MODELLING OF POWER ELECTRONICS BY PSCAD: FREQUENCY SCANNING METHOD

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Abstract

Devices based on power electronics play an important role in modern power systems. They are already used in transmission and distribution networks for ensuring continuity of supply and for increasing quality of power supplied to the customers. Simulations are an essential part of design and operation analysis of power systems; as such systems are usually too large and complex for analytical solutions. The paper presents guidelines for modelling power electronics in power engineering applications and concentrates on the PSCAD program. PSCAD is a simulation tool for studying transient behaviour of electrical power networks. A basic description of the program is given in the paper and modelling of power electronics systems is also described.
As a simulation case the frequency scanning method is presented. The method is used to identify the frequency characteristic of a static compensator (STATCOM), which shows the frequency dependence of the device impedance. Simulation results are also compared with analytical calculations. When the device control algorithm is not taken into account the simulation results agree well with theoretical results and show that STATCOM is a frequency dependent device. Its frequency characteristic also depends on the device operating point. When the device control algorithm is included the results change and depend heavily on the used control scheme. The system also becomes quite complex which makes analytical formulation difficult. However, the simulation model can be efficiently used, which shows the usefulness of simulation programs.

Keywords: FACTS, STATCOM, Frequency scanning, Frequency characteristics.

Presenting Author's biography

Boštjan Blažič received the B.Sc., M.Sc. and Ph.D. degrees, all in electrical engineering from the University of Ljubljana, Ljubljana, Slovenia, in 2000, 2003 and 2005, respectively. Currently he is a researcher with the Faculty of Electrical Engineering, Ljubljana, Slovenia. His research interests include power quality, distributed generation, mathematical analysis and control of power converters.

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1 Introduction

Active compensation devices in electrical power networks, which are based on power electronics, have evolved as a result of the development of power systems, dictated by a fast increase of electrical energy consumption and in the last decade also by the electricity market deregulation. The increasing consumption demands new generation and transmission facilities while the growing public ecological awareness stands against these requests. Such conditions resulted in higher utilization of existing facilities, demanding an increase of the power transfer capability of transmission systems, sufficient stability of power systems at increased power flows and the ability to keep the power flow over the designated routes. Also the foreseen large scale integration of distributed energy resources (DER) into power networks brings new challenges for the development of distribution systems. They will have to be changed from an energy delivery system to an energy exchange system. Nevertheless, such networks will still have to ensure an adequate level of stability and power quality that are expected by customers.

In nowadays power systems power electronic devices already play an important role and are used for ensuring the continuity of supply and for increasing the quality of power supplied to the customers. This paper deals with the issue of modelling and analysis of power electronics devices in electrical power networks, focusing on the program package PSCAD. As an example of program use the frequency scanning method is presented and frequency characteristics of a static compensator (STATCOM) are calculated.

2 Digital simulation

Simulations are an essential part of design and operation analysis of power systems; as such systems are usually too large and complex for analytical solutions.

Modelling of power systems strongly depends on study objectives and can be divided into two basic categories [1] – [3]:

- steady state evaluations,
- dynamic (transient) behaviour evaluations.

The first category deals with power system analysis when it has settled at a steady-state operating point. These types of studies include the calculation of steady-state power flows, voltage levels, harmonic distortion and harmonics propagation, analysis of system harmonic resonance, etc. In such studies the power electronic subsystem can be greatly reduced.

The second category of power systems modelling covers an extensive range of practical problems and enables detailed power system analysis in transient and dynamic conditions. Such approach requires a detailed modelling of power electronic subsystems. It enables accurate design of power electronic apparatus and its controls.

2.1 PSCAD simulation tool

PSCAD is a simulation tool for studying transient behaviour of electrical networks, including a graphical interface for system construction and a comprehensive built-in library of electrical system components [4], [5]. It allows the representation of electromagnetic and electromechanical systems and also control circuits. The program is specially suited for modelling of power electronic devices, including FACTS (Flexible AC Transmission System), custom power and HVDC (High Voltage Direct Current) systems.

