Synthesis of a hybrid model of the VSC FACTS devices and HVDC technologies

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Abstract. The motivation of the presented research is based on the need for development of new methods and tools for adequate simulation of FACTS devices and HVDC systems as part of real electric power systems (EPS). The Research object: An alternative hybrid approach for synthesizing VSC-FACTS and -HVDC hybrid model is proposed. The results: the VSC-FACTS and -HVDC hybrid model is designed in accordance with the presented concepts of hybrid simulation. The developed model allows us to carry out adequate simulation in real time of all the processes in HVDC, FACTS devices and EPS as a whole without any decomposition and limitation on their duration, and also use the developed tool for effective solution of a design, operational and research tasks of EPS containing such devices.

1. Introduction

Progress of power electronic allows to more efficient use of High-voltage direct current (HVDC) and Flexible Alternative Current Transmission Systems (FACTS) technologies in electric power systems (EPS). Voltage Source Converter (VSC) based on high-speed fully controlled power semiconductor switches is the main element of the most devices implementing these technologies [1, 2].

However, the introduction of technologies based on VSC opens up new possibilities for improving a controllability of EPS, as well as significantly complicates the design, operational and research tasks [3, 4]. Primarily this circumstance is connected with the specific operation of these devices: phase-phase operation of VSC; continuous high-speed operation of all possible normal, emergency and post-emergency operating conditions of EPS.

The mentioned specificity of HVDC and FACTS technologies excludes currently used in modern digital simulation tools of real EPS a processes decomposition and application of substantial simplifications of mathematical models of power equipment and EPS in general [3, 5, 6].

Thus, the mathematical model of EPS excluding these simplifications inevitably contains a rigid, non-linear system of differential equations of high order. According to the theory of discretization methods for differential equations the required model is ill-conditioned on the restrictive conditions of application of numerical integration and can't be adequately solved [7].

Consequently adequate modeling of three phase real EPS containing HVDC and FACTS devices using a purely numerical simulation becomes impossible [3, 5, 6].

Complex modeling approach, representing the hybrid simulation is an alternative for solving this problem.

2. The concept of the hybrid simulation tools and power systems

The basic provisions of the concepts:

- power equipment of EPS is described by mathematical models implemented via a hybrid coprocessors (HCP).
- methodically accurate with guaranteed instrumental error solution of differential equation systems carried out by means of the continuous implicit integration method.
- all types of commutation of power equipment and ensuring unlimited expandability of simulated EES carried out on a physical level model.
- the interconnection between the physical and mathematical modeling levels, control parameters of the simulated equipment and different switching elements are provided by means of appropriate voltage-current converters.
- model of automatic control and relay protection systems are implemented via a microprocessor units (MPU), containing a central processing unit (CPU) and functionally oriented peripheral processors (PP), as well as Server depending on the required composition of the input signals and the speed of algorithms execution.

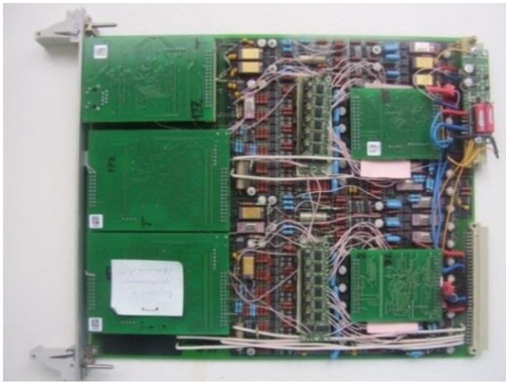


Figure 1. Appearance of the experimental SHP

The structural diagram of the hybrid software and hardware simulation of EPS corresponding to above mentioned conception is shown in Figure 2:

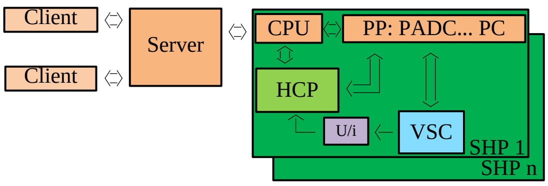


Figure 2. The structural diagram of the hybrid software and hardware simulation of EPS: SHP - specialized hybrid processor, CPU - central processing unit; PADC – processor of analog-to-digital converter; HCP – hybrid coprocessor; PC - switching processor; U / i - voltage-current converter; VSC - physical model of the power semiconductors VSC topology.

Developed according the described approach the concept and tools of the hybrid real time simulation of EPS allow to carry out:

- adequate simulation of all processes in VSC and three-phase power system as a whole without any decomposition and limitation on their duration;
- continuous methodically accurate solution in real time and on an unlimited range with guaranteed accuracy stiff nonlinear systems of differential equations of high order, adequately and accurately described a full spectrum of various processes in the power equipment and

power system as a whole, taking into account the automatic control and relay protection systems, preventive and emergency control of power systems;
- interconnection with various external software and hardware tools: operational information systems, SCADA system, etc.

