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Performance Assessment of the RTDS/RSCAD VSC Model

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Abstract. This document presents a performance assessment of the three-phase two-level voltage source converter (VSC) model of the real-time digital simulator RTDS/RSCAD. This evaluation is conducted through two case studies. One case is a simple two-bus power electronic-based system, and the second case is a three-bus system with a frequency-dependent transmission line model and a closed-loop controlled VSC with communication delay. The results obtained reveal that the RTDS/RSCAD VSC model presents some issues on stability, harmonic spectrum, ripple, and power quality in general, as compared with the PSCAD VSC solutions. These results also suggest the need for better power electronic components models.

1. Introduction

Due to the increasing complexity of power systems and the necessity of efficient and reliable analyses, real-time digital simulations are becoming a standard tool in the electrical industry, and research laboratories [1]. The real-time simulators are used not only to simulate electrical grids efficiently but to test physical devices such as control schemes, relays, motors, converters, among others, bringing more reliability for planning and designing electrical systems, specific components, and controller devices [2], [3]. Depending on the implementation scheme, these tests are called hardware in the loop (HIL), but more specifically they are divided into controller hardware in the loop (CHIL) and power hardware in the loop (PHIL) simulations [4], [5]. However, real-time simulations require specialized software and hardware, and there are limitations due to the minimum time-step that can be used, in particular for the commutation frequency of power electronic converters [6].

The RTDS/RSCAD simulator offers two different work environments, large-time step and small-time step, for simulating electric systems. In the large-time step environment, the minimum time step allowed is 10 microseconds, while in the small-time step is 1.4 microsecond. These two environments can be interfaced such that the power electronic converters, which need a smaller time step due to the commutation frequency, are modelled in small-time step, and the rest of the electric grid is modeled in the large-time step environment. Nonetheless, despite that the small-time step environment allows higher commutation frequencies, it has a few disadvantages such as increased hardware consumption, and it cannot include frequency-dependent transmission line models. On the other hand, after interfacing large-time and small-time step environments, the large-time step suffers the disadvantage that the smallest time step has to be at least 17 times larger than in the small-time step environment, which decreases the simulation accurateness. To cope with these limitations, RTDS offers FPGA-

based models that have been developed for execution on the GTFPGA unit, which is an additional dedicated hardware component housing a Xilinx FPGA board.
Previous works have analysed the disadvantages related to simulations with high commutation frequencies [7]. On the one hand, simulating high switching frequencies represents a more realistic behavior of the VSC converter. However, it demands more resources, and its implementation becomes complex. On the other hand, strategies have been presented to solve this like the Average Models. Normally, this simplification causes the loss of realism in the VSC converter. At the best knowledge of the authors and after a careful review of state of the art, the analyses do not present detailed comparisons between the RTDS/RSCAD results and other professional simulators, such as PSCAD, including frequency-dependent transmission lines and control delays for stability analyses [8] - [11]
In this way, this paper assesses the RTDS/RSCAD simulation accuracy and reliability subject to high commutation frequencies, transmission lines, and controlled power electronic components. The results presented in this work shows that for detailed real-time power systems simulations, further research for the inclusion of refined power electronic component models is required.

2. RTDS/RSCAD small-time step performance assessment

This section presents two case studies to show the performance, advantages, and drawbacks of the RTDS/RSCAD small-time step environment for power systems simulations with power electronic components. For this purpose, the comparison assessment includes the professional simulator PSCAD.
In the first case study, the evaluation of a small-sized system is presented. The comparisons between RTDS/RSCAD and PSCAD is in terms of computed magnitudes and waveforms in both transient and steady-state, power losses, harmonic spectrum, and total harmonic distortion (THD). In the second case study, the system includes two frequency-dependent transmission lines and a closed-loop controlled voltage source converter (VSC). This case also presents a stability comparison between RTDS/RSCAD and PSCAD by including control time delays.
On the other hand, Table 1 shows the RTDS/RSCAD small-time step VSC block parameters for both case studies. It is worth mentioning that the selection of these parameters is not a straightforward task since it is a trial and error process.

Table 1. Parameters of the RTDS/RSCAD small-time step VSC block.

Parameter	Value
Valve switching voltage magnitude	700 kV
Valve switching current magnitude	0.2 kA
Valve RLC damping factor	0.9 p.u.
Base frequency of power systems	50 Hz
Add parallel R equal to fund. freq. OFF Z times	1 p.u.

