

Real-Time Simulation and Research on Photovoltaic Power System based on RT-LAB

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Abstract: The maximum power point tracking (MPPT) controller in the Photovoltaic system is the key to verify all kinds of MPPT control algorithms. But the development of actual controller has the defects of needing long periods, artificial code writing and so on. RT-LAB real-time simulation platform is an advanced model-based engineering design and test application platform. The outstanding real-time performance in the current experimental study and engineering design made it used more and more widely. Therefore, it is necessary to introduce its hardware and software structure and real-time performance in detail. This paper gave a comprehensive and systematic introduction to hardware architecture, software architecture and simulation process of RT-LAB. It also presented a semi-physical simulation experiment of photovoltaic system MPPT using the features of Photovoltaic MPPT and semi-physical Real-Time simulation technology. The MPPT control strategy is achieved by establishing model using Simulink package. Other parts of the main circuit were physical circuit except controller. The parameter adjustment functions of online RT-LAB can easily optimize controller parameters. Two special tools, ARTEMIS and RT-Events used in power electronics were described in detail. The RT-LAB software modeling standard was also illustrated. The testing results showed that the usage of RT-LAB for the development of photovoltaic controller can resolve many problems in the current controller development. The application of RT-LAB in photovoltaic systems provides a reference for the micro grid, smart grid and other real-time systems.

Keywords: Photovoltaic generation, power electronics, RT-LAB, real-time simulation, the maximum power point tracking.

1. INTRODUCTION

It is the key point to realize the maximum power point tracking of Photovoltaic Power System [1-3]. Recently, research on MPPT control methods is carried out by MATLAB simulation software to verify the effectiveness of different methods. With the proposal of different kinds of MPPT methods, design and development of MPPT controller is needed. Total digital simulation can't certify controller's effectiveness of actual design, rapid control prototyping and hardware in the loop are also needed in actual controllers. Nowadays, physical simulation adopts digital signal processing, but it costs much time and energy. In this paper, digital-analog hybrid real-time simulation is carried out based on RT-LAB [4-6] developed by Opal-RT to make up these problems. As for RT-LAB, special technology on hardware and software architecture offers high accuracy, which can verify the superiority of the MPPT controller accurately. Also, RT-LAB has two special modules ARTEMIS and RTEVENTS which can be applied to power electronic modeling, its advanced solving technology and compensation technology offer more advantages.

In this paper, a kind of MPPT controller's designing method based on RT-LAB rapid control prototyping has been introduced. It has many advantages; firstly, it is

convenient online change controller parameter; secondly, different kinds of MPPT methods can be applied or be combined to get a better MPPT control effect, which is very flexible; thirdly, it belongs to real-time simulation, The simulation time scale is the same to clock time scale. The two system are synchronous; fourthly, the code of simulation algorithm can be generated automatically; fifthly, it costs little time and fund to design the controller with high controlling accuracy; at last, extreme conditions can be simulated.

2. SIMULATION IMPLEMENTATION OF RT-LAB REAL-TIME SIMULATION SYSTEM

2.1. Structural Characteristics of RT-LAB Real-Time Simulation System

RT-LAB is a set of test application platform based on modeling, which is developed by Canada's company named Opal-RT. Rapid control prototyping and hardware in the loop can be carried out by RT-LAB. It has a unique method to divide a complex model into many subsystems operating at the same time. Then these subsystems are distributed to many CPU nodes to compose a changeable distributed parallel real-time simulation system. System structure is shown in Fig. (1).

Target machine is equipped with a programmable FPGA; the frequency of digital I/O channel, pulse resolution is 10ns. In RT-LAB simulation platform, many pulse events can be

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got or generated in one simulation step, since it can offer high precision timing to the IGBT switch in the electric inverter. The simulation step can be $10\mu s$ by combining FPGA's events detecting function and unique real-time algorithm of RE-EVENTS.

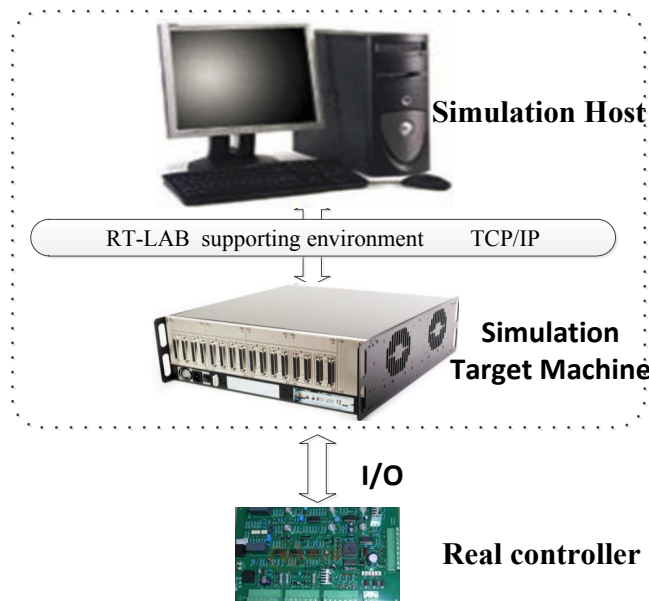


Fig. (1). Structure diagram of RT-LAB system.