The presented concept of model development of the traditional power equipment was tested and analyzed [8]. Only fragments of the development and research results of VSC model are presented within the format of this work.

3. VSC Simulation

The models of power switches according to the described concept are implemented on a physical level via the integrated microelectronic digital controlled analog switches (DCAS). To provide similarity of the model to a real device, the switching algorithms accounting input and output current and voltage values, as well as gate control signal should be implemented at the digital level. Thus, depending on the selected control algorithm, the DCAS can simulate any type of power electronic switches, including anti-parallel pair of different switches. The above mentioned algorithms implemented in MPU of SHP (Fig. 3).

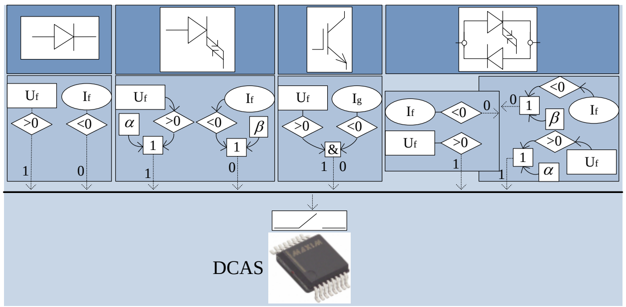


Figure 3. The control algorithms implementation scheme of power switches via DCAS.

According to the obtained DCAS characteristics (Fig.4) the switching time (t) is about $300ns$, while a switching time of IGBT is more then $2\mu s$ (Fig.5), as a result the DCAS can be considered an Ideal Switch.

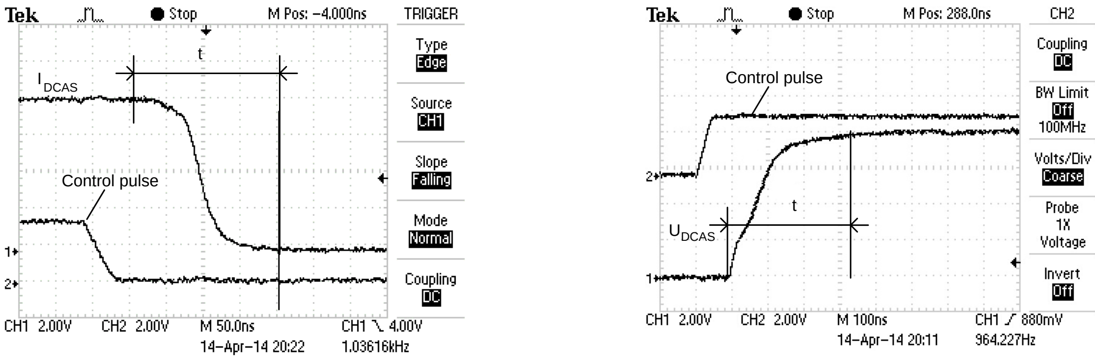


Figure 4. The current (a) and the voltage (b) waveforms of the DACS commutation

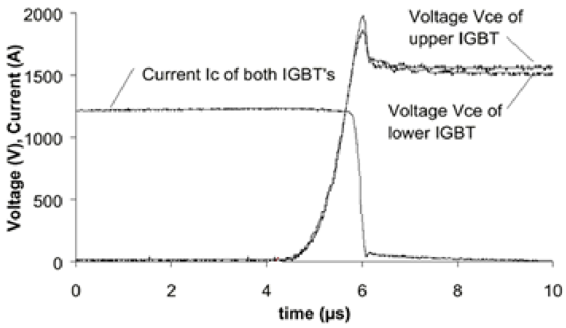
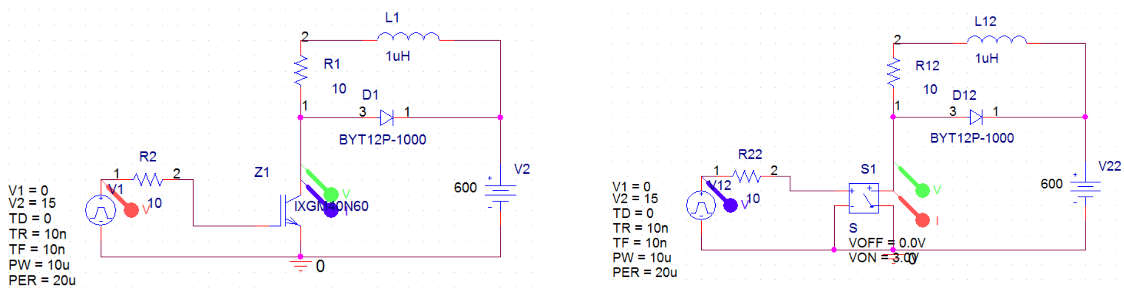