2.1. Case study 1: Small-time step evaluation.

Figure 1 shows the test system; it includes one VSC connected to the grid through a resistive-inductive (RL) branch with R=0.1 Ω and L= 0.1167 H; an ideal AC source with a nominal frequency of 50 Hz represents the grid equivalent voltage. The nominal RMS-L-L VSC's voltage is 380 kV, with an amplitude modulation index of 0.927, and a DC voltage of 700 kV.

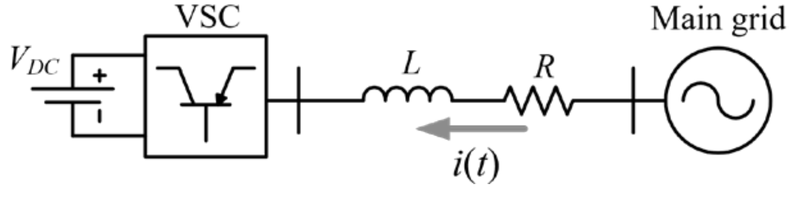

Figure 1. Case 1 single line diagram.

2.1.1. First scenario: commutation frequency of 3 kHZ. Figure 2 shows the phase A line current transient and steady-state, obtained with PSCAD and RTDS/RSCAD. Observe in (a) that the transient-state current signal obtained with RTDS/RSCAD is different in terms of magnitude for the first two cycles as compared with the results obtained with PSCAD; however, note in (b) that the steady-state solution is practically the same in magnitude and ripple. Fig. 2(c) shows the harmonic spectrums and THDs of the PSCAD and RTDS/RSCAD solutions; note that the RTDS/RSCAD THD has and error of 4% compared with the PSCAD results. In addition to this, the harmonic spectrum has one harmonic order error, as if the commutation frequency were 2950 Hz instead of 3 kHz.

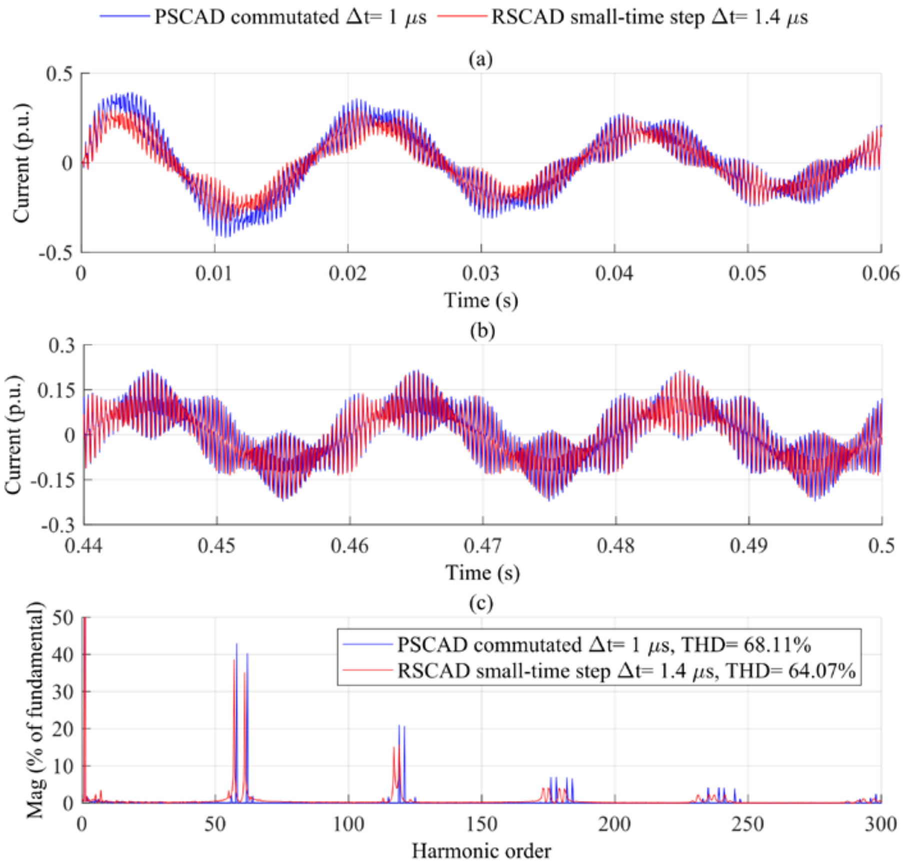

Figure 2. (a) Transient and (b) steady-state of the phase A line current, using PSCAD and RSCAD with a commutation frequency of 3 kHz; additionally, (c) shows the harmonic spectrum and THD obtained.

