DSIM

User's Manual

DSIM Technology Co.

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DSIM Technology Co.

Email: support@powersimtech.com
Web: powersimtech.com

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General Information

1.1 Introduction

DSIM is a simulation engine specifically designed for power electronics. With a ground breaking simulation engine and innovative modeling approach which fully exploits the characteristics of power electronic systems, it achieves an unprecedented and unparalleled performance. It increases the simulation speed by several orders of magnitude compared with any existing simulation software. Moreover, its ability to simulate large converter systems and at the same time switch transients is unique, and it makes it ideally suited for large scale power converter systems, high power converter systems, microgrid, and any systems that are computation intensive.

The DSIM engine is embedded in the PSIM simulation environment, and shares the same graphic user interface. The simulation environment consists of the PSIM schematic capture, the DSIM simulation engine, and the waveform processing program SIMVIEW.

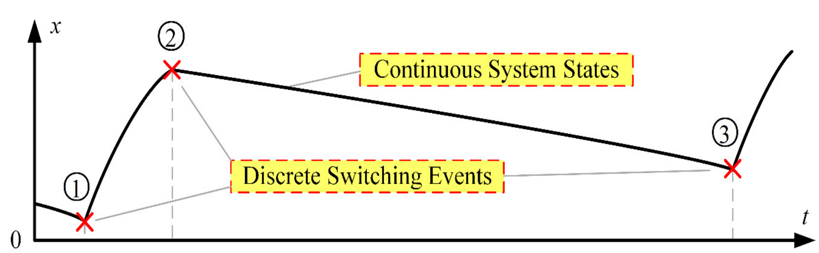
This manual covers necessary details about DSIM. The organization of this manual is as follows:

Chapter 1	DSIM circuit structure, software/hardware requirement, and parameter format.
Chapter 2	Elements supported in DSIM simulation.
Chapter 3	Examples showing the performance of DSIM.

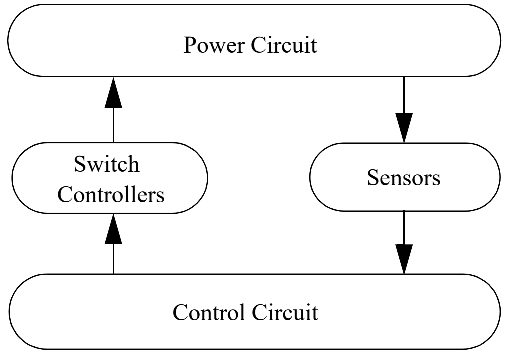
First of all, in Chapter 1, the working principles of DSIM will be briefly introduced, in terms of ***modeling*** and ***simulating***, so that users can have a basic understanding of the DSIM engine.

1.2 Modeling Power Electronic Systems in DSIM

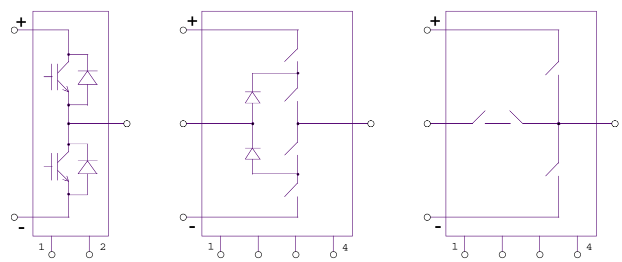
Power electronic systems are intrinsically hybrid dynamic systems composed of continuous states and discrete events. Usually, continuous states include physical variables such as capacitor voltage and inductor current, while discrete events, such as switching events of semiconductor switches, lead to the transition of the system from one operating mode to another. In power electronic systems, these continuous states and discrete events not only coexist, but also deeply interact with each other and co-determine the operating mode of the system, as shown below.



Power electronic system is represented in DSIM in four blocks: power circuit, control circuit, sensors, and switch controllers. The figure below shows the relationship between these blocks.



The power circuit usually consists of switching devices, RLC branches and transformers. For the switching devices, DSIM do not offer discrete switch elements such as a single diode, IGBT, or MOSFET, to build the converter. Instead, switch modules such as two-level bridge leg, three-level T-type bridge leg and three-level NPC bridge leg should be used to construct the circuit. See **Elements >> Power >> Switches >> Switch Modules** for all the switch modules supported in DSIM. DSIM does support bi-directional switches, but the bi-directional switch should be used for one-time event only (such as load change, open-circuit, or short-circuit). It should not be used for PWM operation as the DSIM engine is not optimized to handle it.



Two-level bridge leg

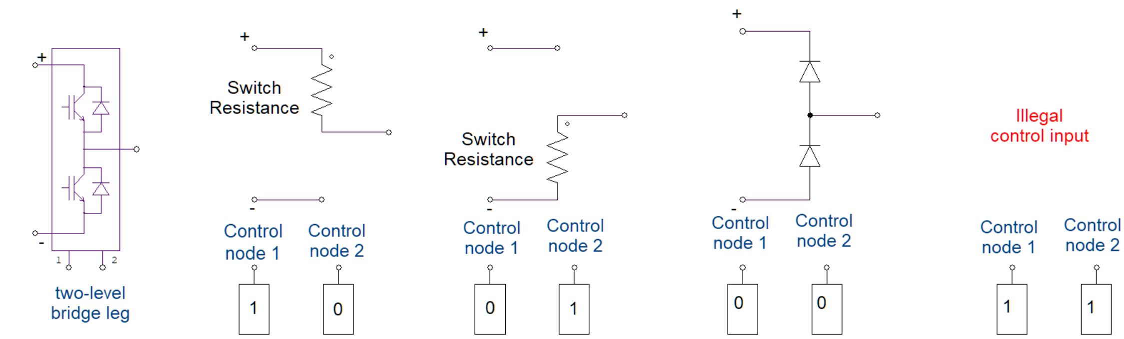
Three-level T-type bridge leg

Three-level NPC bridge leg

For the switching modules, two types of model are supported in DSIM, namely ideal model and transient model.