2.2. Simulation Flow of RT-LAB Real-Time Simulation System

RT-LAB and Matlab/Simulink can realize seamless connection. In Matlab/Simulink environment, mathematical modeling of the simulation system should be carried out firstly with real-time transformation of the model; then segmentation, editing, compilation and code generation of the mathematical model is conducted; at last, the model is loaded to operate. Simulation Flow of RT-LAB Real-Time Simulation System is shown in Fig. (2).

RTEVENTS are equipped with timestamp. In simulation, these modules are used to replace the modules that can be effected by events. Then it can make up for the impacts caused by events. PWM signal generated by controller operating in RT-LAB has timestamp. It can control the changing of pulse accurately between two simulation steps. These signals will be output with the accuracy of $10\mu s$, which will cause little error to IGBT that can realize accurate control.

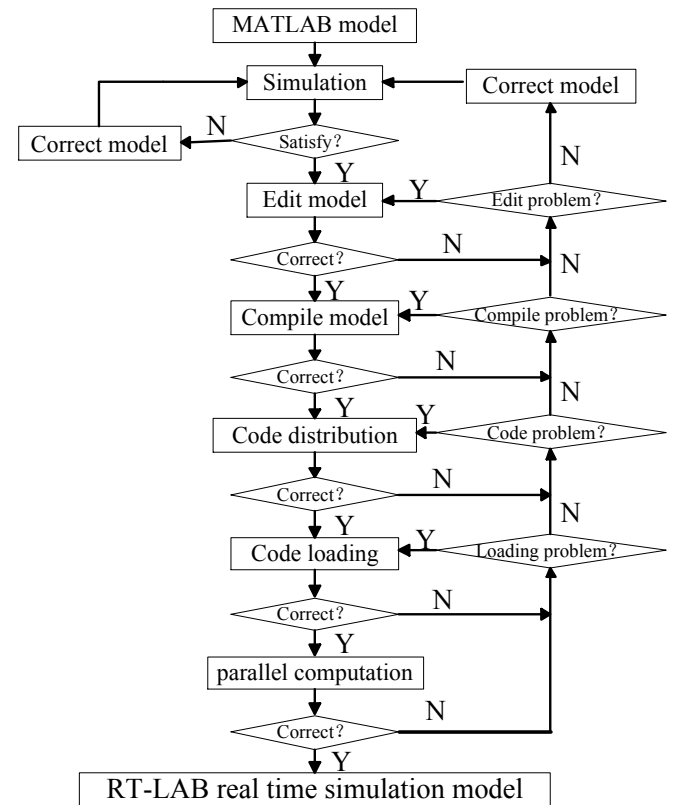


Fig. (2). Simulation flow of RT-LAB Real-Time simulation system.

3. MODELING AND TESTING SYSTEM OF PHOTOVOLTAIC GENERATION

3.1. Effect of RT-LAB in Photovoltaic Power System

The PWM signal is usually used to control the switching device IGBT in photovoltaic power system, the power output by circuit is controlled by pulse time and pulse width of the PWM signal. As for real-time simulation, the simulation step is fixed (simulation step of RT-LAB ranges from $10\mu s$ to $15\mu s$). The signal can be only treated in interval time, but actually common signal is generated between two simulation steps. The actual output signal should be delayed to the next time because of limited simulation steps, which is shown in Fig. (3). This will cause error of pulse width of PWM signal, which will lead to error of power, which is not allowed.

