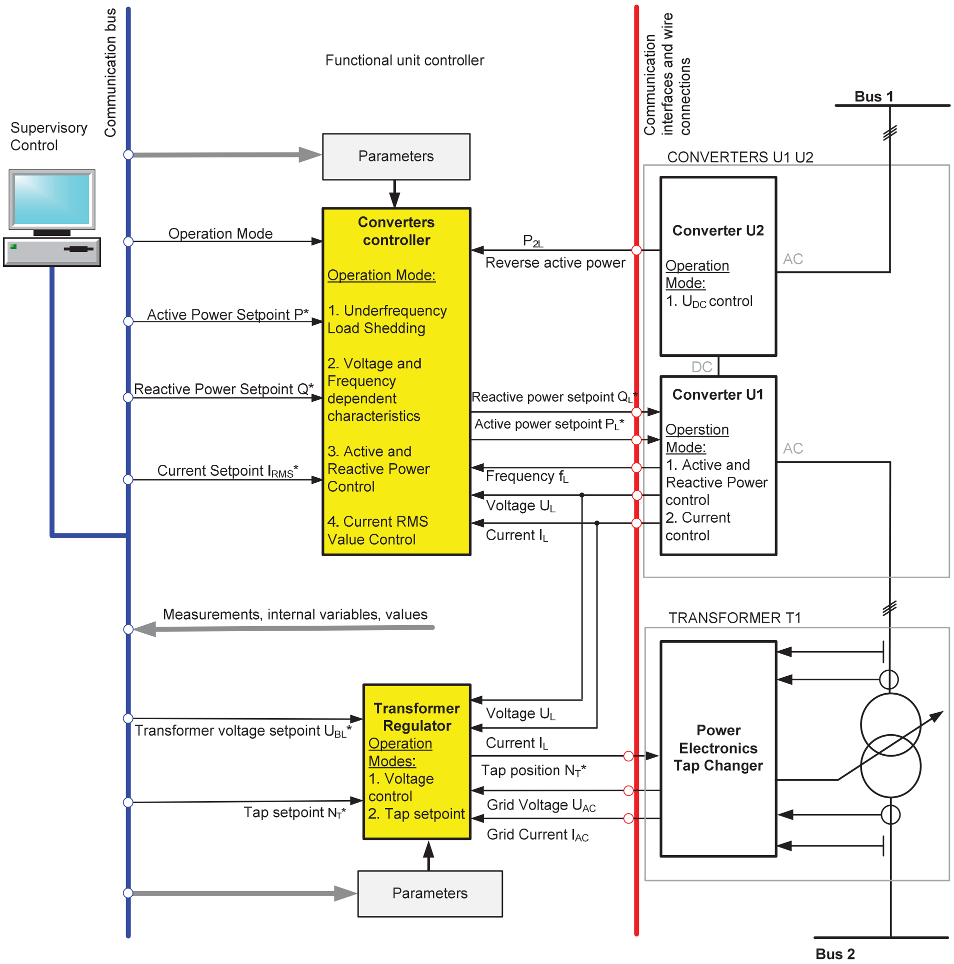


Fig. 2 Concept diagram of the power system component simulator including its control functions assignment

What is more, the controller model used for generating the real-time application can also be used in solely simulation environment, which if supplied with a proper model of simulated device power circuits and low-lever controllers, can form a Software- or Harware-in-the-Loop environment, enabling to test the controller parameters before actually using them in the laboratory.

The control over the real-time application is carried out by SCADA, which utilizes dedicated communication API for this purpose.

One of the assumptions in designing the model was ensuring open loop supervisory control. This approach allows changing control algorithm in functional unit controller, where all control variables are calculated. Control functions assignment is shown in Fig. 2.

Simulink Real-Time was used to create real-time applications directly from Simulink models. In the next step applications were loaded on a target computer connected to physical devices what provided opportunity to perform Hardware in the Loop (HIL) tests, as well as mentioned Rapid Control Prototyping process.

With Simulink Real-Time, Simulink models were extended with I/O cards driver blocks, what made possible automatic generation of real-time applications and performing interactive or automated runs on a dedicated target computer equipped with a real-time kernel, multicore CPU and I/O cards.

A. Main Technical Parameters

Laboratory load model described in this paper consists of: 150 kVA power frequency converter based on IGBT switches, 150 kVA 400/400 V/V transformer equipped with thyristor-controlled tap changer and functional unit controller based on PC with I/O cards and Simulink Real-Time platform. Electrical parameters of devices are listed in Tab. 1.