Ideal Model

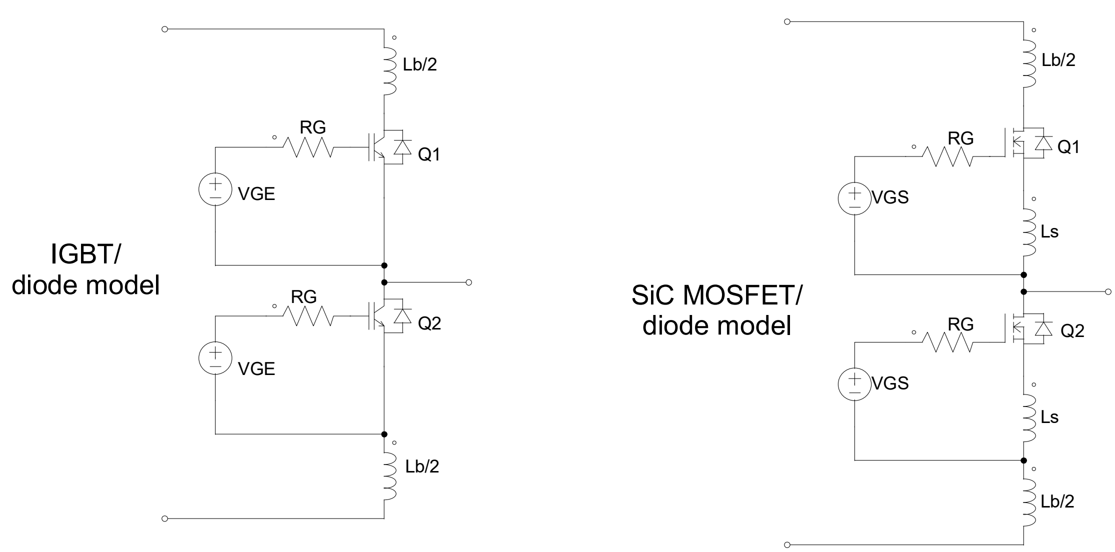
If ideal model is selected, DSIM will model the switch as a small resistance in on-state and as open circuit in off-state. The on-state resistance is defined as a parameter called **Switch Resistance**. It is considered the same for all the active switches and the diodes in the module. The off-state resistance is ignored. The transitions between on-state and off-state are also ignored, so the system can be viewed as a piecewise-linear time-invariant (PLTI) system, which can be characterized by a set of n first-order ordinary differential equations (ODEs). Taking two-level bridge leg as an example, the figure below shows how DSIM model the switch module. Please refer to online help of each module to see its legal control input.



Transient Model

Switching transients between the two steady states are sometimes significant in terms of device protection, switching loss, voltage/current balancing and EMI analysis. However, simulating switching transients in a large system is often challenging due to high stiffness of the circuit. DSIM adopts an innovative modeling approach called **Piecewise Analytical Transient (PAT)** model, which is capable of simulating the switching transients in a very fast and stable way. All the model parameters are available from device datasheet.

Taking a two-level bridge leg as an example, the equivalent circuit for IGBT/diode bridge and for SiC MOSFET/diode bridge is shown as below. Note that the stray inductors are already incorporated in the model whose values should be entered as parameters. One should not put extra stray components in the main circuit which will cause highly stiff equations and therefore low simulation speed.



DSIM now offers transient model for all the switching modules except three-level NPC bridges. One can choose between IGBT/diode model and SiC MOSFET/diode model. Please turn to online help for more information about the definitions of the model parameters. In **Chapter 3 Examples**, comparisons of the model results and experimental results will be presented.

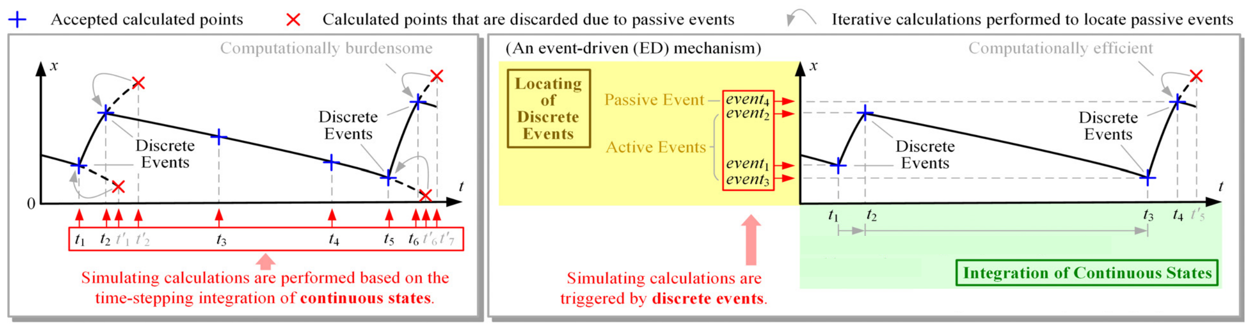
The control circuit is represented in block diagram. DSIM supports only digital control temporarily. Components in z-domain, logic gates and computational blocks can be used in the control circuit. Sensors are used to measure power circuit quantities and pass them to the control circuit. Gating signals are then generated from the control circuit and sent back to the power circuit through switch controllers to control switches.

The whole DSIM engine works in an event-driven manner, and one should use the switch controllers under **Elements** >> **Other** >> **Switch Controllers** to generate switching signals. The offered components cover most of the PWM generators including carrier-based PWM, SVPWM, square wave controller, etc. Otherwise, one should be careful in current DSIM version since switching events may not be located accurately.

