A HYBRID SIMULATION MODEL FOR VSC HVDC

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ABSTRACT: The large scale introduction of high voltage direct current (HVDC) systems requires solving a number of complex tasks aimed at ensuring the reliability and stability of new combined HVDC/AC systems. In this paper, we are increasing the level for improving the efficiency and reduction the losses. The development of their control protection and analysis of the mutual influence of HVDC and HVAC components is proposed. To create an adequate model of HVDC it is necessary to provide completeness and accuracy of the process description in the steady-state and transient operating conditions. This paper presents the specialized concept of a hybrid simulation for advanced modeling of VSC HVDC. To confirm the adequacy of the simulation process, the analysis of developed 2-level VSC HVDC model characteristics in the static modes on a model of two-machine has been provided. The multilevel inverter has many advantages, such as high power quality, lower order harmonics, lower switching losses, and better electromagnetic interference. If we increasing inverter with 5 level then we get a pure sinusoidal waveform and also reduce the losses. This paper presents the hybrid simulation technology and approach allowing synthesizing hybrid models of power equipment, including the elements of HVDC systems, which aim is to maximally meet modern requirements for modeling and simulation tools.

INTRODUCTION

Nowadays, multilevel inverters have received more attention for their ability on high-power and medium voltage operation and because of other advantages such as high power quality, lower order harmonics, lower switching losses, and better electromagnetic interference [1], [2]. These inverters generate a stepped voltage waveform by using a number of dc voltage sources as the input and an appropriate arrangement of the power-semiconductor-based devices. In recent year we can see the increasing in complexity of power systems which addresses to new challenges for ensuring their reliability and sustainability[1]. Along with that to achieve progress in power electronics which promises the new prospects of using HVDC systems ,we had already improve and achieved their effectiveness in solution of conventional tasks such as asynchronous interconnection and long distance transmission, as well as of the relatively new challenges related to the integration of the distributed renewable energy sources into AC grids.

Power electronic converter are based upon the power semiconductors which is the main element of this technology. HVDC is depend upon two types of converters. They are line commutated converter (LCC) and voltage-source converter (VSC), which are widely used in EPS[2]. VSC depends upon fully controlled high-speed power switches (IGBT, GTO) which may have different types of advantages when compare with the LCC such as:

- Control of active and reactive power;
- Provision of reverse of power flow without changing the polarity of the voltage.

But emergence and large-scale installation of new HVDC equipment and schemes such as voltage source converter (VSC) based systems and multi-terminal links both open new opportunities to improve controllability of power systems and increase the number of operational and research tasks

The most complex and urgent of those tasks include :

- Analysis of the mutual influence of HVDC and HVAC systems, including their control and protection upon each other and the power system on the whole, especially in transient conditions;
- Development, testing and adjustment of the local and generalized control and protection systems.

A solution of these tasks requires full-scale experiments in a real power system, which cannot be conducted. Therefore, the simulation remains the main tool for analyzing HVDC systems in the structure of large power systems .

But the high requirements to power system simulators are dictated by the complexity of the tasks contributing to a comprehensive study of the processes occurring in power systems, as well as by convertors characteristics.

Currently, digital simulators are widely used for power system analysis. The limitations of the digital simulators are well known and are mainly determined by the utilized numerical integration methods, which impose some significant simplifications and assumptions on power equipment models. This leads decomposition of power system tasks, application of various numerical methods and lack of the model's details.

A hybrid simulation technology can serve as an alternative for purely digital simulation. This technology is based on the synthesis of simulation tools and models of power system elements according to the requirements of the research tasks[3]. However, the use of the mentioned hybrid simulation technology complicates the development of the models and applies some additional requirements to them. This paper proposes an approach and demonstrates results of the development of a hybrid model of HVDC system that completely meet the requirements to the advanced power system simulation.

OPERATION OF VSC

To create an adequate model of HVDC it is necessary to provide completeness and accuracy of the process description in the steady-state and transient operating conditions, determined by modeling implementation errors at all the mentioned digital, analog, and physical levels of simulation. Digital simulation is carried out only for the control system of HVDC.