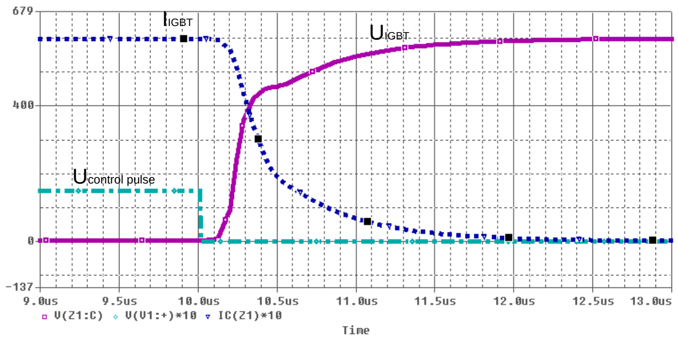
Figure 5. The current and voltage waveforms of real IGBT [9].

According to the shown in Fig. 6 schemes the IGBT (series 5SMY) and Ideal Switch commutation process is reproduced on the OrCAD software.

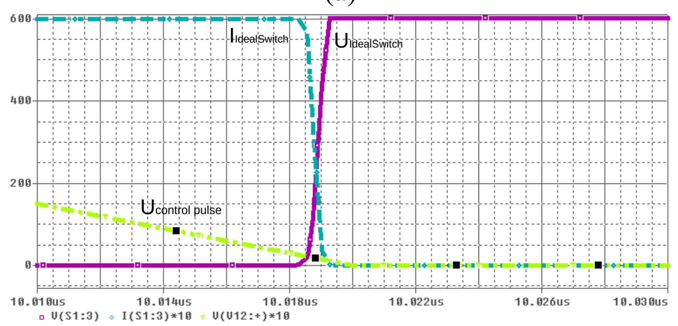


(a) (b)

Figure 6. Scheme of computer simulation of the IGBT (a) и Ideal Switch (b) commutating process

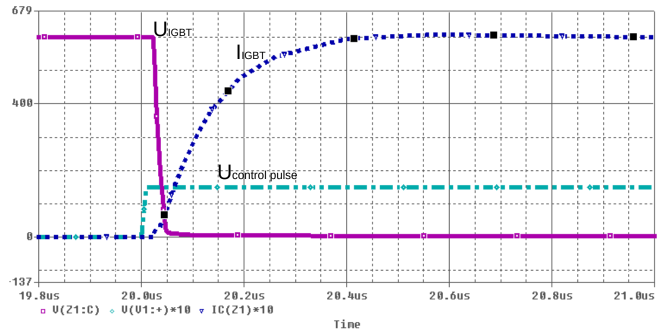


(a)

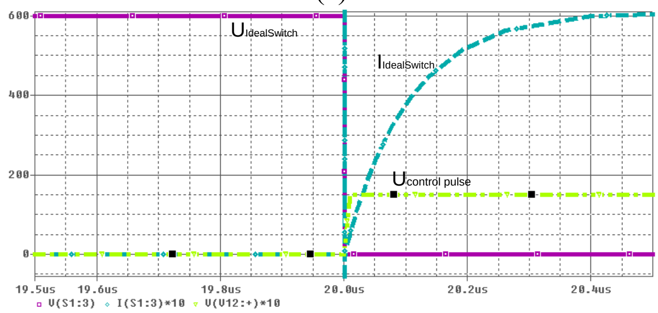


(b)

Figure 7. The current and the voltage waveforms of the IGBT (a) и Ideal Switch (b) turning on process



(a)



(b)

Figure 8. The current and the voltage waveforms of the IGBT (a) и Ideal Switch (b) turning off process

Application of this idealized VSC commutation is acceptable in the framework of solution the problem of modeling the real EPS. However, to research a process in the VSC, such as a control system and snubber circuits design and etc, the adequate commutation reproduction of real power semiconductors. For this purpose DCAS parameters should be adapted based on the analysis parameters and equivalent circuits of power semiconductors, taking into account a corresponding scaling. However, this task requires additional research.

4. Conclusion

- The presented concept and experimental implementation results confirm the required level of modeling adequacy of the power semiconductors and VSC based on them.
- An additional adaptation of the DCAS parameters will allow for adequate simulation of real power semiconductor switches and voltage converters based on them, as well as a full spectrum of quasi-steady-state and transient processes in power equipment and EPS as a whole with all possible normal, emergency and post-emergency processes in EPS as a whole containing devices based on VSC.
- The developed model allow to carry out the adequate simulation in real time of all the processes in HVDC, FACTS devices and EPS as a whole without any decomposition and limitation on their duration, and also use the develop tool for effective solution of the design, operational and research tasks of EPS containing such devices.

Acknowledgements

This work was supported by State Task «Science» 2.1318.2014 «Research and development of hybrid simulation complex of electric power system with active-adaptive network».

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