2.1.2. Second scenario: commutation frequency of 5 kHz. Fig. 3 shows the phase A line current transient and steady-state obtained with PSCAD and RTDS/RSCAD. Additionally, this figure also presents the harmonic spectrum and THD obtained with both simulators. Note that, as in the last case, the small-time step approach has errors in terms of magnitude in the transient-state. Nonetheless, the small-time step approach steady-state is similar in terms of magnitude and harmonic distortion regarding the PSCAD results. On the other hand, observe in Fig. 3(c) that there is a THD difference of 1.5% between RTDS/RSCAD and PSCAD, and again, the harmonic spectrum of RTDS/RSCAD has one harmonic order error.

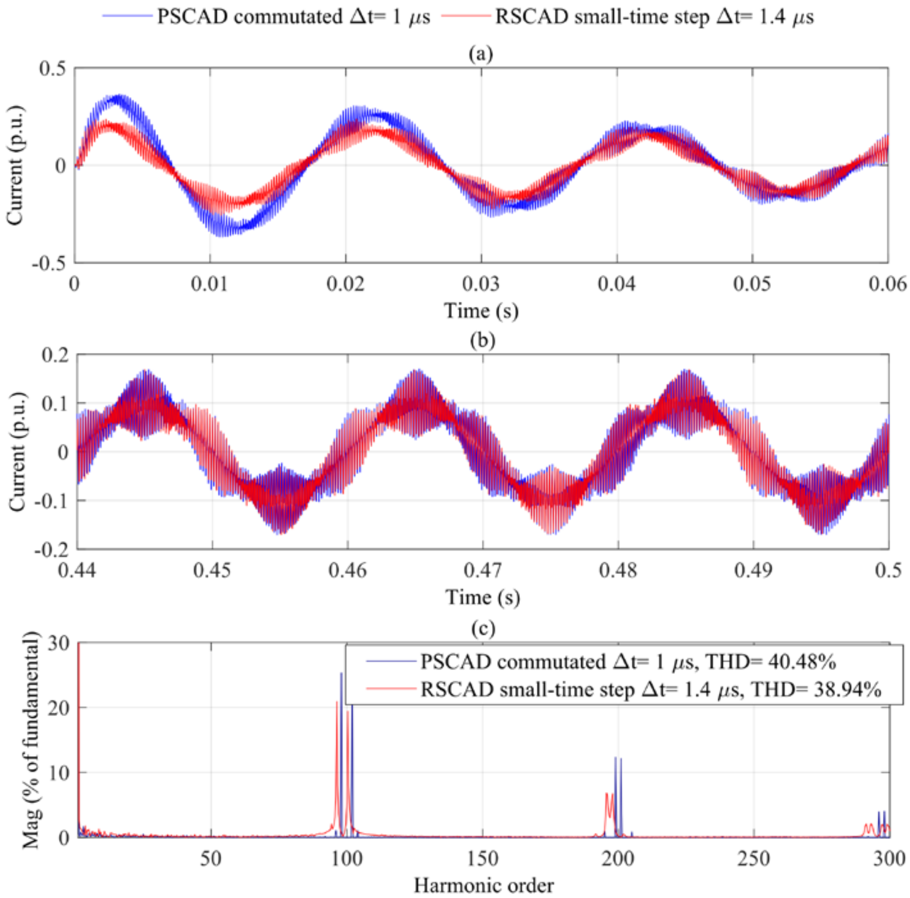

Figure 3. Transient and steady-state of the phase A line current, using PSCAD and RTDS/RSCAD with a commutation frequency of 5 kHz; additionally, the harmonic spectrum and THD.

An essential feature in power electronics-based power system simulations in RTDS/RSCAD is to maintain low power converter losses. The RTDS/RSCAD and PSCAD VSC models used in this case study neglect the semiconductor resistance and emulate ideal switch semiconductor model. Therefore, the VSC losses are expected to be zero in this case. Table 2 shows the VSC losses obtained with PSCAD and RTDS/RSCAD. Note that the VSC losses with the RTDS/RSCAD simulator are excessive and therefore unrealistic in practical systems.

Table 2. VSC losses in case study 1.

Simulator	VSC losses with 3 kHZ	VSC losses with 5 kHZ
PSCAD	0.0065%	0.0044%
RTDS/RSCAD	16.39%	28.76%

It is important to note that in both scenarios, the first transient cycles differ in terms of the current magnitude between PSCAD and RTDS/RSCAD. Moreover, there is a significant difference in the second scenario, being the RTDS/RSCAD first cycle current magnitude result approximately half of the PSCAD current magnitude result. Two reasons may cause this difference: (1) numerical error, since the integration step is not small enough to capture the transient dynamics of the system; and (2) the parameters of the small-time step VSC block are not optimally tuned for the case study system, nonetheless, the tuning of the parameters is not straightforward, and in power systems, the topology and/or parameters of the system are continually changing, therefore, is not practical to be changing the

VSC block tuning. In this way, this may lead to low reliability for transient power system studies such as protections synchronization, fault analysis, among others.
On the other hand, note that in both scenarios, the RTDS/RSCAD gets smaller THDs than in the PSCAD simulations. This means that the magnitudes of the harmonics are smaller than expected, thus leading to false positives that harmonic magnitudes are within the standard limits. Thereby, the integration time step plays a vital role in order to be able to capture the complete harmonic information of the system, which in real-time simulation is limited.