Functional unit controller includes two RT-DAC4/PCI multifunctional analog/digital I/O boards. The boards use PCI bus and are dedicated to real-time control and data acquisition. Each board supports 16 analog input channels (±10 V), 4 analog output channels (±10 V) and 32 digital input/output channels. Load model internal parameters and variables setpoints can be changed and adjusted using Syndis-RV SCADA system or through Control Panel interface included in Simulink Real-Time package. Block diagram of RT-DAC4/PCI board is shown in Fig. 3.

TABLE I
ELECTRICAL PARAMETERS OF POWER SYSTEM COMPONENT SIMULATOR

Element	Name	Value
Power converter	Nominal power	±150 kVA
	Rated voltage	3×400 V
	Efficiency	80%
Transformer	Nominal power	100 kVA
	Operation mode	S1 15min
	Rated voltage	400 V/ 400 V
	Tap changer range	±12 °/±15%
Functional unit controller	Supply voltage	230 V
	No of Analog input channels	32 (±10 V)
	No of Analog output channels	8 (±10 V)
	No of binary I/O channels	64

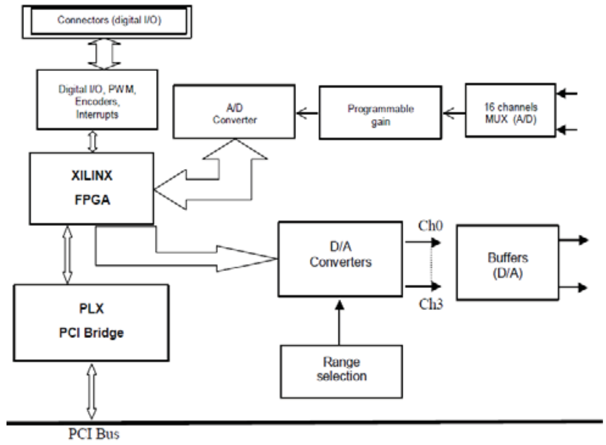


Fig. 3 Block diagram of the RT-DAC4/PCI board

B. Physical Realization

Power system component simulator consists of three cabinets. One cabinet contains power transformer, one cabinet contains power converter and one cabinet contains functional unit controller. Fig. 4 presents physical realization of the cabinets.

Laboratory power system component simulator transformer is designed in Y-Y connection with 25 taps in each phase of the secondary side what allows of voltage regulation in range 340–460 V with 5 V step [5]. As switches, anti-parallelly connected thyristors were used, with individual gate driver of each thyristor. Transformer is equipped with driver executing the following functions:

- conversion of received voltage and current measurement signals
- synchronization with output current signal
- communication with functional unit controller
- communication with gate drivers
- optical fibre communication control

Fig. 4 LOAD laboratory unit cabinets

The driver is also responsible for execution of the protections: internal short-circuit protection, overcurrent protection, electronics protections.

Concept diagram of on-load thyristor controlled tap changer is shown in Fig. 5.

