Comparative Study Between Power System Blockset and PSCAD/EMTDC for Transient Analysis of Custom Power Devices Based on Voltage Source Converter

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Abstract **– This paper presents a comparative study between two commercial programs considering transient analysis of custom power devices based on voltage source converters. The programs investigated were the Power System Blockset for use with Matlab/Simulink, which employs state-variable analysis, and PSCAD/EMTDC, which is based on nodal analysis. The objective is to determine the main differences between them considering computation time, easiness of implementation of the necessary models, evaluation of the existent libraries and accurateness of results. The custom power devices analyzed were the DSTATCOM and the DVR. In all studies presented, such devices were simulated by using detailed models, *i.e.* the switching elements IGBTs/diodes and the PWM signal generator were explicitly represented. In the end of work, the main advantages and disadvantages of each program are argued.**

Keywords – Custom power devices, DSTATCOM, DVR, Power System Blockset, PSCAD/EMTDC.

I. INTRODUCTION

Recently, various power electronic devices have been proposed especially to be applied to medium voltage networks, generally named Custom Power [1], [2]. Among these new devices, special attention has been given to the family based on the voltage source converter technology due to several attractive features, such as faster response, output little influenced by network variables and possibility of utilization together with energy storage devices, allowing active and reactive power compensation simultaneously. Two devices belong to this kind of equipment are the DSTATCOM (Distribution Static Synchronous Compensator) and the DVR (Dynamic Voltage Restorer).

Generally, such devices have been used to improve power quality and reliability aspects. Whatever the application being considered, it is necessary to carry out electromagnetic studies to predict the dynamic behavior and to project suitably these devices. Nowadays, these transient studies are usually accomplished through digital simulation. In this context, various approaches have been developed and implemented for the formulation and solution of the network equations. Broadly, such approaches can be classified on methods based on state-variable analysis or nodal analysis. Power System Blockset (PSB) for use with Matlab/Simulink employs state-variable analysis [3], whereas, PSCAD/EMTDC is based on analysis nodal [4]. Thus, in this work, such tools were tested during transient analysis of the previously mentioned custom power devices. It is important to declare that all models and cases investigated in the next sections are the same presented in [5]. Such fact become easier to validate the results obtained here.

II. CUSTOM POWER DEVICES

Custom power concept has been proposed to ensure high quality of power supply in distribution networks using power electronics devices [1], [2]. Additionally, various custom power devices are based on the voltage source converter technology [6], [7]. Thus, two voltage source converter-based devices were investigated in this work. The chosen devices were the DSTATCOM and the DVR. In distribution voltage level, usually, the employed switching element is the IGBT (Integrated Gate Bipolar Transistor), due to its lower switching losses and reduced size. Moreover, the converter rating employed in these devices is relatively low. Hence, the output voltage control can be executed through PWM (Pulse Width Modulation) switching pattern, reducing the low order harmonic generation. Furthermore, here, the converters are indirectly controlled, *i.e.* only the output voltage angle is controlled and the magnitude remains proportional to the dc voltage [2],[6].

A. DSTATCOM

A DSTATCOM (Distribution Static Synchronous Compensator), which is schematically depicted in Fig. 1, consists of a voltage source converter connected in shunt to the distribution network through a coupling transformer [1]- [3]. Such configuration allows the device to absorb or generate controllable active and reactive power. The DSTATCOM has been utilized mainly for regulation of voltage, correction of power factor and elimination of current harmonics [2], [5].

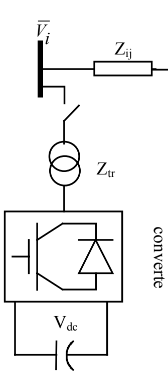


Fig 1 DSTATCOM structure.

Here, such device is employed to provide continuous voltage regulation using an indirectly controlled converter [6]. The controller is shown in Fig. 2. The controller input is an error signal obtained from the reference voltage and the value rms of the terminal voltage measured. Such error is processed by a PI controller and the output is the angle δ, which is provided to the PWM signal generator. This controller is the same employed in [5]. It is important to note that in this case, indirectly controlled converter, there is active and reactive power exchange with the network simultaneously [2], [5]-[7].