PSCAD is essentially an off-line simulation tool that formulates and solves the non-linear differential equations of the electrical network. Such tools are often referred to as EMTP-type (Electromagnetic Transient Program) tools. Differential equations are solved with integration, using the trapezoidal rule. The results are instantaneous values in time and all frequencies are included, bounded only by the selected time step.

PSCAD works with finite time step which must be chosen carefully to obtain accurate results and sufficiently short simulation at the same time. In case of power electronics devices which use switching elements, accurate switching is of crucial importance. Namely, switching delay introduced by a too long time step may produce inaccurate results. One solution would be to reduce the time step, which also increases the computation time. PSCAD uses an interpolation algorithm to find the exact time of the switching event. The interpolation algorithm is illustrated in Fig. 1 for the case of diode current. The diode is conducting the current i_d and should turn of when the current reaches zero. The first graph shows the turn off without the use of interpolation. The current

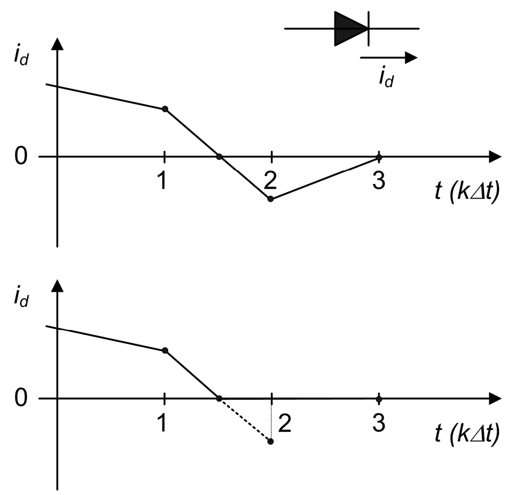

Fig. 1 Illustration of interpolation algorithm – diode current

reaches zero between $1\Delta t$ and $2\Delta t$ and becomes negative at $2\Delta t$. The diode subroutine detects the negative current and the switch off occurs only at $3\Delta t$. The second graph shows switching of the device with the use of the interpolation. In this case the program calculates when the diode current actually crossed zero. Then it interpolates all voltages and currents to this time (e.g. $1.5\Delta t$) and switches the diode off at that instant. The program then calculates the values for the next time step (at $2.5\Delta t$) and then interpolates the solution back to $2\Delta t$. The simulation continues with the integral time step. The interpolation approach is faster and more accurate then reducing the time step.

The PSCAD program uses also a chatter detection and removal algorithm. Chatter is a symmetrical oscillation phenomenon inherent to the trapezoidal integration method and usually occurs when closing a switch in a branch containing inductors. Chatter is detected when voltage or current change direction in five consecutive time steps. Chatter is removed with the use of half time step interpolation.

The PSCAD program allows also the use of ideal branches, i.e. branches with zero impedance. As the admittance of such branches is zero some extra computations are involved to solve the system equations.

3 Modelling power electronics

Some generic guidelines for modelling power electronics systems in power systems are given next. Representation of semiconductor switching devices in simulation programs is described. Modelling of power electronics devices, power systems and control algorithms is also outlined.

3.1 Semiconductor switching devices

Semiconductor switching devices are the main construction component of power electronics devices. The most commonly used are power diode, thyristor, gate turn-off thyristor (GTO) and insulated gate bipolar transistor (IGBT). The diode is an uncontrollable two-terminal device, while all others are three-terminal controllable devices.

In PSCAD all devices are represented as a two-state resistive switch with an optional RC snubber circuit connected in parallel. Controllable devices require an input gating pulse. A general switching device model is shown in Fig. 2.

The *U-I* characteristics of a diode is shown in Fig. 3. The diode has a large off and small on resistance (R_{off} and R_{on} respectively). Conduction starts when the forward biased voltage exceeds the forward voltage drop (U_{on}). The diode turns off at zero current and remains off at reverse biased voltage.