Modeling errors at the physical model level lead to a deviation of loss level, distortion of voltage and current waveforms on both the DC and AC side in the significant frequency spectrum of the EPS. Based on this, the simulation of process at the physical model level is critical to the modeling results, especially for the pulse mode of VSC. Errors at this level can be caused by incorrect characteristics of power semiconductors or parameters of the DC circuit. The latter problem is successfully solved by the selection of components[4]. The characteristics of the physical models of power semiconductors require additional analysis and will be addressed in future works.

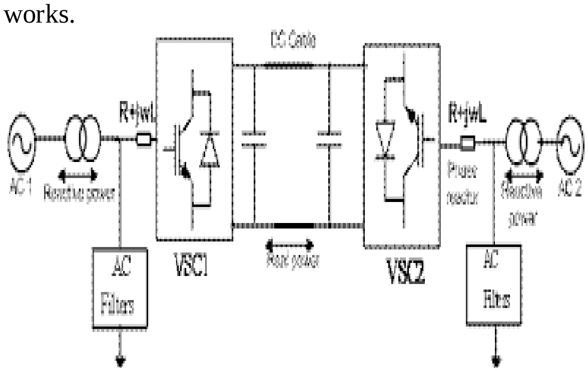

Fig : 1 block diagram of VSC HVDC model

SIMULATION CHALLENGES

To improve the problem of the reliability and adequacy of the simulation processes in a real VSC HVDC the modeling system should take into account the specifics of the operation of these devices, in particular:

• Phase-Phase operation of VSC;
• Use of high-speed fully controlled power semiconductors;
• Continuous high-speed operation in all possible normal, emergency and post-emergency operating conditions of EPS.

Furthermore, to solve the above mentioned problems, the simulation systems should meet the following requirements.

• Models of EPS elements must be three-phase (or more) to account properly for all the unbalanced conditions;
• Simulator must be capable (scalable) to implement an EPS model of any size;
• Simulation of EPS must exclude the decomposition of processes and limitations on their duration (without separation of electromagnetic and electromechanical transient processes modeling in power equipment and EPS as a whole);
• Real-Time Simulation and the possibility of interconnection with external devices and systems.

Recently digital modeling complexes are highly used for the analysis of the EPS. This complexes have been shown to be successful in the electromagnetic transients and closed loop testing of ACS in the simulation[5] , but in digital simulation tools the numerical integration methods do not enable to perform real time simulations of EPS without processes of decomposition over an unlimited period of time because of the integration time step issue.

Along with that the digital simulation of large EPS is affected by problems associated along with the limitations on the size of a model solved by a single processor. Then the model partitioning and application of the travelling wave transmission line models to connect the parts of a power system model distributed between several processors is required[6]. A trick of the application of the travelling wave model is that a traveling time of a transmission line has to be greater or equal to an integration time step which is not always accessible and thus may require forced correction of inductance and capacitance values of a transmission line model.

The distribution of EPS model limits the number of processors, that can be connected to one node, and leads to forced simplifications and equivalent representations of power equipment and EPS models. These limitations of digital modeling complexes are shown in simulation of short transmission line (in back-to-back HVDC system), or simulation of Multiterminal HVDC projects with a short DC (direct current) link .

Along with that issue of simulating in real time large EPS without any division of electromagnetic and electromechanical transient processes have been not improved . from this statement is confirmed by observed trends in research and development of hybrid simulation tools, based on application of various numerical simulation methods

Moreover, after the detailed analysis of some of mentioned and hybrid complexes obviously that required detailed and comprehensive modeling of EPS is not fully achieved[7]. Thus, to analyze the processes caused by faults in HVDC convertors authors used simulation time step around 50 µs, whereas the switching time of Gate turnoff thyristor is about 30 μs, for IGBT 5 μs. Besides the data exchange between the used complexes is carried out with bigger simulation time step than the simulation time step of electromagnetic transients modeling.

To improve the mentioned problem of the real time simulation of HVDC systems and EPS as a whole, the hybrid simulation technology depend upon the application of digital , analog and physical modeling approaches and realized in Hybrid Real-time Simulator of EPS (HRTSim), developed in Tomsk Polytechnic University, which is proposed.

The results of the development and research of the VSC model, realized in HRTSim, are shown in this article.