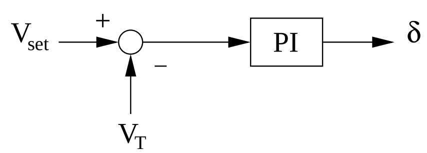


Fig 2 Indirect controller.

B. DVR

A DVR (Dynamical Voltage Restorer) also consists of a voltage source converter connected to the distribution network through a transformer. On the contrary to the DSTATCOM, the transformer is connected in series with the distribution line. In general, the DVR has been employed to protect critical and sensitive loads against short duration voltage dips and swells as well as to eliminate voltage harmonics [2], [5]. The controller structure employed here is the same presented in Fig. 2. The objective is to avoid voltage sags during short-circuits in the network. Moreover, it is considered that the DVR acts only during fault period, on the contrary, it is considered by-passed.

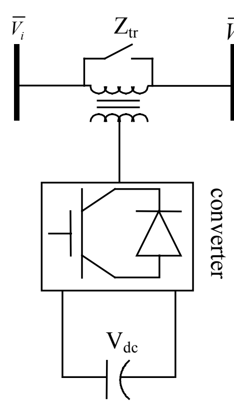


Fig 3 DVR structure.

III. Electromagnetic Transient Analysis

Several electromagnetic transient analysis computational tools have been developed during the last decades. Consequently, there are various approaches for the formulation and solution of the network equations. In a simplified way, such approaches can be divided in state-variable analysis and nodal analysis. Based on such fact, two programs are analyzed here. Power System Blockset for use with Matlab, which employs state-variable analysis, and PSCAD/EMTDC, which is based on nodal analysis.

A. Power System Blockset

Power System Blockset for use with Matlab/Simulink is based on state-variable analysis and employs either variable or fixed integration-step algorithms [3]. In this software, the dynamics of the linear part of the electrical circuit are represented by continuous or discretized time-domain state-space equations. Additionally, the non-linear part of electrical circuit is solved separately using predefined models, and combined with the solution of the linear part. In this simulation package there are various electrical system apparatus, electrical machines and power electronics components. Furthermore, such tool has a graphical interface very friendly. The version 2.2 was adopted in this work.

B. PSCAD/EMTDC

PSCAD/EMTDC employs the well know and established nodal analysis together with trapezoidal integration rule with fixed-step algorithms [4]. The version 3.0, which is employed in this work, is written using Fortran 90, it has allowed a speed-up of the computing time comparing to older versions. Such software present various electrical system apparatus, electrical machines and power electronics components. The graphical interface is also very well developed.

IV. Computer Simulations

A. DSTATCOM

The test system employed to carry out the simulations concerning the DSTATCOM actuation is shown in Fig. 4, which is the same system presented in [5]. Such system is composed by a 230 kV, 50 Hz transmission system, represented by a Thévenin equivalent, feeding a distribution network through an 3-winding transformer connected in Y/Y/Y, 230/11/11 kV. To verify the working of a DSTATCOM, a variable load is connected at bus 2 and a three-phase capacitor bank at bus 1. During the simulation, in the period from 300 to 600 ms, the switch 1 is closed and from 900 to 1200 ms the switch 2 is closed, which remain closed until of the end of the simulation

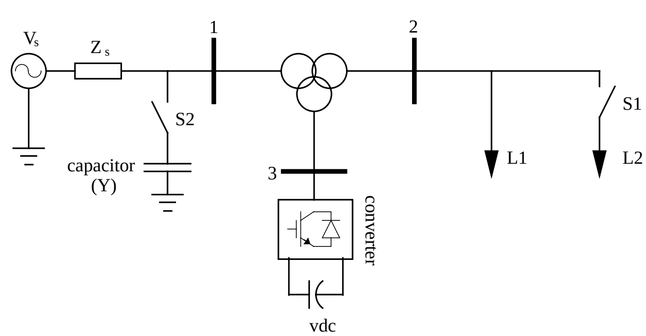


Fig 4 One-line diagram of the test system 1.