2.2. Case study 2: power system with transmission lines
Figure 4 shows the single line diagram of case study II. The system includes a current-controlled VSC connected through an RL feeder with R=0.1 Ω and L= 0.1167 H. The point of common coupling (PCC) is connected through frequency-dependent transmission lines to two voltage sources with an impedance of R=0.1 Ω and L= 0.00125 H. The VSC DC voltage value is 700 kV. The voltage sources have a RMS-L-L voltage value of 380 kV and a nominal frequency value of 50 Hz. The VSC current controller configuration and parameters, and the transmission line parameters were taken from [12]; it is worth mentioning that the current control includes a delay associated to the modulation technique implementation.

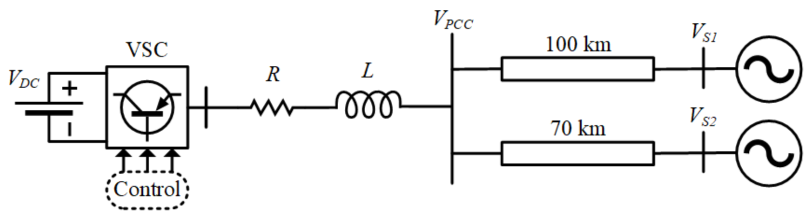

Figure 4. Case 2 single line diagram.

2.2.1. System energization with no control delay. Figure 5 shows the PSCAD and RTDS/RSCAD PCC voltage transient response for both a commutation frequency of 3 kHz and 5 kHz. Observe that, even though the voltage magnitude is similar between PSCAD and RTDS/RSCAD for both commutation frequencies, the RTDS/RSCAD simulation gives a voltage signal more distorted than the one obtained with PSCAD. Therefore, the results show that the reliability of transient studies using RTDS/RSCAD is low for this particular case as compared with PSCAD. On the other hand, only the Bergeron transmission line model is available when using the RTDS/RSCAD small-time environment, which is another drawback for RTDS/RSCAD in case of the frequency-dependent transmission line model is needed.

2.2.2. System energization with control delay. The delay in the control system is modified until the power system becomes unstable to show the reliability of RTDS/RSCAD for stability analyzes. Fig. 6 shows the PCC voltage response, including the control delay value just before and after the system becomes unstable. Observe that the PSCAD simulation maintains stability with a delay up to 290 µs and larger delay becomes the system unstable. On the other hand, the RTDS/RSCAD simulation maintains stability only up to 90 µs. Therefore, the reliability of RTDS/RSCAD for stability studies is low, as compared with PSCAD because the correct value is 290 µs. Finally, the VSC losses are shown in Table 3. Observe that, as in Case 1, the VSC losses difference between RTDS/RSCAD and PSCAD is high, being RTDS/RSCAD the one with the bigger losses.

Table 3. VSC losses in case study 2.

Simulator	VSC losses with 3 kHZ	VSC losses with 5 kHZ
PSCAD	0.0087%	0.011%
RTDS/RSCAD	9.70%	13.79%