A thyristor *U-I* characteristics is shown in Fig. 4. If the forward biased voltage exceeds the forward voltage drop (U_{on}) the device is turned on by a firing

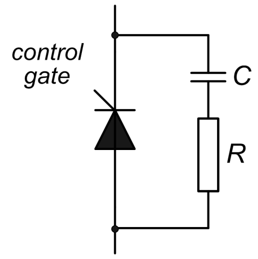

Fig. 2 General model of a switching device

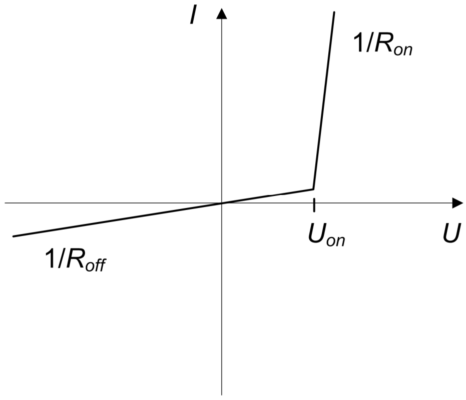

Fig. 3 Diode *U–I* characteristics

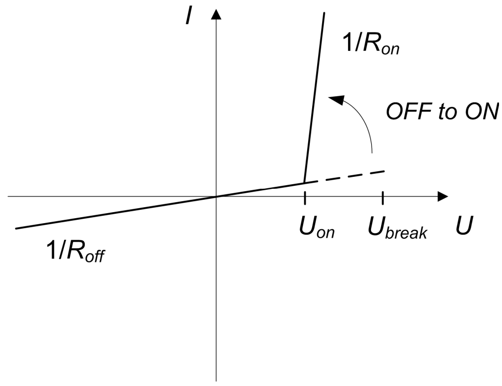

Fig. 4 Thyristor *U–I* characteristics

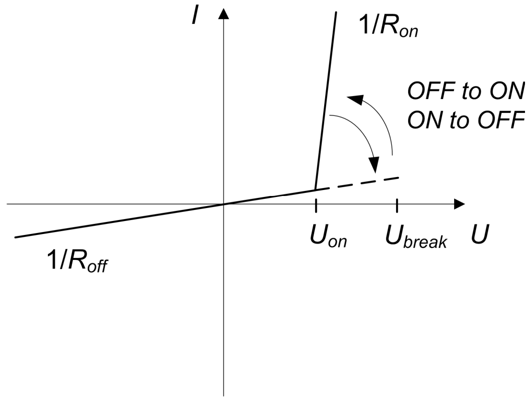

Fig. 5 GTO/IGBT *U–I* characteristics

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pulse supplied to the control gate. The device is turned off when the current reaches zero.

IGBT and GTO models are the same. Their *U-I* characteristics is shown in Fig. 5. The GTO and IGBT are turned on and off by firing pulses supplied to the control gate. Therefore, in comparison to thyristor, IGBT and GTO are devices which can be also turned off by a control signal.

3.2 Modelling power electronics devices

Power electronics devices can be composed of a large number of semiconductor switches. Usually it is not necessary to model all the switches but is possible to use equivalent models instead of parallel and series connected elements. In some cases a power electronic sub-system can be represented by an equivalent source injection. When interfacing to the utility is of concern, only the front end of a power electronics system can be represented. System dynamic and control should be included when necessary.

3.3 Modelling the power network

The power network is a large system so simplifications are required to avoid bulky and complicated models. The degree of simplification depends on the study objectives. For example, if the goal is to study the harmonic distortion of power electronics, the power network can be represented with a voltage source at the high-voltage bus connected over impedance. Network-voltage harmonic distortion and imbalance, if any, must also be properly represented. Larger network models are required if the aim of the study in to analyze the influence of power electronics devices on sensitive loads (e.g. motor drives), harmonic or flicker propagation, etc.