1.3 Simulating Power Electronic Systems in DSIM

DSIM engine uses a discrete state (DS) algorithm under an event-driven (ED) manner. It fully exploits the characteristics of power electronic systems and exhibits ultra-fast performance especially in large-scale or high-frequency systems, where typically hundred-fold acceleration can be achieved under the same accuracy, compared with existing simulation tools. **Chapter 3 Examples** shows some examples where such comparisons are presented.

The DS algorithm is intrinsically a variable step-size algorithm which achieves adaptive numerical integration of system states with less computational costs, and the ED manner avoids unnecessary iterative calculations for the frequently-occurred switching events in power electronics. Since a variable step-size algorithm is employed, it's not necessary for users to select a proper step-size. Instead, DSIM engine will choose the step-size adaptively in each calculation step. The following figure illustrates the DSIM simulation framework compared with the conventional one.



Conventional simulation framework

DSIM simulation framework

1.4 Installing the Program

Some of the files in the DSIM directory are:

PSIM.exe	PSIM circuit schematic editor
SIMVIEW.exe	Waveform processing program

File extensions used in DSIM are:

*.psimsch	schematic file
*.psimpjt	project file
*.schpack	package file
*.lib	library file
*.txt	Simulation output file in text format
*.smv	Simulation output file in binary format

1.5 Simulating a Circuit

To simulate the buck converter circuit "buck.dsimsch" in "examples\DSIM\dc-dc":

- Start PSIM. From the **File** menu, choose **Open Examples...**, then, go to "DSIM\dc-dc" folder to load the file "buck.psimsch".
- From the **Simulate** menu, choose **Run DSIM Simulation** to start the simulation. Simulation results will be saved to File "buck.smv".
- By default, **Auto-run SIMVIEW** is selected in the **Options** menu. SIMVIEW will be launched

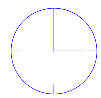
automatically. In SIMVIEW, select curves for display. If this option is not selected, from the **Simulate** menu, choose **Run SIMVIEW** to start SIMVIEW.

1.6 Simulation Control

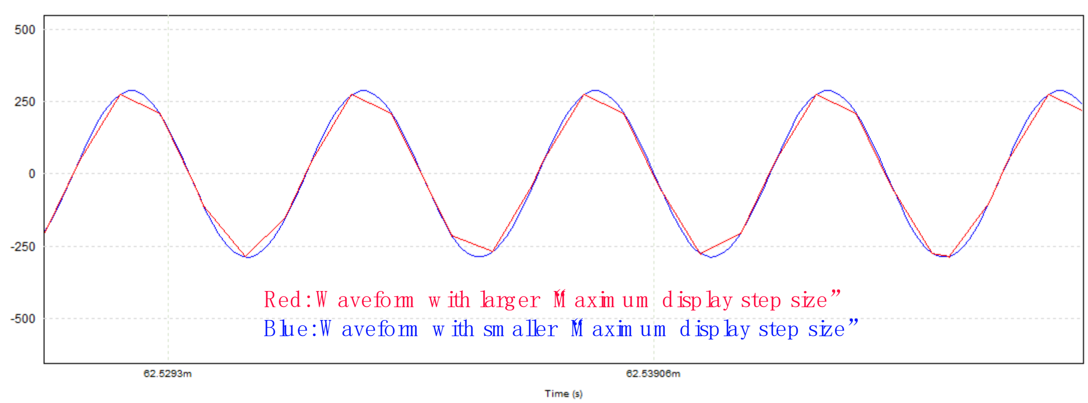
DSIM adopts a variable-step algorithm, and users do not have to specify the simulation step. The Simulation Control element defines parameters and settings related to simulation.

To place the Simulation Control in the schematic, go to the **Simulate** menu, and select **Simulation Control**.

Image:



End Time	The total simulation time, in sec.
Maximum step size	The maximum time step, in sec. If the adaptively chosen time step is larger than the "Maximum step size", the step size is forced to be "Maximum step size".
Relative error	"Relative error" is used to control the numerical error in state integration. The engine chooses the step size based on "Relative error". Decreasing it leads to smaller time step, hence more accurate results but longer consuming time. In most cases, at least 1e-3 "Relative error" is recommended. One can also decrease it until no changes are observed in the simulated waveforms.
Maximum display step size	The "Maximum display step size" (in sec.) is used to limit the display step between two points in the output waveforms. This is typically used for high-frequency waveforms when the engine gives accurate results at each point, but with low "sampling frequency" due to relatively large step size, as shown below (red waveform). Decreasing "Maximum display step size" forces the engine to show details between two points (i.e. during each time step), as shown below (blue waveform). This will cause extra calculations but is more efficient than decreasing the "Maximum step size". It is recommended to use larger "Maximum display step size" to save time when simulated waveforms are displayed with enough resolution.



Some tips on how to change simulation settings:

1) Try decrease the "Relative error" if you think the simulation is not accurate enough;

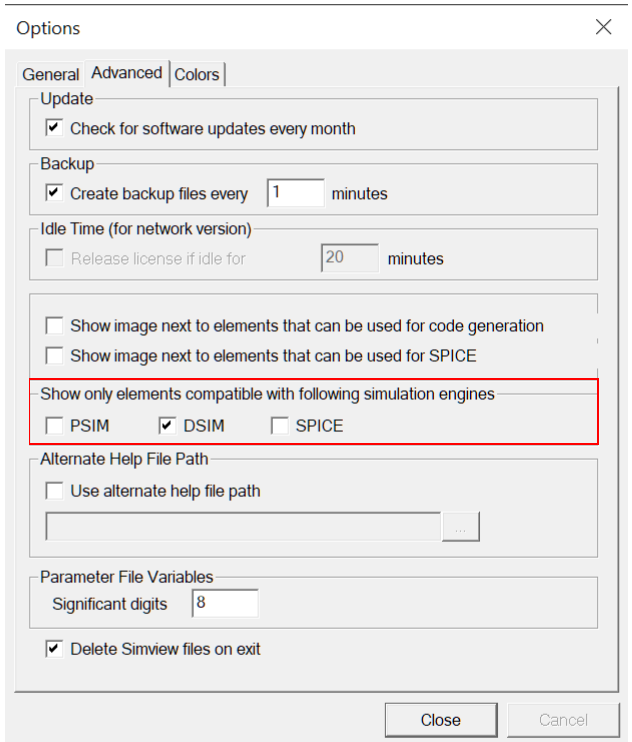
2) Try decrease the "Maximum display step size" if you think the results have low resolution;

3) Try decrease the "Maximum step size" when you find that the simulation results do not converge.