Concepts of Hybrid Simulation of EPS

Here, the concept of hybrid simulation is depend upon the use of three modeling approaches: physical , analog and digital, each of which achieves maximum efficiency in solving individual subtasks. A detailed description of the concepts and tools is presented

The basic points of the concepts are:

• Power Equipment of EPS is described via complete systems of differential equations adequately representing the whole significant range of quasi-steady and transient processes in this equipment and forming comprehensive mathematical models of corresponding types of the simulated equipment;

• Methodologically accurate with guaranteed instrumental error solution of differential equation systems in real time and over an unlimited period of time are carried out by means of the continuous implicit integration method;

• Types Of Commutation of power equipment, including the power semiconductors, are carried out on a model physical level;

• Interconnection between a physical model and mathematical simulation levels is provided by means of appropriate voltage-current converters;

• Mutual conversion of mathematical and model physical variables in conjunction with simulation on the physical model level of the commutation of power equipment provides the ability of unlimited scalability of the simulated EPS;

• Informational and control functions, as well as modeling control and protection systems are implemented on a digital level using a digital-to-analog, analog-to-digital conversion and specialized local and server software.

Specialized hybrid processor (SHP) is the basic element of the modular structure of the HRTSim and provides an adequate comprehensive simulation in the real-time of power equipment models, as well as control and protection systems.

According to this concept, the solution of comprehensive mathematical models of the simulated equipment is carried out via the hybrid coprocessors (HCP). The result of solution is transmitted to the MPU (microprocessor unit) via the PADC (processors of analog-to-digital converter). The whole range of data transformations required to oversee the process of simulation, as well as real-time control of parameters of the modeled power equipment, depending on the desired solution speed of a control algorithm, are implemented in the MPU.

The universality of the concept and modular structure of the HTRSim allow the development of a model of any element of EPS, including devices and HVDC, and to integrate them into the HTRSim, as well as to provide interconnection with various external software and hardware tools: operational information systems, SCADA system etc.

Simulation of Commutation Process

As mentioned above, the physical model level is particularly important, because at this level an operation of power switches is modeled via integrated microelectronic digitally controlled analog switches (DCAS).

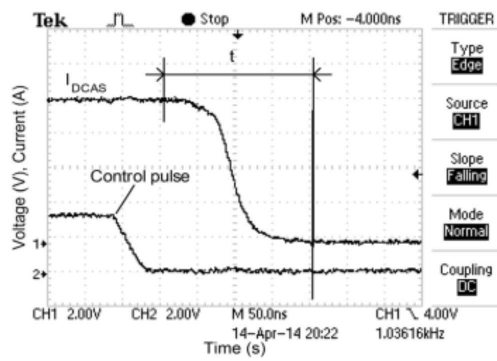

Fig. 2. The current waveform of the DCAS commutation

Furthermore, to ensure the similarity of the model to real power switches and to simulate any type of power semiconductors, the corresponding commutation algorithms have been developed and implemented in MPU of SHP. According to the obtained DCAS characteristics (Fig. 2-3) the switching time (t) is about 300 ns, while a switching time of IGBT is more than 3 μs (Fig. 4). As a result, the DCAS can be considered an Ideal Switch.

Consequently, the equivalent circuit of DCAS can be adapted to simulate real power switches. Analysis of equivalent circuits of DCAS and real IGBT (type 5SNR), a comparison of their parameters, taking into account modal and technical scaling coefficients were carried out to verify the adequacy of this simulation.

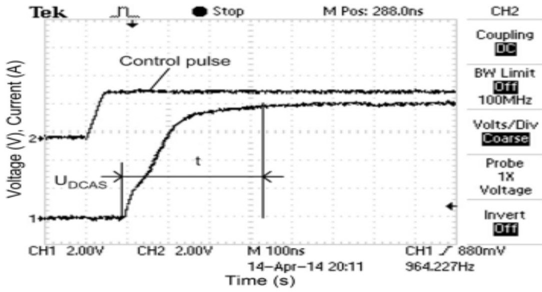

Fig. 3. The voltage waveform of the DCAS commutation.