The implementation of this system using PSB and PSCAD/EMTDC are shown in Fig. 5 and 6 respectively. The main components are described to follow.

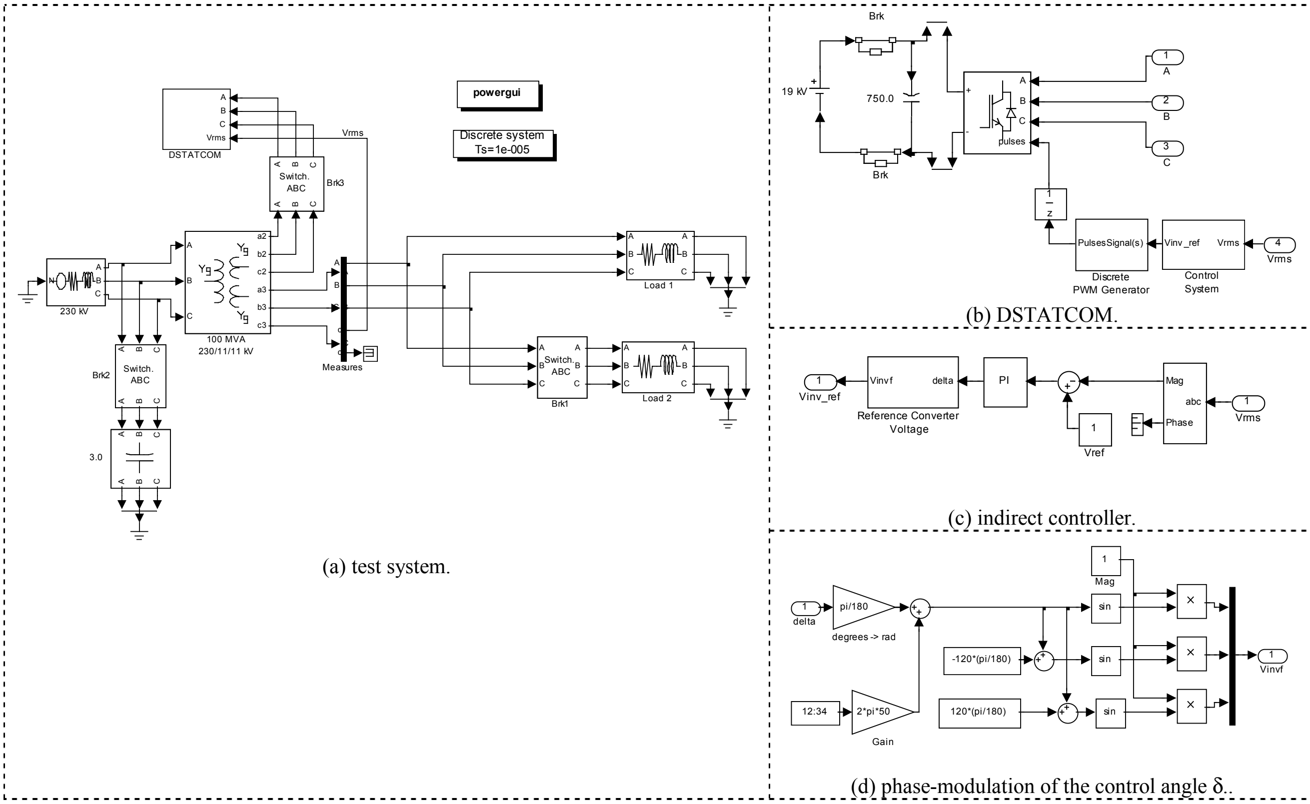


Fig 5 DSTATCOM and associated controllers implemented in PSB.