2

Elements Supported in DSIM Simulation

This chapter lists all the elements that are supported in DSIM simulation. Users can choose to display only DSIM supported elements in **Options** >> **Settings** >> **Advanced.**



The following elements are supported in DSIM.

<u>Under **Elements >> Power**:</u>

- **RLC branches**
  - Resistor
  - Inductor
  - Capacitor
  - Capacitor (Electrolytic)
  - R3
  - L3
  - C3
  - RL3
  - RC3
  - RLC3
- **Switches**
  - Switch Modules
    - 1-ph Inverter
    - 2-level Bridge Leg

3-level T-Type Bridge Leg
3-level NPC Bridge Leg
3-ph Inverter
3-ph 3-level T-Type Bridge Leg
3-ph 3-level NPC Bridge
Dual Active Bridge (DAB)
1-ph Diode Bridge
3-ph Diode Bridge

- Bi-directional Switch
- 3-ph Bi-directional Switch

- **Transformers**

Ideal Transformer
1-ph Transformer
1-ph Transformer (no Lm)

- **Renewable Energy Module**

Solar Module (physical model)

- **Motor Drive**

Squirrel-cage Ind. Machine (with load)
PMSM (with load)

*The above motor drive modules contain the following types of mechanical loads: constant torque, constant speed, constant power, general.

Under **Elements >> Control**:

- **Computational Blocks**

Multiplier
Divider
Square-root
Sine
Sine (rad.)
Sine (p.u.)
Arcsine
Cosine
Cosine (rad.)
Cosine (p.u.)
Arccosine
Sine/Cosine (rad.)
Sine/Cosine (p.u.)
Tangent
Arctangent
Arctangent (p.u.)
Arctangent 2 (rad.)
Arctangent 2 (p.u.)
Exponential (a^x)

Power (x^a)
LOG (base e)
LOG10 (base 10)
Absolute Value
Sign Block
Maximum / Minimum Block

- **Other Function Blocks**

  Multiplexer (2-input)
  Space Vector PWM
  Space Vector PWM (alpha / beta)

- **Logic Elements**

  AND Gate
  AND Gate (3-input)
  OR Gate
  OR Gate (3-input)
  XOR Gate
  NOT Gate
  NAND Gate
  NOR Gate

- **Digital Control Module**

  Zero-Order Hold
  Unit Delay
  Integrator
  Differentiator
  PI
  z-domain Transfer Function

- Under the **Control** menu

  Proportional
  Comparator
  Limiter
  Upper Limiter
  Lower Limiter
  Range Limiter
  Summer (+/-)
  Summer (+/+)
  Summer (3-input)

Under **Elements >> Other**:

- **Switch Controllers**

  On-Off Controller
  Square Wave Controller (Variable freq.)
  Carrier PWM Controller (z-domain)
  Square Wave Controller (z-domain)

Phase Shift Controller (z-domain)
Phase Shift Controller (fixed D) (z-domain)
Space Vector PWM (2-level) (z-domain)
Space Vector PWM (3-level) (z-domain)

- **Sensors**

  Voltage Sensor
  Current Sensor
  Voltage Sensor (average)
  Current Sensor (average)

- **Probes**

  Voltage Probe
  Current Probe
  Voltage Probe (node-to-node)

- **Function Blocks**

  abc-dqo Transformation
  dqo-abc Transformation
  Clarke Transformation (abc-alpha/beta)
  Clarke Transformation (ab-alpha/beta)
  Clarke Transformation (ac-alpha/beta)
  Inverse Clarke Transformation (alpha/beta-abc)
  Park Transformation (alpha/beta-dq)
  Park Transformation (alpha/beta/sin/cos-dq)
  Inverse Park Transformation (dq-alpha/beta)
  Inverse Park Transformation (dq/sin/cos- al/be)
  x/y-r/angle Transformation
  r/angle-x/y Transformation
  Math Function
  Math Function (2-input)
  Math Function (5-input)
  Math Function (10-input)
  C Block
  Simplified C Block

<u>Under **Elements >> Sources**:</u>

- **Voltage**

  DC
  Sine
  3-ph Sine
  Grounded Source (multiple) (constant, sine, triangular, sawtooth, square, step, step(2-level))

- Under the **Sources** menu:

  Constant
  Time
  Ground

Ground (1)
Ground (2)