RT-LAB offers effective solutions for the problems:

3.1.1. RTEVENTS: Module Tool Equipped with Timestamp

The RTEVENTS toolbox of RT-LAB simulation system together with integrated circuit board FPGA can solve the problem that the pulse events can't find. All modules of

3.1.2. ARTEMIS: Real-time Decoding Tool

ARTEMIS offers supplement for SimPowerSystem toolbox, which uses a kind of new algorithm. When building model for power system using SimPowerSystem toolbox, the model of power system can be turned to real-time operation using ARTEMIS. This is because that the ARTEMIS solver can reduce the calculation time to the smallest when the switch is cut, which is in the same level with normal calculation. Then the real-time operation of ARTEMIS models can be realized. The characteristics of algorithm contains numerical solver with high stability, precomputation of circuit topology and parallel computing of system state equation. ARTEMIS power system can be used in many situations, such as power electronic topology, motor speed control new energy power generation and HVDC Transmission System.

3.2. Testing System Structure and Experiment Circuit

The hardware of RT-LAB real-time simulation [7-9] system consists of photovoltaic cell, boost circuit, RT-LAB simulation machine and simulation target machine, whereas

the software consists of Matlab/Simulink, RT-LAB main program, ARTEMIS toolbox and RTEVENTS toolbox. Structure diagram of the system is shown in Fig. (4). Schematic diagram of experiment circuit is shown in Fig. (5).

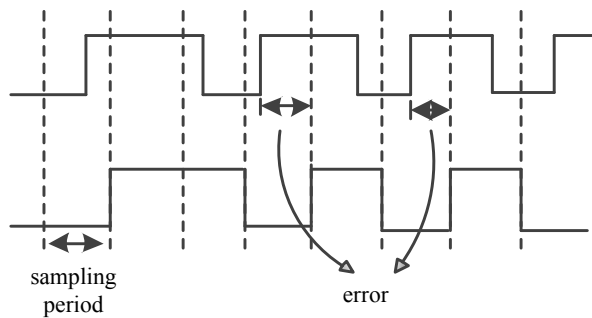


Fig. (3). Error of PWM signal catching.

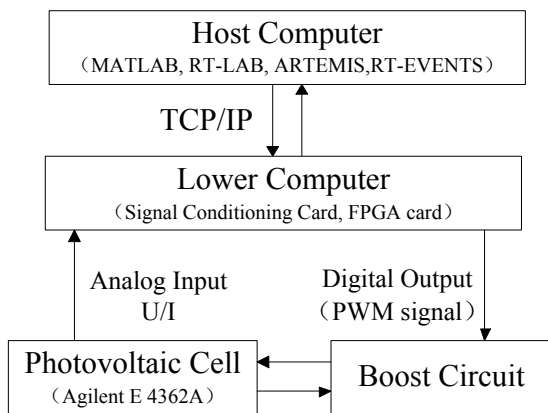


Fig. (4). Structure diagram of the system.

In this experiment DC/DC circuit applies Boost circuit [10-12] to realize MPPT. During simulation MPPT controller is realized by RT-LAB, while others are realized by actual hardware. Voltage and current signals of photovoltaic cell is collected and sent to RT-LAB real-time simulator after treatment. MPPT control algorithm is realized by modeling in RT-LAB. PWM signal is output by OP5312 of RT-LAB. Schematic diagram of experiment circuit is shown in Fig. (5), where I is current of photovoltaic cell, U+ and U- are two sides of photovoltaic cell, U and I are collected voltage and current signals respectively.

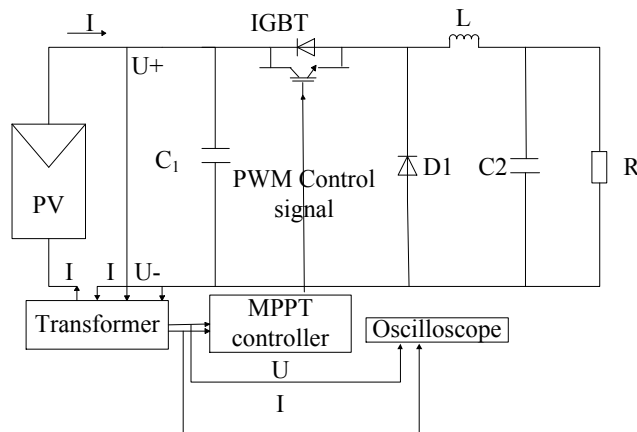


Fig. (5). Schematic diagram of experimental circuit.

Performance index of main components of the circuit is shown in Table 1.