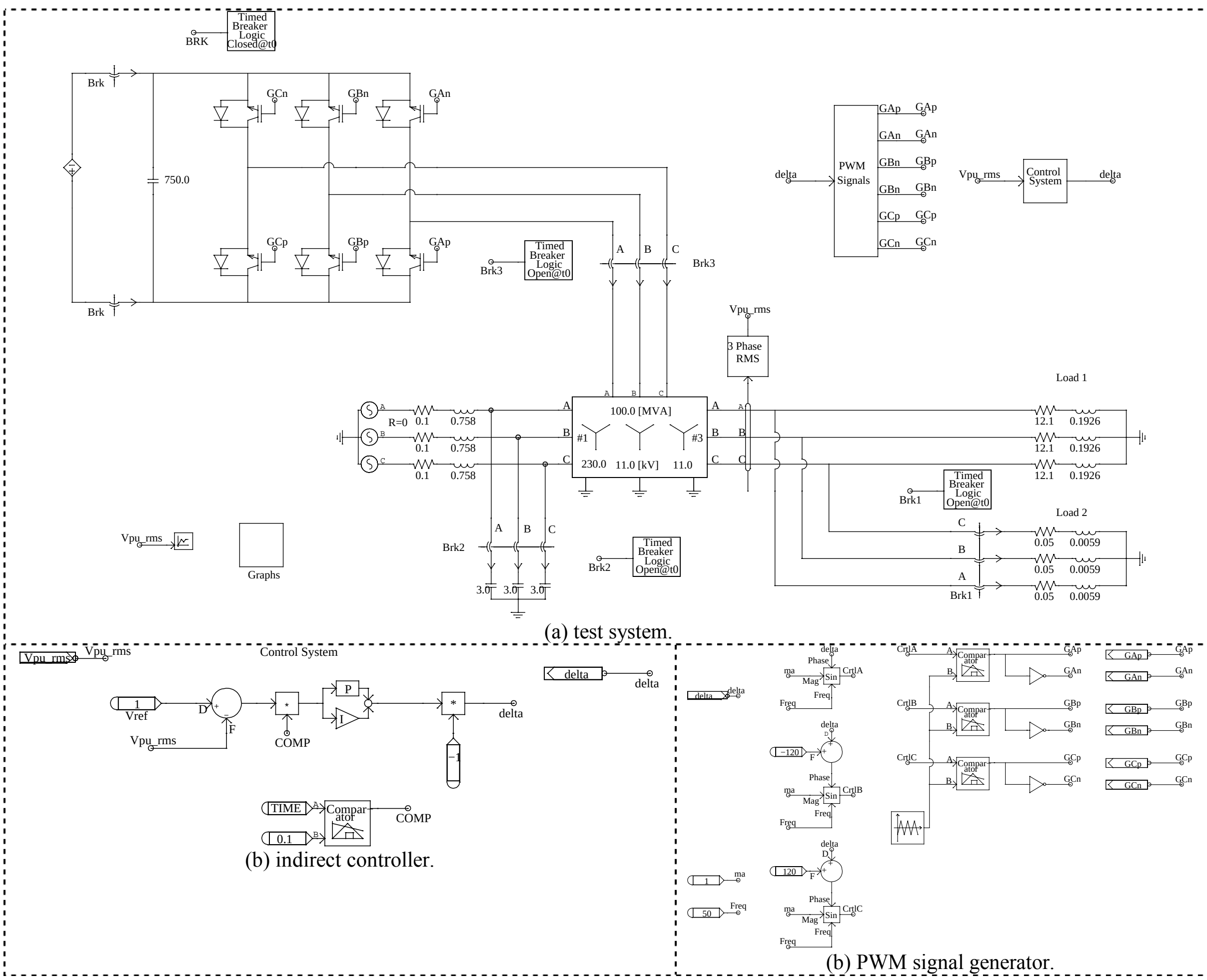


Fig 6 DSTATCOM and associated controllers implemented in PSCAD/EMTDC.

All necessary elements to implement the network; for example, three-phase transformers, circuits breakers, capacitors; are existent in the PSB library, Fig. 5(a). Furthermore, a three-phase converter model is also included, Fig. 5(b). Such converter can employ various kinds of switches, *e.g.* GTO, IGBT, MOSFET. The PWM signal generator is also available in the PSB library, which can be used to generate signals for 6 and 12 pulses converters, Fig. 5(b). The implementation of the indirect controller is well easy using the Simulink blocks, Fig. 5(c). Moreover, the phase-modulation of the control angle δ is presented in Fig. 5(d).