3

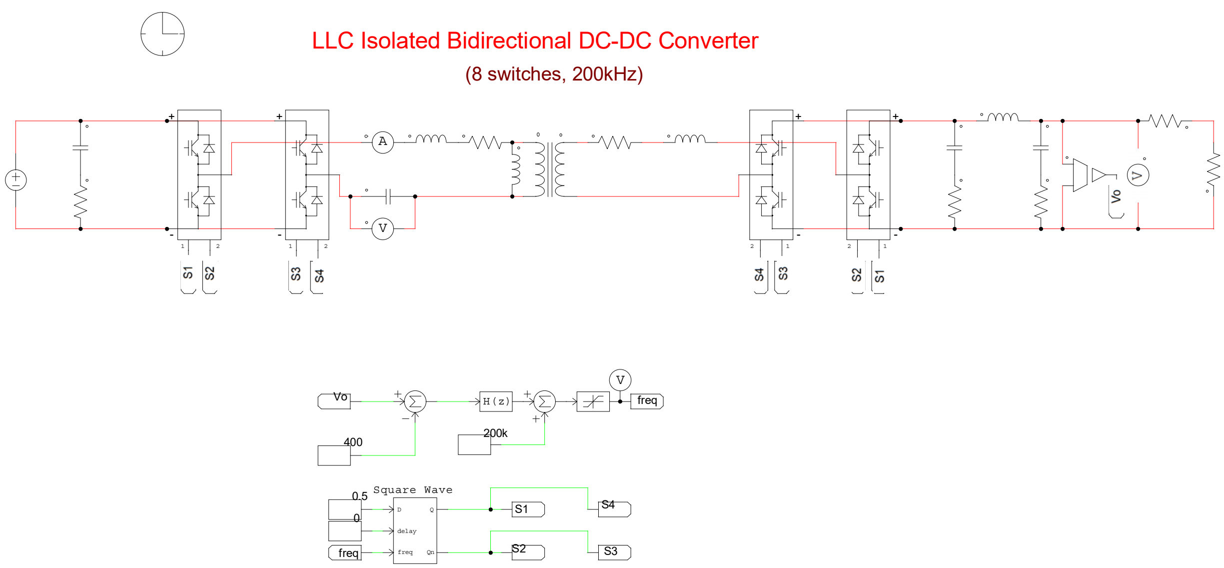
Examples

The high performance of DSIM and its ability to simulate switching transients makes it an ideal solution for large scale power converter systems, high power converter systems, microgrid, and any systems that are computation intensive. In this chapter, some examples are described to show how DSIM empowers the design and research of relatively complicated systems.

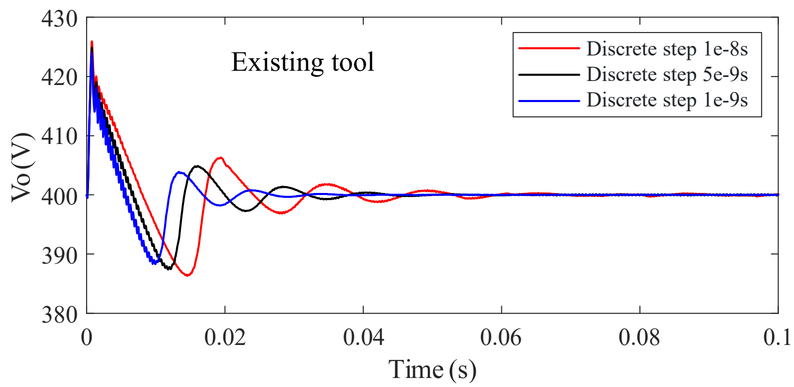
Example: 200kHz LLC Circuit

LLC circuit usually operates in a high-frequency range. With conventional simulation approach, very small simulation time step is needed to get correct results, making the whole simulation time consuming. DSIM offers an event-driven mechanism which greatly shortens the simulation time. This LLC circuit can be found under **examples** >> **DSIM** >> **LLC converter (200kHz)**.

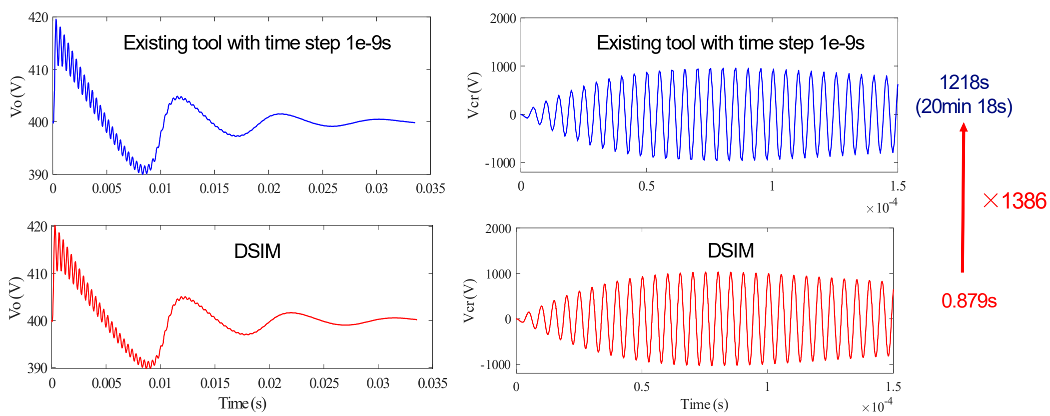
The following figure shows the circuit structure. The studied case is a LLC isolated bidirectional DC-DC converter, with a variable-frequency control around 200kHz. A variable-frequency square wave controller is used to generate the switching signals. Note that for simplicity, the same switching signals are used for both primary and secondary side bridges. This is not the case in practice, but just an approximation to show the performance of DSIM in similar cases.



To use an existing simulation tool with fixed step-size, a very small time step must be selected. A test result is shown in the following figure, where the simulated waveforms of the output DC voltage V_o under different time steps are shown. It can be observed that any time step larger than 1e-9s is not enough to get correct waveforms.