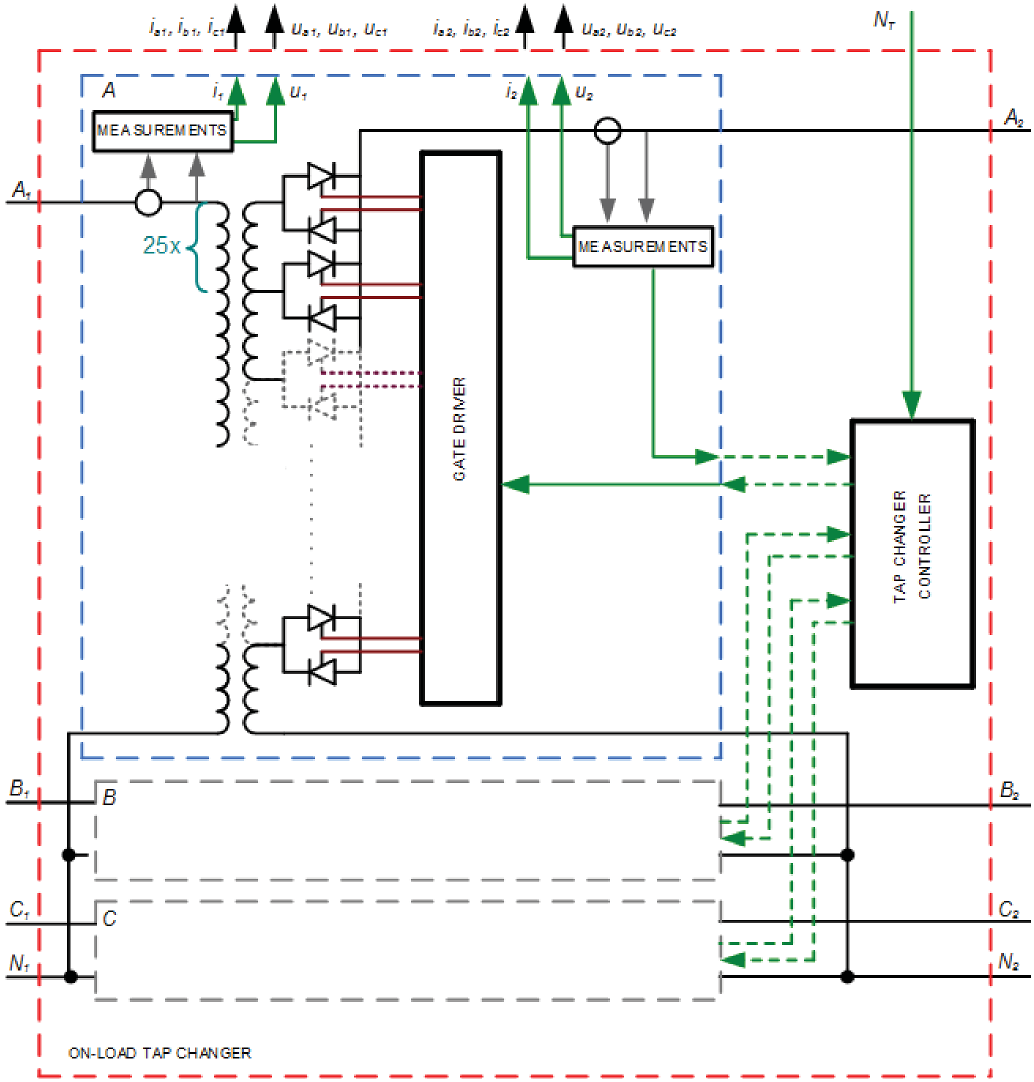


Fig. 5 Concept diagram of on-load tap changer

Control algorithm parameters:

- Algorithm full calculation cycle time 10 µs
- Data transmission time <10 µs
- Full algorithm time <20 µs
- Thyristor firing error <2π·10-3 rad
- Tap-Changer Switching time between maximum and minimum tap 20 ms
- Normal operation maximum voltage THD: 10%
- Normal operation maximum current THD: 10%

Transformer tap changer controller algorithm was equipped with two control modes:

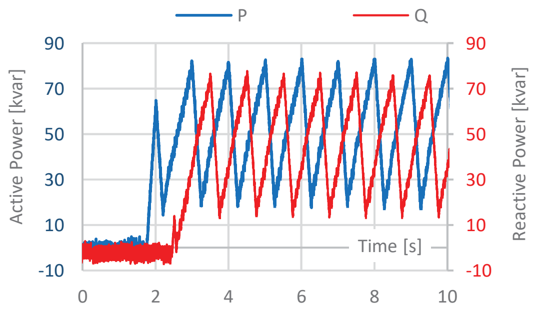
- voltage control mode maintaining voltage value according with set reference value and chosen transformer side
- reactive power control mode maintaining reactive power value according with set reference value and chosen transformer side.

Additionally, transformer tap changer controller algorithm was equipped with option of electromechanical tap changer emulation. Therefore, algorithm contains additional time constant, which is used to delay of each tap switching.

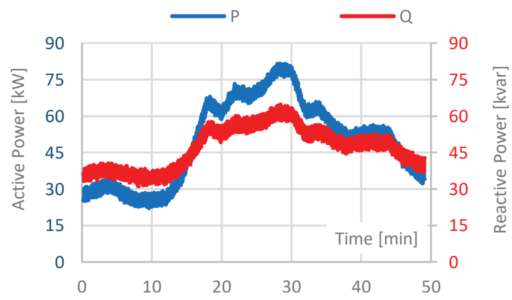
IV. Experimental Results

A. Simulated Device Power Variation

Designed power system component simulator offers wide spectra of defining and obtaining power time dependent characteristics. Examples of obtained various load power characteristics are shown in Fig. 6.