In the experiment, index model of I-U curve is applied, equation of index model is shown as below:

$$U = \frac{U_{OC} \ln(2 - (I / I_{SC})^N) - R_S(I - I_{SC})}{\ln(2) + \frac{R_S I_{SC}}{U_{OC}}} \quad (1)$$

$$R_S = \frac{U_{OC} - U_{MP}}{I_{MP}} \quad (2)$$

$$a = \frac{U_{MP}(1 + \frac{R_S I_{SC}}{U_{OC}}) + R_S(I_{MP} - I_{SC})}{U_{OC}} \quad (3)$$

$$N = \frac{\ln(2 - 2^a)}{\ln(\frac{I_{MP}}{I_{SC}})} \quad (4)$$

In the formula, U_{OC} is open circuit voltage of photovoltaic cell, I_{SC} is short circuit current of photovoltaic cell, R_S is series resistance of the cell, U_{MP} is voltage of the maximum power point, I_{MP} is current of the maximum power point, a and N are coefficients of the cell. $I_{scref} = I_{sc} \frac{S_{ref}}{S} (1 + \alpha \Delta T)$

3.3. Modeling of Simulation Software and Testing Program

3.3.1. Modeling Standard of RT-LAB

The model put up by Simulink should be encapsulated from the apex, the naming of RT-LAB should use SC, SM and SS to ensure the functions of different parts [13-15]. SC subsystem carries out real-time monitoring and data communication of key parameters and curve in the simulation system, the program consists of basic module to collect and display data. SM subsystem takes charge of real-time calculation and network synchronization. SS subsystem is usually part of system model taking part in simulation. Divided model consists of one SC subsystem, a few SS subsystems and one SM subsystem. SC subsystem doesn't have calculation parts, it just has an oscilloscope, a switch and a logic selection. When the computational complexity of SM subsystem is too big, *i.e.* it can't complete all calculation in one step, some of the calculation can be given to SS subsystem [16-18].

Opcomm synchronous communication module is an important part of simulation. All signals must go through the Opcomm module before going to subsystem on the top.

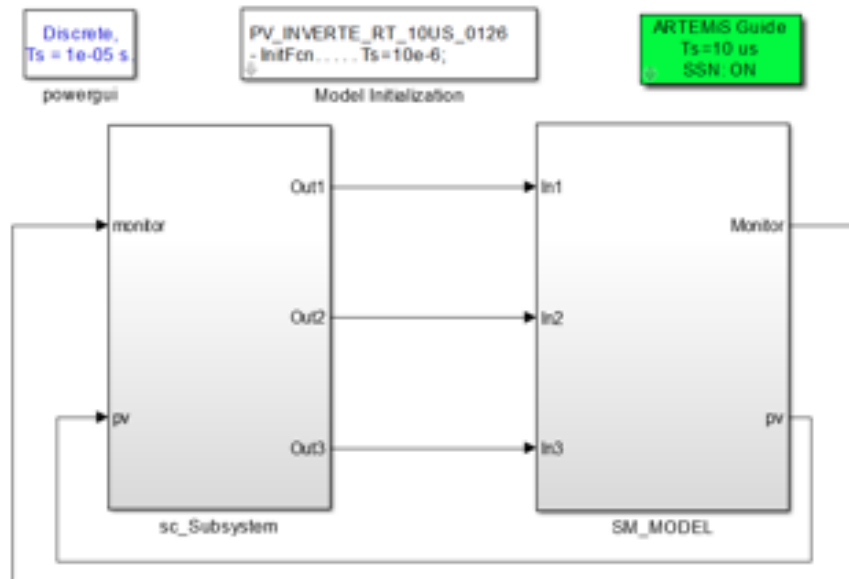
3.3.2. Testing Program

Testing main program is shown in Fig. (6). Simulation step is $10\mu s$.

SM subsystem is shown in Fig. (7). It aims at completing the simulation calculation and synchronous communication of MPPT. In the experiment a kind of improved conductance

Table 1. Performance index of main components of the circuit.

Component	Main index
Photovoltaic cell	maximum power is 512W, short circuit current is 8.6A, open circuit voltage is 68V
Target machine	U11-0021HILBOX, Inter quad core2.4 GHz, 2GRAM.QNX6.3.2 real-time operating system
Host computer	RT-LAB main program, RTEVENT and ATEMIS toolbox
IGBT	maximum reverse voltage is 1200V, maximum current is 100A, maximum switching frequency is 20kHz
Load resistance	The range of resistance id 0-100 Ω , chosen as 60 Ω

**Fig. (6).** Schematic diagram of experiment circuit.

increment method is applied. Modules which are easily affected by events are changed to RTEVENTS modules. PWM signal is output accurately. OP5110-5120 Digital Out is the digital output module of RT-LAB [19, 20], which can realize the output of PWM signal. OP5110-5120 Analog In is the analog input module, which can realize input of voltage and current of photovoltaic cell. OP5110-5120 Op-sync is the synchronous drive module combined with FPGA.