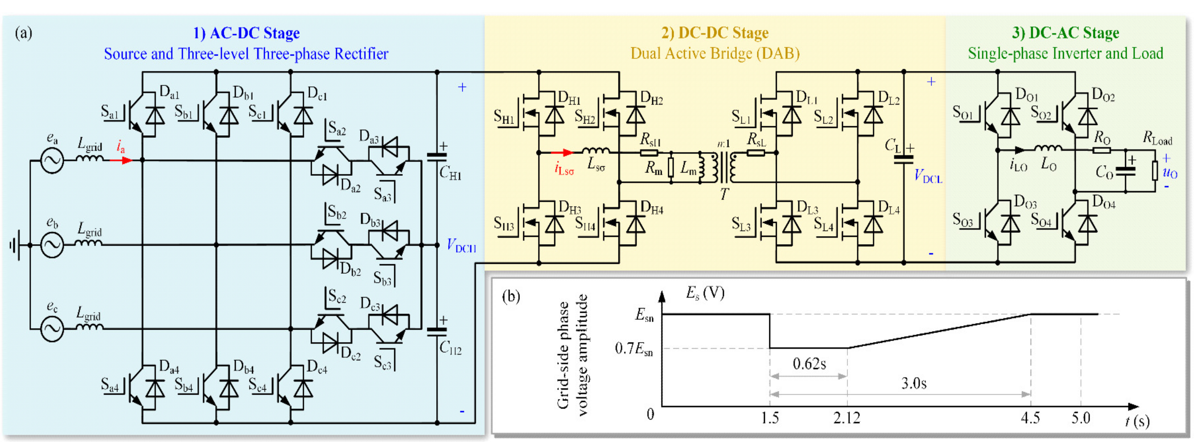


With 1e-9s time step, existing tool takes more than 20 minutes for 0.1 second simulation. However, with the Discrete State Event-Driven algorithm, DSIM takes less than 1 second to get the same results, which is more than 1300 times faster. The following figure shows the comparisons of the simulated results, where Vo is the output DC voltage, and Vcr is the resonant capacitor voltage. The tests are conducted with an Intel Core i7-6600U CPU.



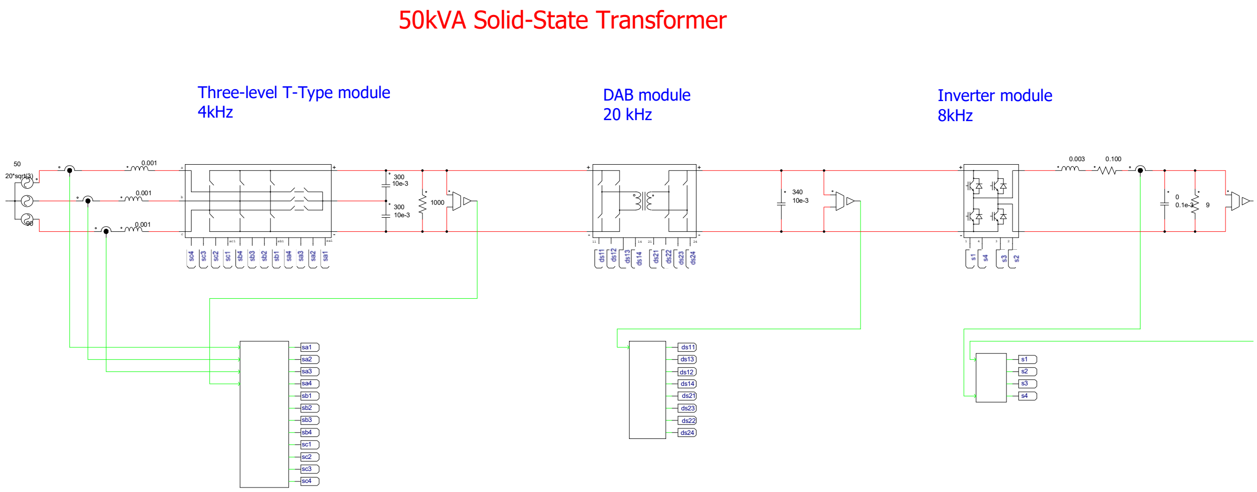
Example: 50kVA Solid-State Transformer

This example shows a 50kVA solid-state transformer (SST). The system consists of three stages, as shown in the following figure. It is tested under a 5-second grid-side low-voltage ride-through dynamic, where the waveform of the grid-side voltage is also shown below.



Overall circuit of the 50kVA SST and simulated low-voltage ride-through dynamic

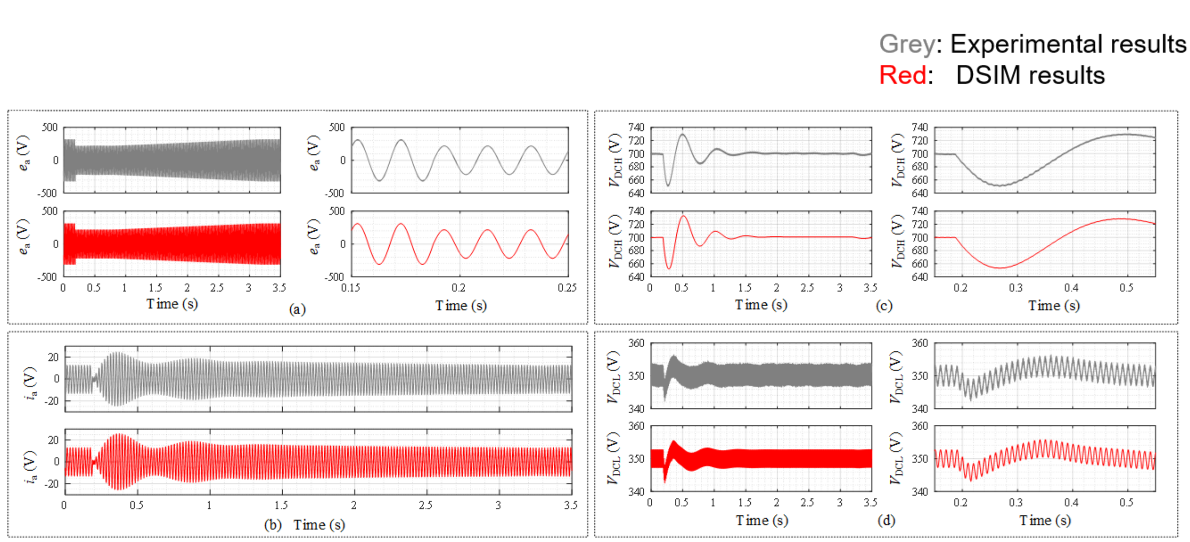
The DSIM circuit of this example is shown below.