3.4 Representation of system controls

The system control is one of the most important components of the simulated system. It consists of the next main parts: monitoring and sampling of the system parameters, signal processing, calculation of reference values and generation of firing pulses. The highest resolution of signal sampling depends on the selected time step. If the time step is too large for the desired sampling errors and system instability may occur. Also the delay of system controls must be properly modelled. The delay in an actual system is caused e.g. by the computational time, by filtering of the measured signals due to harmonics or unbalance etc. Special attention has to be paid also to synchronisation to the network. When generating firing pulses for semiconductor control the maximum switching frequency of the used device must be taken into account. The maximum switching frequency depends on the maximum working temperature of each element.

4 Frequency characteristics of a STATCOM

The use of the PSCAD simulation tool will be demonstrated on the case of STATCOM frequency characteristic determination [6] – [8]. A frequency characteristic shows the frequency dependence of system impedance. With known frequency characteristics of a device it is possible to identify resonance frequencies which may cause operational problems. The characteristics will be first calculated analytically and then obtained by means of simulation with the use of the frequency scanning method.

4.1 STATCOM description

STATCOM is a device from the FACTS family. It is capable of generating reactive power internally and enables network voltage control, limited power flow regulation, stability enhancement etc.

The basic circuit of a STATCOM is presented in Fig. 6 and a three-phase voltage source converter (VSC) is shown in Fig. 7. The converter is shunt connected to the network through a coupling reactance. A VSC with a dc-capacitor on the dc-bus is the main building block of a STATCOM. The VSC basically generates ac voltage from dc voltage, where the magnitude, the phase angle and the frequency of the output voltage can be controlled. The converter consists of connected

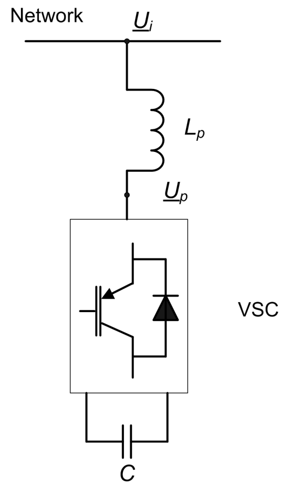

Fig. 6 Basic circuit of a STATCOM

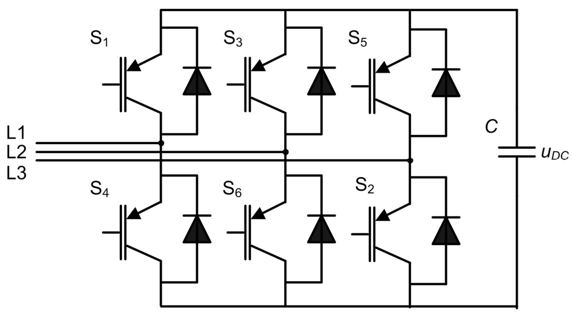

Fig. 7 Three-phase VSC

semiconductor valves and has a capacitor on the dc side.

4.2 Calculated frequency characteristics [7]

The analytical calculation of the frequency characteristics is based on the STATCOM mathematical model without taking into account the control algorithm. It was already shown that when the network ac source contains other frequencies f (beside the fundamental f_0) a VSC generates current components f (positive phase sequence) and $f - 2f_0$ (negative phase sequence) on the ac-side and $f - f_0$ on the dc side.

The calculation results are presented in Fig. 8. Presented are the magnitudes for the resulting current and voltage components as a function of frequency (at different operating points). The graphs show the response curves of the generated currents at frequencies f and $f - 2f_0$ (negative phase sequence) and of the dc-side voltage at $f - f_0$. The results indicate resonance points which depend on the STATCOM operating point.

The results will be verified in PSCAD with the frequency scanning method.

4.3 Frequency scanning method

The frequency scanning method is used to identify the system impedance frequency dependence. A series connected voltage source was connected on the network side. The source generated voltage of small amplitude and a wide range of frequencies. Then the STATCOM currents and dc-side voltage were measured and the effect of voltage distortion was evaluated.