It should be noted that the character of the transition process can be adapted by appropriate selection of parameters and variation of the equivalent circuit depending on the type of simulated power semiconductors. Moreover, transition process of voltage is of more particular importance, because the voltage signal is used for calculation processes in the rest of control system of VSC.

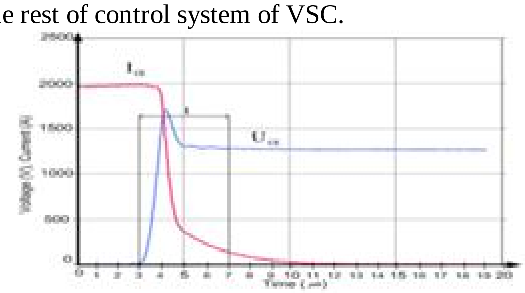

Fig. 4. The current and voltage waveforms of real IGBT (type 5SNR).

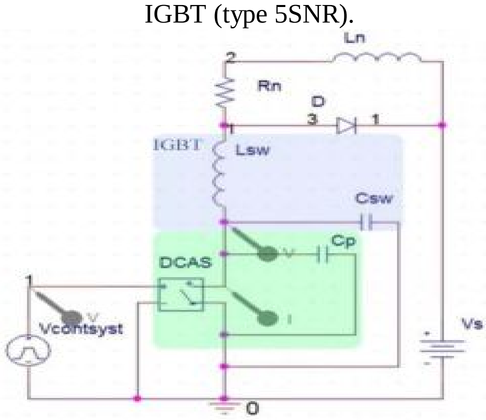

Fig. 5. The scheme of IGBT commutation process without the snubber circuit: Csw, Lsw - equivalent capacity and inductance of IGBT, Cp - coupling capacitance of DCAS, Rn, Ln- equivalent load, D – bypass diode.

A fragment of the results of this research and modeling in the software environment OrCAD is presented in the format of this work.

The scheme of IGBT commutation process (type 5SNR) without the snubber circuit is shown in Figure 5. This scheme combines the equivalent circuit of DCAS and IGBT, which in aggregate allow us to form the parameters of a circuit to simulate the commutation of real switch.

The value of the IGBT direct and reverse resistance is set in the DCAS.

The current and voltage oscillograms of the IGBT in different operation modes without the snubber circuit are shown in Fig. 6-7.

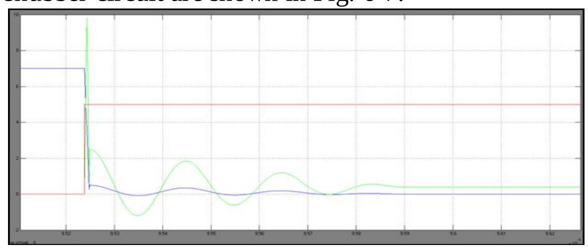

Fig. 6. Turning on process without the snubber circuit.

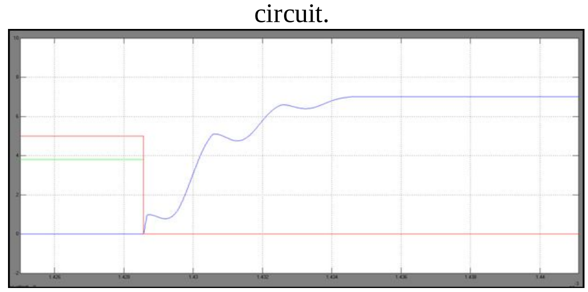

Fig. 7. Turning off process without the snubber circuit.

The scheme of IGBT commutation process (type 5SNR) with the snubber circuit presented is shown in Figure 8.

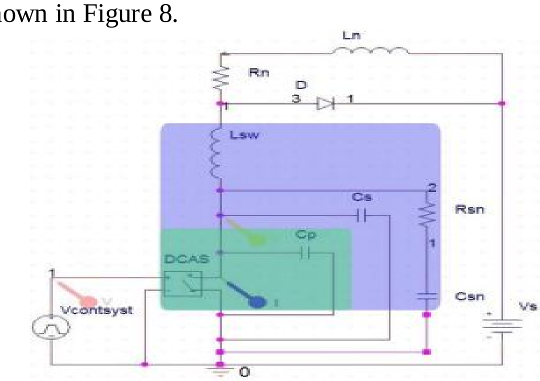

Fig. 8. The scheme of IGBT commutation process with the snubber circuit. Csn, Rsn – snubber circuit

The current and voltage oscillograms of the IGBT in different operation modes with the snubber circuit are shown in Fig. 9-10.