For the 5-second dynamic, if ideal switch model is used, DSIM takes less than 5 second to finish the simulation, which is about 50 times faster than current software; if transient switch model is used, DSIM takes about 50 seconds, which is 700 times faster than another commercial software. The comparisons are shown as below. The tests are conducted with an Intel Core i7-7700K CPU.

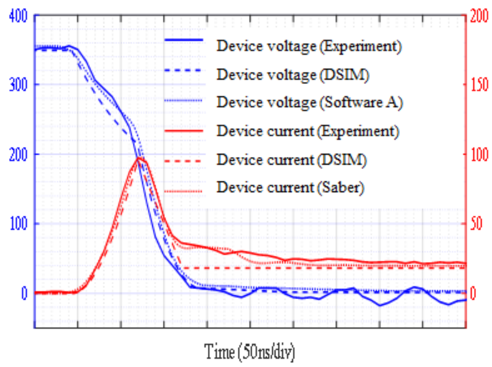
Tool	Device Model	Solver	CPU Time (s)	
Software A	IGBT/PiN diode: *igbt_b* and *dp1* SiC MOSFET/SiC SBD : *mp1* and *dp1*	Trapezoidal method and Newton-Raphson iteration	33712.0 (9h 21min 52s)	
Software B	Ideal switch model	Ode23tb (Rapid mode)	250.9	×717.3
DSIM	Transient model (PAT)	DSED	47.0	×51.8
DSIM	Ideal model	DSED	4.82	

The simulated results are in good agreements with experimental results. Some comparisons of the grid-side waveforms and the DC-link voltage are shown below.

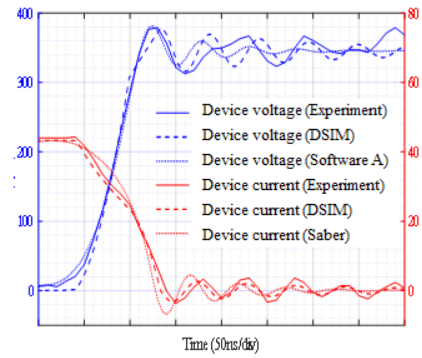


(a) grid-side voltage (b) grid-side current (c) high-voltage side DC-link voltage (d) low-voltage side DC-link voltage

The PAT model in DSIM also gives good results compared with measured ones, as shown below.



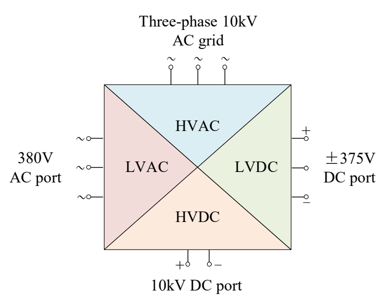
IGBT



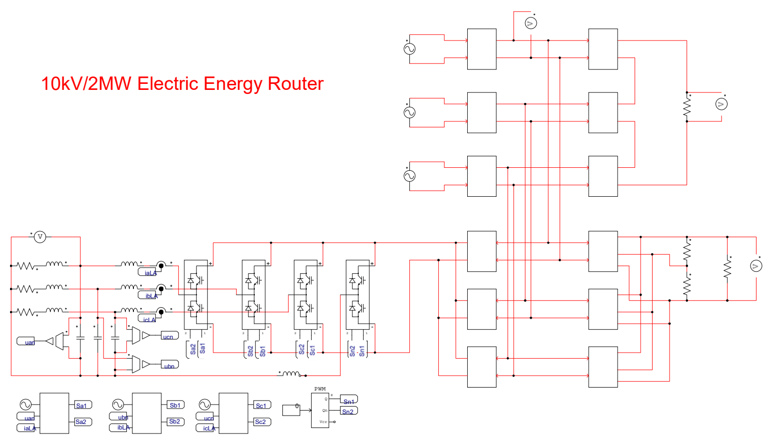
SiC MOSFET

Example: 10kV four-port Solid-State Transformer

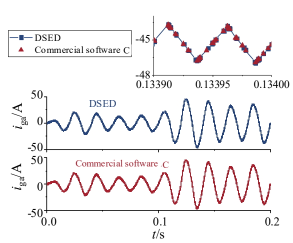
This example shows how DSIM helps to simulate a very large system: a four-port solid-state transformer (SST), also known as electric energy router (EER). It consists of **576 switches** in total and the rated power for each port is 1MW. The system diagram and the circuit built in DSIM is shown below.



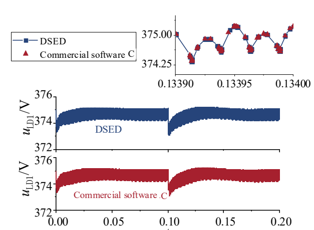
Structure of the EER



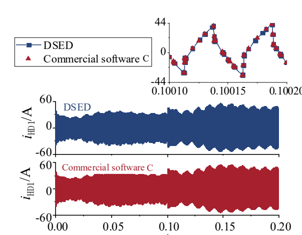
To simulate a 0.2s dynamic, DSIM takes only 17 seconds, which is more than 1000 times faster than a commercial software specialized in power electronics, while the simulated results are very close, with less than 0.01% relative error, as shown below. DSED represents the DSIM algorithm.