The STATCOM was modelled in detail in the PSCAD program as shown in Figures 6 and 7. IGBT's were used as VSC semiconductor switches and firing pulses were generated by means of pulse-width modulation (PWM). The same device parameters were used as for analytical calculations.

4.4 Calculated and simulation results [7]

The results of calculation and simulation together are shown in Fig. 9. As it can be observed the results obtained by analytical calculations and by frequency scanning in PSCAD agree very well.

In the next step influence of the control algorithm on STATCOM frequency characteristics was determined by means of simulation in PSCAD. When the control algorithm is included the system becomes relatively complex and difficult to analyze analytically. This makes simulation tools especially useful for analysis of system behaviour.

Simulation results are shown in Fig. 10. It can be seen that the characteristics deviates substantially from the calculated values where the control algorithm is not taken into account. This is due to the fact that the input quantities of the control algorithm were not

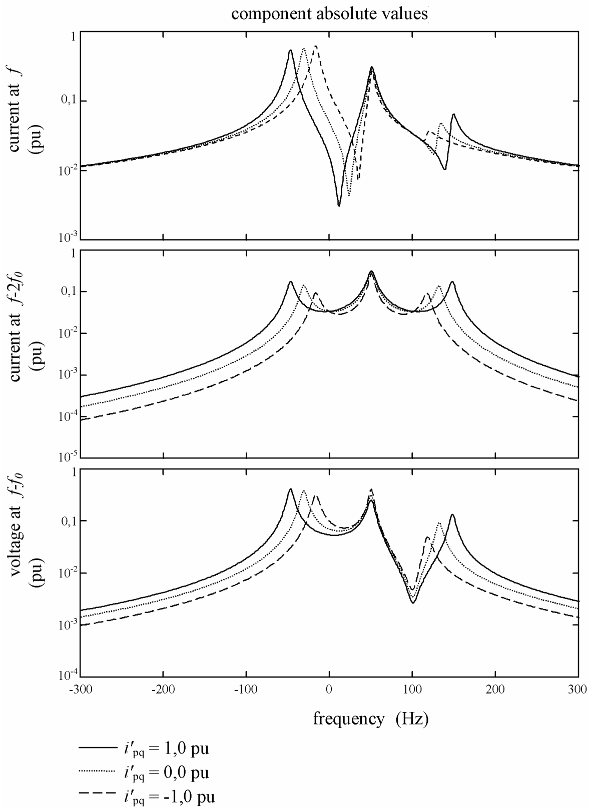

Fig. 8 STATCOM frequency response for different operating points

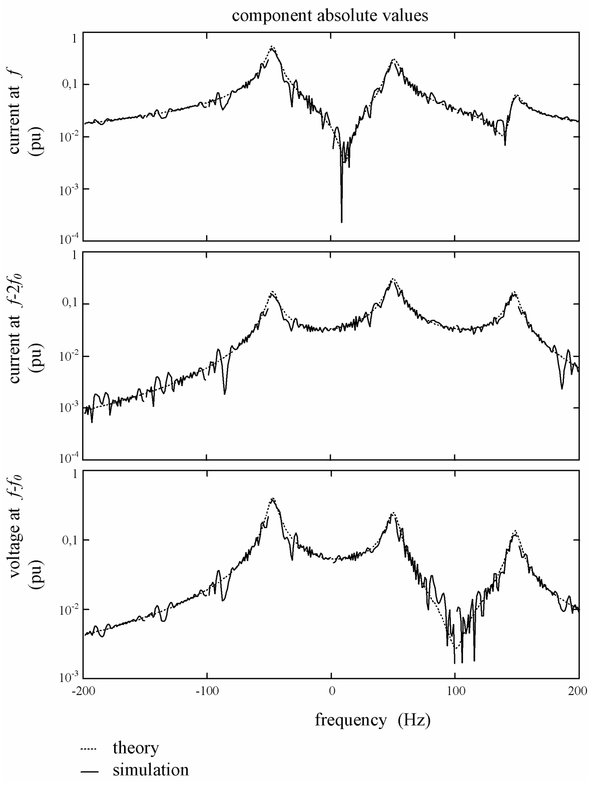

Fig. 9 Comparison between theoretically calculated STATCOM frequency response and simulation results.

filtered. Therefore the control system dumps the injected harmonic frequencies. If an input filter would be used the frequency characteristics would deviate from the calculated one only around the system frequency 50 Hz.

