



中国南方电网
CHINA SOUTHERN POWER GRID

**Hardware-in-the-loop Test Bench for
flexible DC Distribution Network using RT-
LAB and EFPGASIM**

1. Context

With the development of power-electronic technology, micro-grids have been widely connected to distribution networks. The Flexible DC distribution network has recently brought great attentions to the power system industry in the world because of its lower construction and integration cost, reduced energy losses, as well as a higher reliability of power supply.

In order to make an intense study into flexible DC distribution technologies, Shenzhen Power Supply Bureau (of China Southern Power Grid), in associate with Tshinghua University and Zhejiang University, undertook the research work of “Key Technology of Flexible DC based Smart Distribution”. This project focused on the power quality problems of AC distribution networks in urban area introduced by the rapid development of distributed generations (DGs), and studied the application of VSC and flexible DC schemes to improve the power quality and provide customized power supplies to specific customers. In addition, the research also explored new applications in the flexible DC technologies, which allow to connect DGs and energy storages to the DC distribution networks, and directly feed the DC loads.

Keliang, the exclusive distributor of OPAL-RT in China, built a hardware-in-the-loop test platform with RT-LAB real-time simulator for control and protection systems of flexible DC distribution. This platform played an important role in this project and helped Shenzhen power supply bureau accomplish the first phase of simulation test of flexible DC distribution networks.

3. Challenge

In China, the technical research of operation control, power quality and steady-state, and fault analysis of DC distribution networks are mainly carried out with off-line simulation software. However, offline simulation software based research of flexible DC distribution protection system can neither simulate effectively the characteristics of protection system, nor anticipate possible problems existed in hardware implementation. Besides, it is inconvenient for testing the communication and coordination between controllers of different control levels or of different devices.

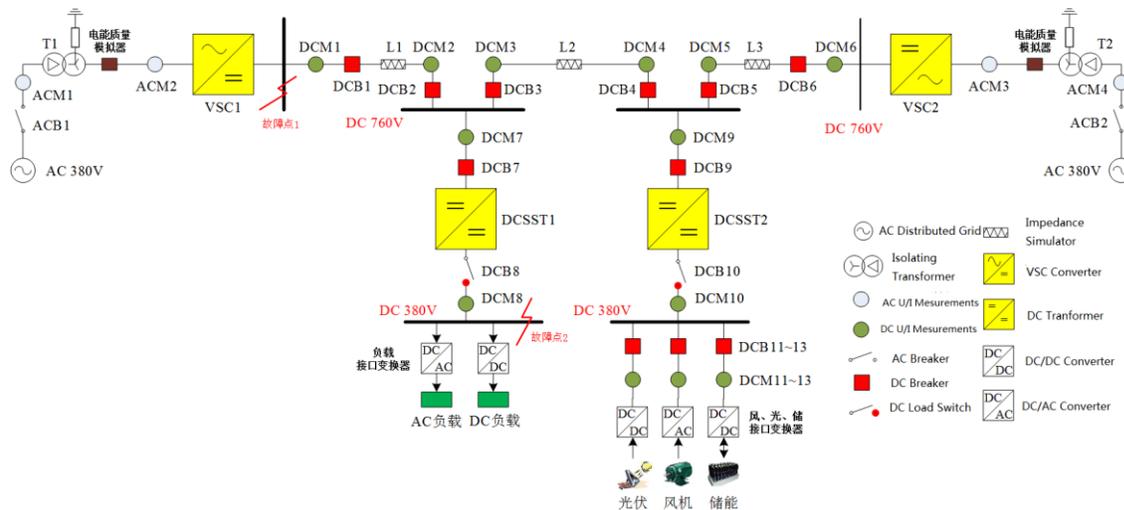
However, how to build an accurate and easy-to-use digital model to simulate the flexible DC distribution networks in real time, especially to accurately simulate MMC VSC (Voltage source converter) and High-frequency Solid state transformer, whose switching frequency is typically up to tens of KHz, remain technically challenging in the world.

First of all, the simulation time step has to be small enough to fully demonstrate the electromagnetic phenomenon; Secondly, the sampling resolution of switching signals should be as low as a few nanoseconds to accurately test the controller's performance. In addition, it must be possible to extend the power electronics model and connect with other power electronics devices or power grids to conduct system-level analysis. Finally, it should be easy for users to learn and do further development quickly.

4. Solution

To solve the problem, OPAL-RT developed the FPGA-based real-time model suite, eFPGAsim. Using the advanced eHS solver, eFPGAsim simulates the electric circuit using sub-microsecond time step. Users can build models completely using graphical-based tools, which are usually the off-line simulation software they used. The eHS can

parse the netlist of the circuit, and automatically construct the matrix to resolve the circuit on the FPGA without programming it. Furthermore, the eHS model can be seamlessly integrated with an RT-LAB simulator to perform multi-rate and multi-domain simulation, such as power electronics subsystems simulated with a time step below one microsecond connected to a power grids simulated at 20 to 50 microseconds.



With RT-LAB real-time simulation platform, Keliang accomplished the modeling for flexible DC distribution network system which includes power converters, distributed power sources, energy storage systems and AC/DC loads, and performed hardware-in-the-loop test for protection systems in responses to various faults of flexible distribution network in an AC network, or in the converters and the DC circuit, which validated the efficiency of the modeling for key equipment and the effectiveness of the protection strategy of DC distribution system.)

5. Results

Keliang provided technical support and engineering service throughout the whole project, and helped client unfold the research on the key technology and realize the development of key equipment for the control and protection of DC distribution system. With the seamless integration of RT-LAB real-time simulation system with protection devices, Shenzhen Power Supply Bureau has built the first HIL test platform based on typical four-terminal flexible DC distribution network in China, and studied thoroughly into typical structures, control and protection schemes, DC transformer and energy management strategies of flexible DC distribution system. This project has been accomplished with great success and was approved by the acceptance group of Ministry of Science and Technology of China.

The acceptance of this project pushed forward research on flexible DC distribution technologies in China, stimulated the development of the DC control & protection technology and the application of power electronic equipment in distributed networks, and provided useful references for the follow-up projects of real-time simulation for a seven-terminal DC distribution system.