Simulated results comparisons of HVAC phase A grid-side current



Simulated results comparisons of LVDC output voltage



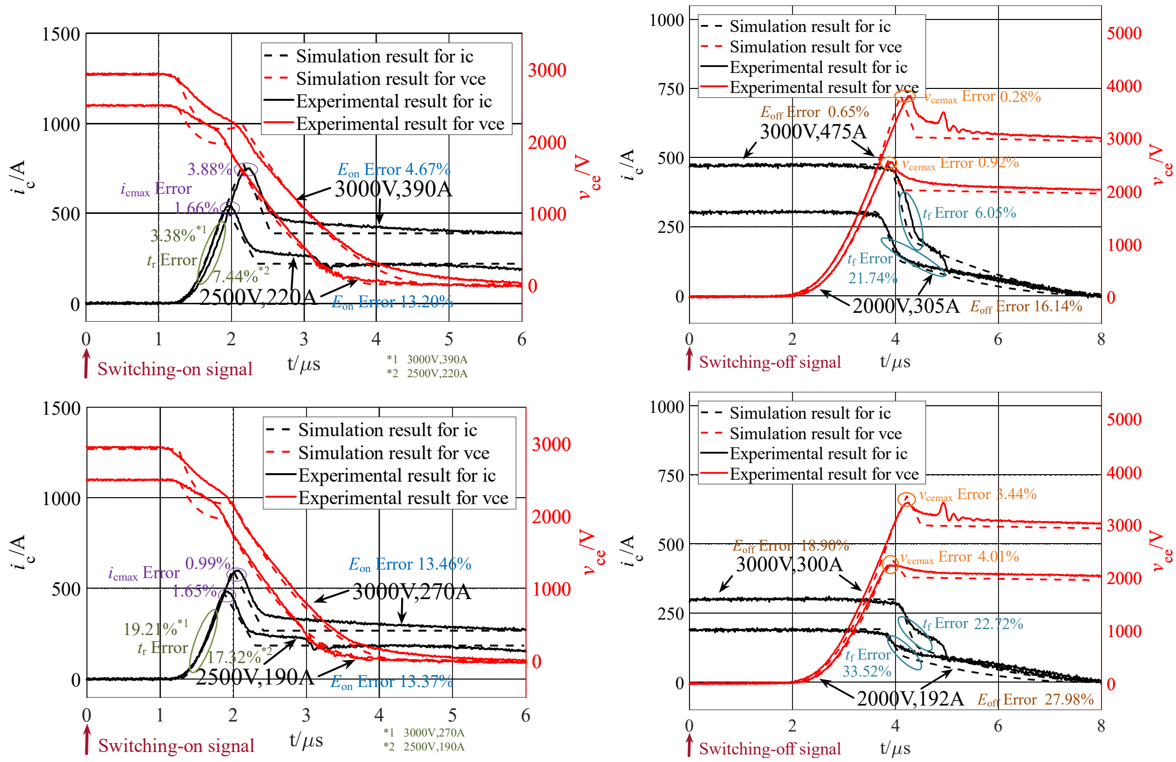
Simulated results comparisons of HVDC module 1 transformer current

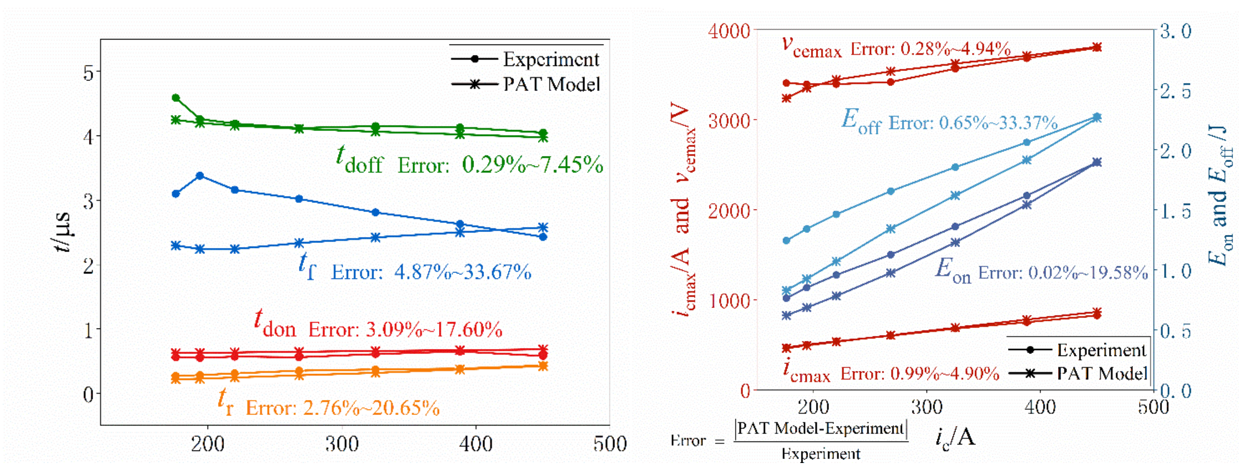
Tool	Configurations	Number of Calculated Points	Relative Error	CPU Time (s)
Software C	Variable-step method Max step-size 1e-3 Absolute tolerance 1e-4	196061	Grid-side Current: 1.3e-5 LVDC Transformer Current: 8.4e-5	22328 (6h 12min 8s)
DSIM	DSED method Max step-size 1e-3 Relative tolerance 1e-3	101874	Grid-side Current: 7.0e-6 LVDC Transformer Current: 4.7e-5	17.7

×1261

Example 4: Experimental Verifications of the Transient Model

This example shows the experimental verifications of the PAT model in DSIM. Double pulse tests are conducted on Infineon IGBT FZ600R65KF1 (6500V, 600A). Some experimental results are shown as below.





Generally PAT model gives good results compared with experimental waveforms, if the input parameters are accurate enough. Under some small-current conditions, the model error can be larger.