5 Conclusions

In the paper basic guidelines for simulation of power electronics devices in power networks were outlined. As a simulation case STATCOM frequency characteristics were analyzed by using the frequency scanning method. When the device control algorithm is not taken into account the simulation results agree well with theoretical results and show that STATCOM is a frequency dependent device. Moreover, the frequency characteristic depends on the device operating point. When the control algorithm is included in the simulation the results change and depend heavily on the used control scheme.

The described case shows the usefulness of simulation programs when the analyzed system becomes to complex for analytical formulation.

6 References

[1] A. M. Gole et. al. Guidelines for modelling power electronics in electric power engineering applications. *IEEE Transactions on Power Delivery,* Vol. 12, No. 1:505-514, 1997.

[2] T. L. Maguire, A. M. Gole. Digital simulation of flexible topology power electronic apparatus in power systems. *IEEE Transactions on Power Delivery,* Vol. 6, No. 4:1831-1840, 1991.

[3] O. Anaya-Lara, E. Acha. Modelling and analysis of custom power systems by PSCAD/EMTDC. *IEEE Transactions on Power Delivery,* Vol. 17, No. 1:266-272, 2002.

[4] PSCAD User's guide, Manitoba HVDC Research Centre, 2001.

[5] EMTDC User's guide, Manitoba HVDC Research Centre, 2001.

[6] X. Jiang, A. M. Gole. A frequency scanning method for the identification of harmonic instabilities in HVDC systems. *IEEE Transactions on Power Delivery,* Vol. 10, No. 4:1875-1881, 1995.

[7] I. Papič. Stacionarne frekvenčne karakteristike vzporedno priključenega statičnega kompenzatorja. Electrotechnical Review 71: 40-46, 2004.

[8] I. Papič, A. M. Gole. Frequency response characteristics of the unified power flow controller. *IEEE Transactions on Power Delivery,* Vol. 18, No. 4:1394-1402, 2003.

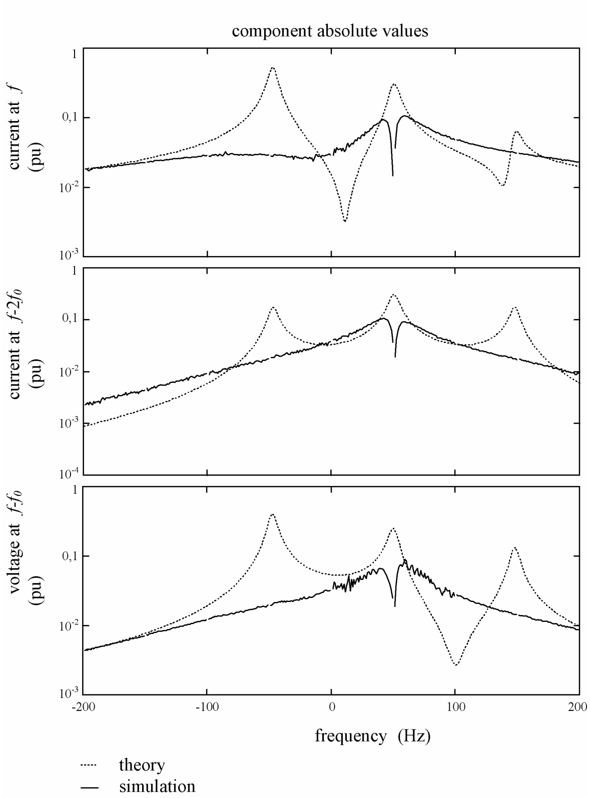

Figure 10 Comparison between the theoretically calculated and scanned frequency response of the STATCOM; the control system is active during frequency scanning