PSCAD/EMTDC has also all necessary components to represent the network, Fig. 6(a). Regarding the DSTATCOM and associated controllers, PSCAD/EMTDC does not have a pre-defined converter model in its library. However, such component can be implemented very easily, Fig. 6(a). The implementation of the indirect controller is also very simple using only existent components, Fig. 6(b). There is a PWM signal generator in the PSCAD/EMTDC library, however, it has not been used in this work. The PWM signal generator adopted here is shown in Fig. 6(c).

In Fig. 7, the voltage response of bus 2 for the events previously described is shown. In this case, there is no DSTATCOM into the network. It can be verified that the results obtained through the PSB and PSCAD/EMTDC are very similar. The difference is mainly due to methodology employed to calculate the three-phase rms voltage. In PSB, the three-phase rms voltage is calculated using Fourier analysis over a sliding window of one cycle of the three-phase instantaneous voltage measured [3]. On the other hand, in PSCAD/EMTDC, the three-phase rms voltage is calculated transforming the three-phase ac instantaneous voltage measured in dc and after smoothing it through a filter [4].

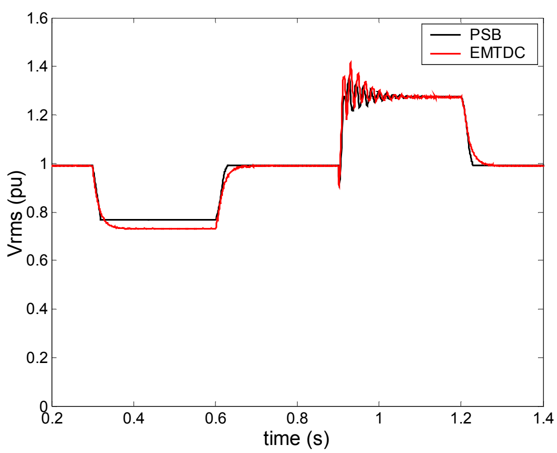


Fig 7 Voltage response of the test system 1 using PSB and PSCAD/EMTDC – case without DSTATCOM.

In Fig. 8, the voltage response of bus 2 in the presence of a DSTATCOM is presented. It can be verified that the DSTATCOM can keep the terminal voltage approximately constant during the transients. The capacity of the DSTATCOM dc element was adopted equal to 19 kV, and such capacitor is previously charged through the circuit breakers shown in Fig. 5(b) and 6(a). It is important to mention that there is no filtering equipment in this simulation. Moreover, the results obtained using PSB and PSCAD/EMTDC are very close and the results obtained here are very similar to the results presented in [5]

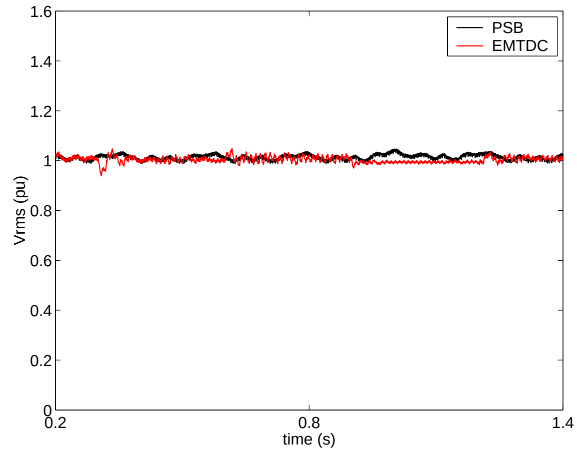


Fig 8 Voltage response of the test system 1 using PSB and PSCAD/EMTDC – case with DSTATCOM.