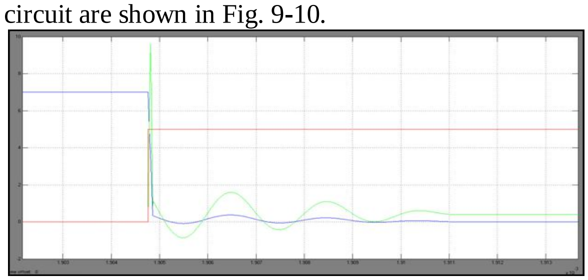

Fig. 9. Turning on process with the snubber circuit.

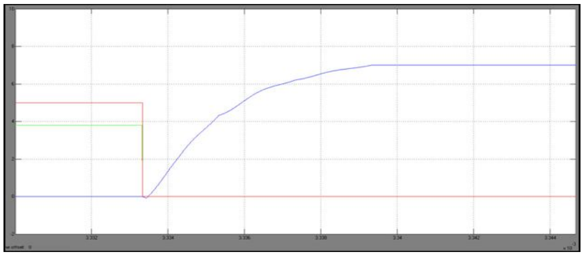

Fig. 10. Turning off process with the snubber circuit.

According to the presented commutation process the switching time (t) is about 6 µs, while the switching time of real.

The difference may be caused by errors in the recalculation of the parameters of the 5SNR IGBT or parameters of the DC circuit that are successfully solved by selection of elemental base and components. For example, precision resistors (with more accurate nominal value) or accurate operational amplifiers can be used to improve the accuracy of representation of commutation process. The characteristics of physical models of switches require additional analysis will be addressed in future works.

Simulation of VSC HVDC

In the simulation of VSC HVDC, including the frequency characteristics of HCP of the basic equipment of HVDC, and static modes at different levels of power consumption/generation and voltage of VSC HVDC were considered.

The scheme of simulation research of the SHP of VSC HVDC in EPS is shown in Figure 11.

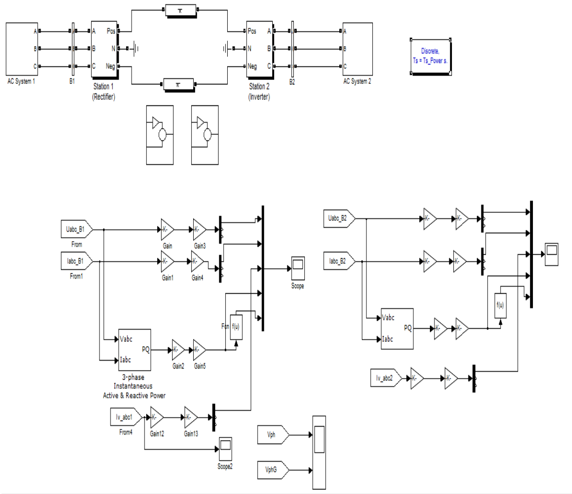

Fig. 11. The scheme of simulation research of the VSC HVDC model: Tr - transformer, F - filter, C – capacitor bank.

The parameters of the study system scheme are resented in Table I.

The obtained waveform of voltage (UA(t)), current (iA(t)), as well as the calculated values of apparent (S(t)), active (P(t)) and reactive (Q(t)) powers are shown in Figures 12-13.

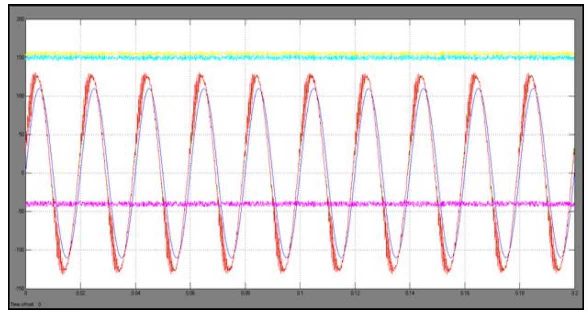

Fig. 12. The mode of consumption of P(t) and generation of Q(t).