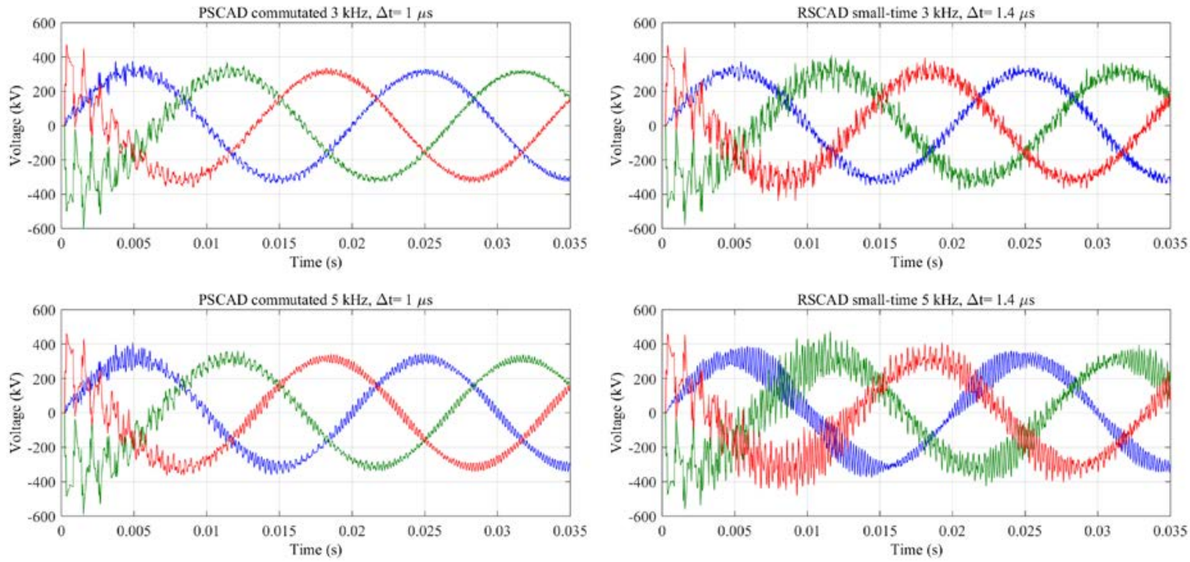

Figure 5. PSCAD and RTDS/RSCAD PCC voltage transient response for a commutation frequency of 3 kHz and 5 kHZ.

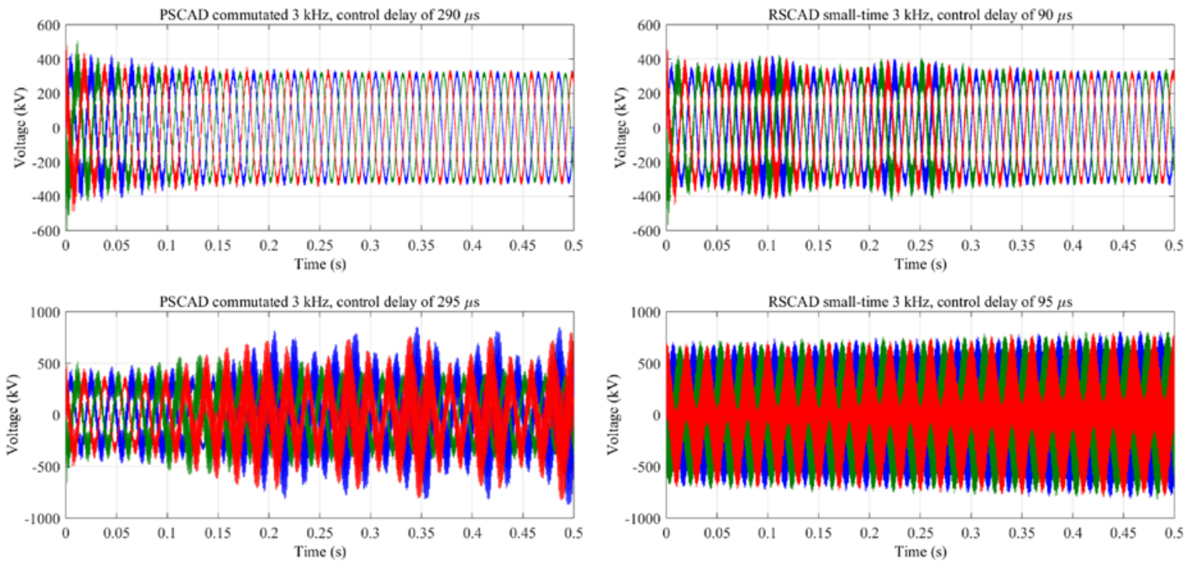

Figure 6. PCC voltage response including the control delay before and after the instability.

3. Conclusions

This document has presented an assessment of the VSC model of the real-time simulator RTDS/RSCAD. Two case studies have been addressed, and comparisons between RTDS/RSCAD and the professional simulator PSCAD were performed. In order to test the performance of the VSC model, the case studies included different components, inter alia, short transmission models, closed-loop controls, and frequency-dependent transmission line models. The results obtained in the comparisons performed showed that the RTDS/RSCAD simulator has some drawbacks when detailed power systems with power electronic components are used for simulation, which led to differences in magnitude, THDs, commutation losses, and harmonic spectrums. Regarding power quality, the RTDS/RSCAD VSC model gives barely acceptable results but gives erroneous results on stability assessment as presented in the case studies. Therefore, further research for better power electronic components models in real-time simulations is pertinent to avoid misleading results.

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4. References

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