A. DVR

The test system employed to carry out the simulations concerning the DVR actuation is shown in Fig. 9, which is the same system presented in [5]. Such network is composed by a 13 kV, 50 Hz generation system, represented by a Thévenin equivalent, feeding two transmission lines through an 3-winding transformer connected in Y/Δ/Δ, 13/115/115 kV. Such transmission lines feed two distribution networks through two transformers connected in Δ/Y, 115/11 kV. To verify the working of a DVR employed to avoid voltage sags during short-circuit, a fault is applied at point X via a resistance of 0.66 Ω. Such fault is applied from 300 to 600 ms.

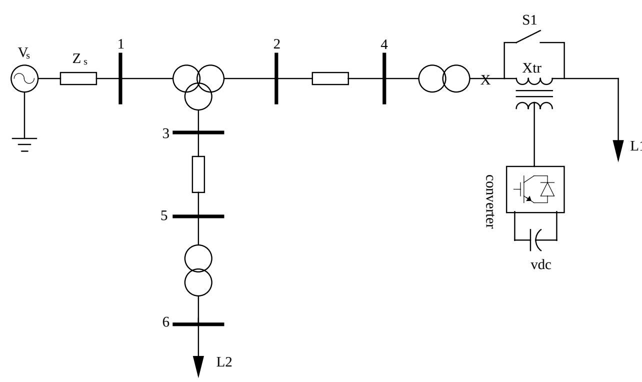
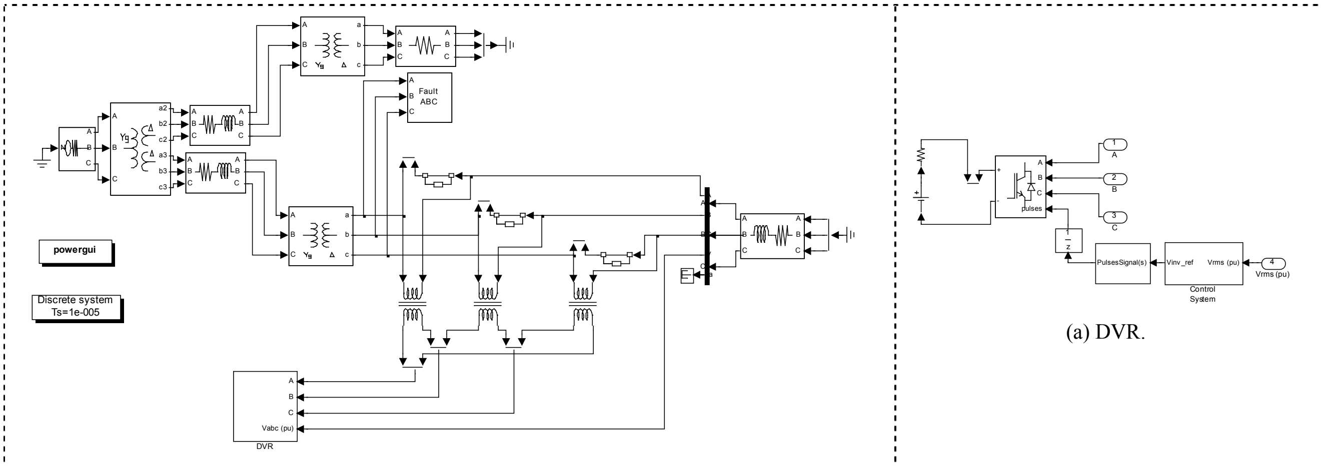


Fig 9 One-line diagram of the test system 2.

The implementation of this system using PSB and PSCAD/EMTDC are shown in Fig. 10 and 11 respectively. The mains components have already been described previously. In such figure, the insertion transformer connection is explicitly shown.



(a) test system.

(a) DVR.

Fig 10 DVR and associated controllers implemented in PSB.