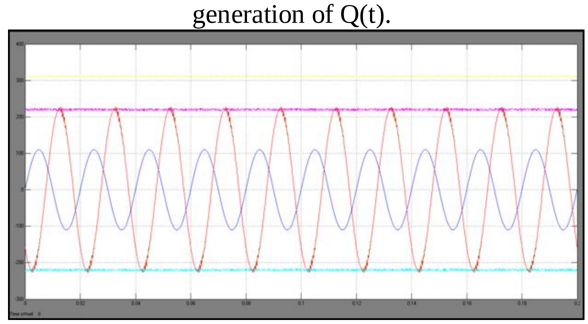

Fig. 13. The mode of generation of P(t) and consumption of Q(t).

Table I

Parameters Of The Study System Of Fig.11

Quantity	Value
Basic voltage, kV	110
Basic power, MVA	200
Basic frequency, Hz	50
Switching frequency, Hz	1050
AC nominal voltage, relative units (r.u.)	1
AC active resistance, (r.u.)	0,02
AC inductive resistance, (r.u.)	0,155
Transformer voltage rating	110/28,6/10
Resistance of high voltage winding of the transformer:	
active resistance, (r.u.)	0,0114
inductive resistance, (r.u.)	0,2625
Resistance of medium voltage winding of the transformer:	
active resistance, (r.u.)	0,01
inductive resistance, (r.u.)	0,6597
Resistance of low voltage winding of the transformer:	
active resistance, (r.u.)	0,007
inductive resistance, (r.u.)	0,0734
Magnetizing branch, (r.u.)	300
Value of capacity of Filter, (r.u.)	0,03091
Active resistance of Filter, (r.u.)	11,44

The oscillograms of the voltage U1(t) (see Fig. 11) on the AC side of the VSC obtained by a digital oscilloscope are shown in Figures 14-15.

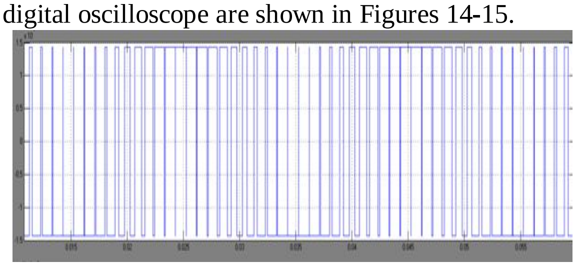

Fig. 14. The oscillogram of the phase voltage of VSC HVDC model.

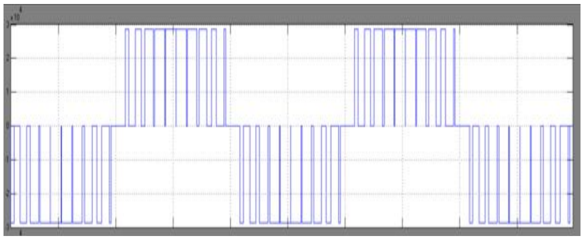

Fig. 15. The oscillogram of the phase-to-phase voltage of VSC HVDC model.

CONCLUSION

This paper presents the specialized concept of a hybrid simulation for advanced modeling of VSC HVDC. The multilevel inverter has some advantages such as high power quality, lower order harmonics, lower switching losses, and better electromagnetic interference. The concept of a hybrid simulation realization will show possibility and efficiency of the proposed approach to the development of the models of power semiconductors and VSC which is established on it, along with that it will Satisfy the entire set of requirements for advanced simulation set by the evolving power system operating tasks; Develop a versatile, flexible and real-time user configurable model of HVDC system. To confirm the adequacy of the simulation process, the analysis of developed 2-level VSC HVDC model characteristics in the static modes on a model of two-machine has been provided. In this paper, we are increasing the level for improving the efficiency and reduction the losses. The results which is used to allow carry out the detailed representation of commutation process of IGBT and adequate modeling of spectral analysis of VSC, at the same time it will comprehensive real-time simulation processes in HVDC and EPS as a whole without any limitation and decomposition on their duration By using the simulation results of specialized hybrid processor of VSC HVDC model confirm the effectiveness of the proposed method.

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