(a)



(a)

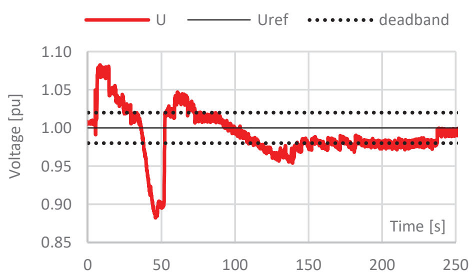
Fig. 6 Obtained power time characteristics (a) Active and reactive power with independently defined time characteristics (b) An example of the daily load variation modeling

Basing on this example and model features the following advantages may be listed:

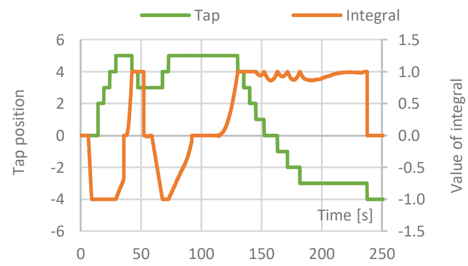
- Independent active and reactive power characteristics Fig. 6 (a)
- Unlimited duration of experiments (minutes, hours) Fig. 6 (b)
- Unlimited capabilities in shaping active and reactive power time characteristics.

B. Transformer Voltage Controller Test

Functional unit controller contains transformer voltage control algorithm. As the transformer is equipped with thyristor-controlled tap changer -additional inertia was introduced to emulate electromechanical tap changer characteristics. For purposes of this test step change of load reactive power was performed, what resulted in step change of transformer voltage. The results of transformer voltage controller operation are shown in Fig. 7.



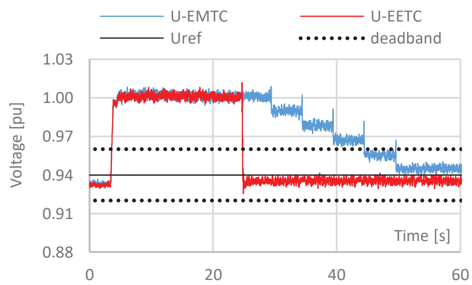
(a)



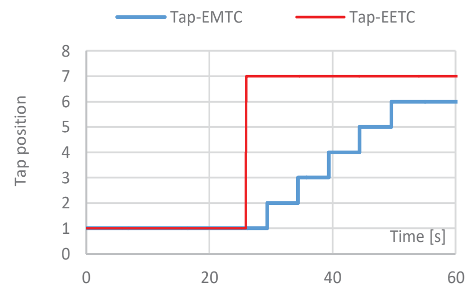
(b)

Fig. 7 Transformer controller operation in electro-mechanical tap changer emulation mode: (a) Voltage variation, (b) Tap position and value of integral

In Fig. 8 experimental results are presented to give an example showing the speed of power electronics tap changer (EETC).



(a)



(b)

Fig. 8 Comparison of tap changer types speed of operation EMTC – modelled as electro-mechanical tap changer, EETC– modelled as power electronics tap changer: a) Voltage variation, b) Tap position

As it can be noticed in Fig. 8, application of power electronics tap changer results in obtaining new range of tap changer operation times what results in new voltage control capabilities and therefore introduces a research field in the area of voltage control.

V. Conclusion

Presented power system component simulator is a flexible device providing technical capability to emulate wide spectra of devices present in modern power systems.

Application of power converter as controlled active and reactive power load device allows obtaining high variation, value and character change in active and reactive power time characteristics. What is more, transformer equipped with power electronics tap changer introduces wide spectra of possible tests with novel and innovative voltage and reactive power control algorithms.

In order to enable Rapid Control Prototyping, dedicated software environment (Simulink Real-Time, SRT) is employed in Functional Unit Controller. Simulink Real-Time is used to create real-time applications directly from Simulink models.

With Simulink Real-Time, Simulink models are extended with I/O cards driver blocks, what makes possible automatic generation of real-time applications and performing interactive or automated runs on a dedicated target computer equipped with a real-time kernel, multicore CPU and I/O cards.

Designing the models in open loop supervisory control allows changing control algorithm in functional unit controller, where all control variables are calculated. Therefore, the experiments with power system component simulator are not compromised by any preset boundaries and are an effective way of designing and testing new control strategies for different types of power system components.

References

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