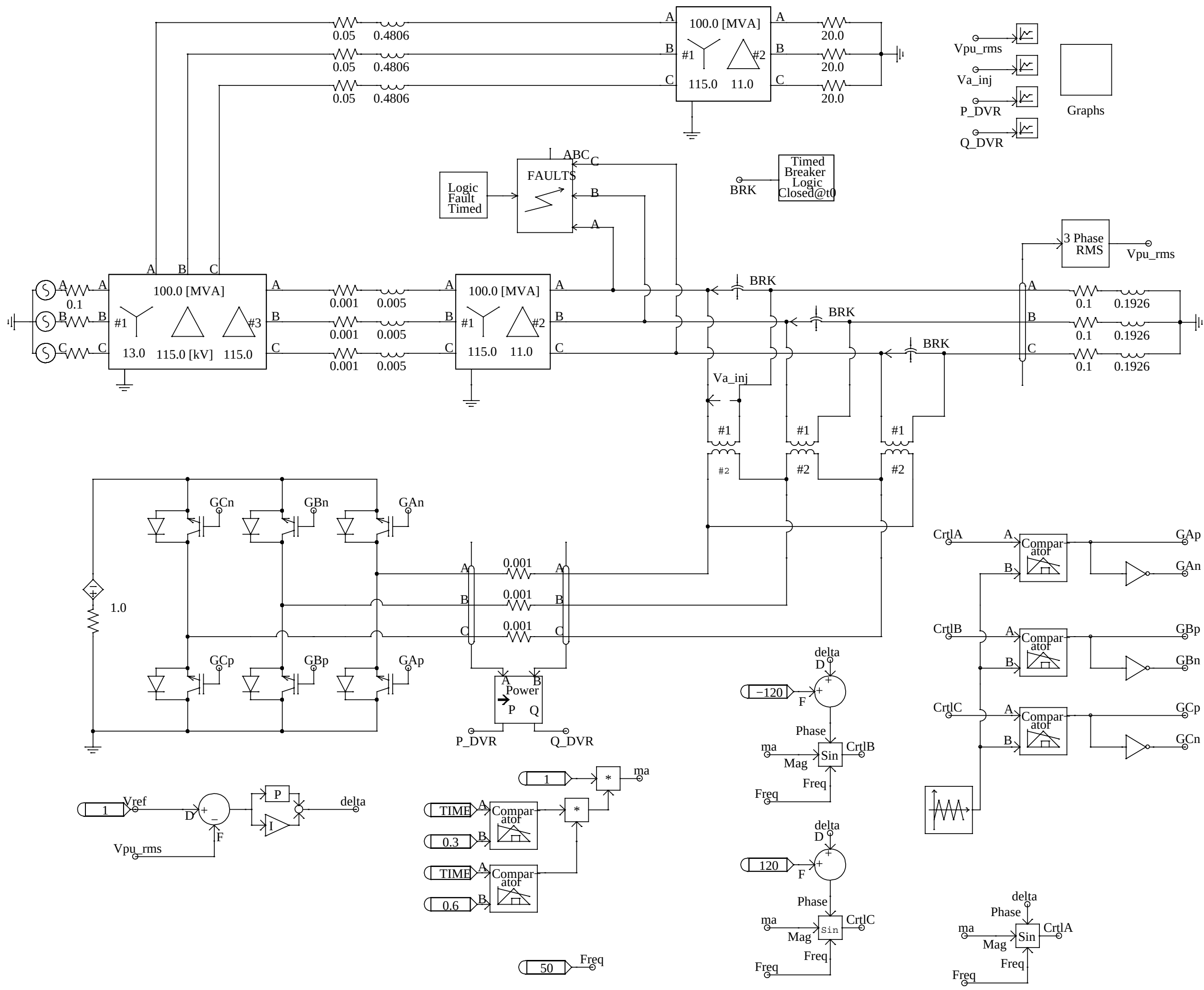


Fig 11 DVR and associated controllers implemented in PSCAD/EMTDC.

In Fig 12, the voltage response of bus 4 is presented; in this case there is no DVR into the network. It can be verified that during the fault occurrence the voltage is very affected. Furthermore, again, the simulation results obtained through PSB and PSCAD/EMTDC are very similar. The voltage response of bus 4 when there is a DVR into the network is shown in Fig. 13. It is possible to note that the DVR is capable of keeping approximately constant the terminal voltage. In this case, the DVR coupling transformer is connected in delta in the DVR side and the leakage reactance is equal to 10%. Additionally, the capacity of the dc element was adopted equal to 5 kV [5]. The other data can be obtained in [5].

The main difference between the results obtained from PSB and PSCAD/EMTDC occurs when the DVR comes in and out. Such fact is mainly due to different methodologies employed for each software to calculate the three-phase rms voltage, as has already been previously discussed. This has large impact on the controller performance. However, it can be considered that the results are very similar. It is important to remember that different measures may also occur using real electric measurement apparatus.

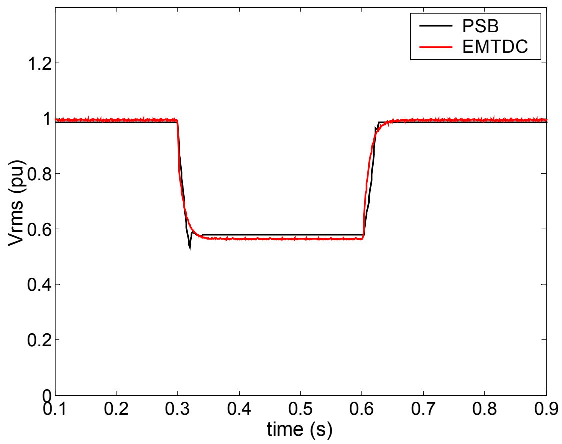


Fig 12 Voltage Response of the test system 2 using PSB and PSCAD/EMTDC – case without DVR.

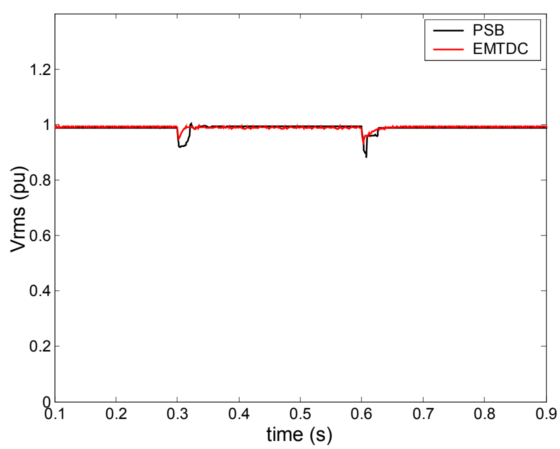


Fig 13 Voltage Response of the test system 2 using PSB and PSCAD/EMTDC – case with DVR.

V. Conclusions

Considering the applicability of the PSB and PSCAD/EMTDC for transients analysis of custom power devices and based on results presented and discussed in previous sections, the following conclusions can be obtained:

- Computation time: in this case the PSCAD/EMTDC is quicker because it is implemented in Fortran 90 and the PSB is based on a script language. However, it is possible to use the Simulink Accelerator and the Real-Time Workshop to improve the PSB performance. In this case a C code is generated. In both programs an integration step equal to 50 µs was utilized.
- Easiness of implementation of the models: both program have all necessary elements to implement the DSTATCOM and DVR models easily. Moreover, the graphical interfaces of these programs are very friendly.
- Evaluation of the existent libraries: in this case the two programs shown to be very complete. Additionally, the non-existent models can be very easily implemented.
- Accurateness of results: it can be verified that the results obtained from PSB and PSCAD/EMTDC are very close. Therefore, it is possible to conclude that both programs present the same kind of accurateness.
- Accomplishment sequential studies for parameter adjustments: both programs have tools to carry out multiple-simulations for determination of parameters; *e.g.* PI constants. However, PSB can be utilized with several toolboxes and blocksets existent in Matlab/Simulink environment, for example Nonlinear Control Design Blockset.

In general terms, both programs are suitable for transient analyses of custom power devices and very easy to use. The main advantage of the PSB is it be developed into Matlab/Simulink environment, such fact become possible to utilize it together with several other control design tools. On the other hand, the main advantage of the PSCAD/EMTDC is computing time. In this software the simulations run very fast.

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