SC subsystem is shown in Fig. (8), which can realize display of voltage, current, power and system information of photovoltaic cell. Only one Opcomm module is needed, because the sampling rate of the four signals is the same.

3.4. Testing Results

Testing real-time simulation waveform is shown in Figs. (9, 10).

In Fig. (9), the cell temperature is 25°C, intensity of illumination changes from 1000W/m² to 200W/m² and then it goes back to 1000W/m², and real-time simulation waveform changes in different time quantum as below:

(1) During t1-t2, the system operates stably at the intensity of illumination 1000 W/m². Stable PWM signal is sent from RT-LAB to MPPT controller. The system operates at the maximum power point.

- (2) During t2-t3, intensity of illumination changes from 1000W/m² to 200W/m². During t3-t4, the system operates at the maximum power point of 200W/m² stably.
- (3) During t4-t5, intensity of illumination changes from 200W/m² to 1000W/m². During t5-t6, the system operates at the maximum power point of 1000W/m² stably.

By analyzing the changing process and waveforms, we can find that the effect of controller can reach the goal with the parameter adjustment functions of online RT-LAB. The control effect is the same as actual theoretical analysis, which is convenient and accurate.

In Fig. (10), intensity of illumination is 1000W/m², the cell temperature changes from 50°C to 15°C, and then it goes back to 50°C. Voltage and current waveforms are shown in this figure. Analysis of the changing process is similar to Fig. (8). Little oscillation can be found in the waveforms, and controller parameter has been optimized to the greatest degree.

From Figs. (9, 10), we can find that RT-LAB can be applied as MPPT controller to verify characteristics of

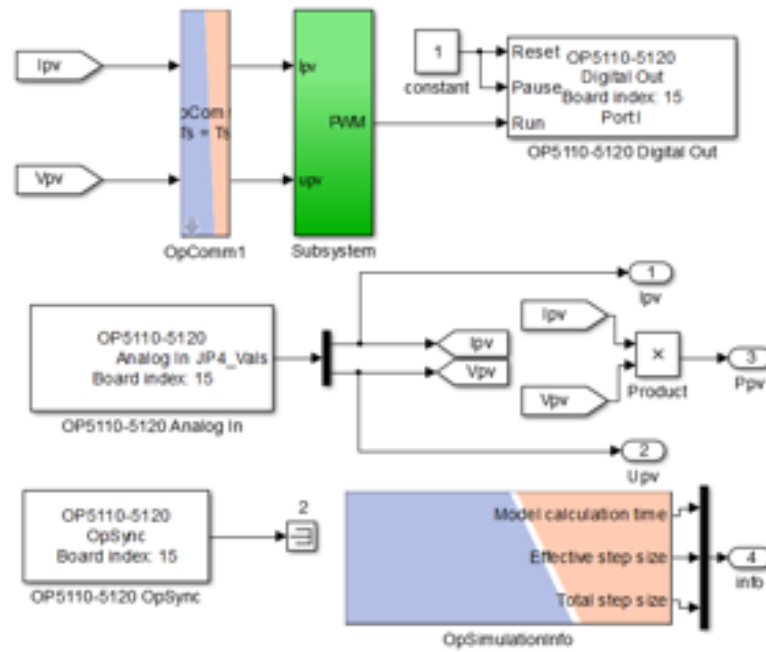


Fig. (7). Simulation diagram of SM subsystem.

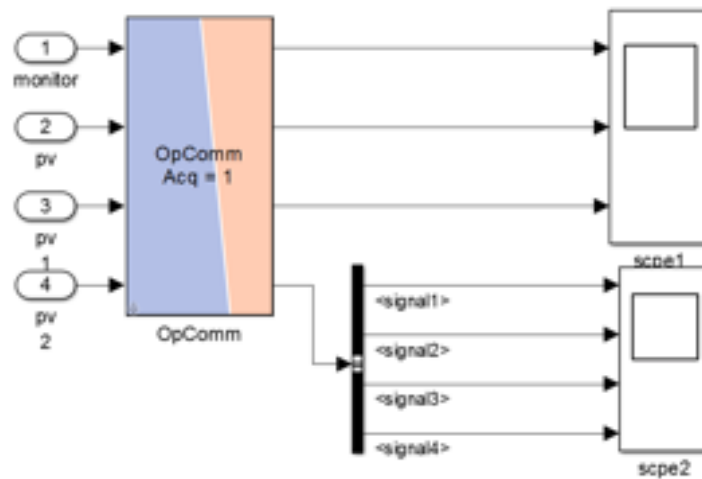


Fig. (8). Simulation diagram of SC subsystem.

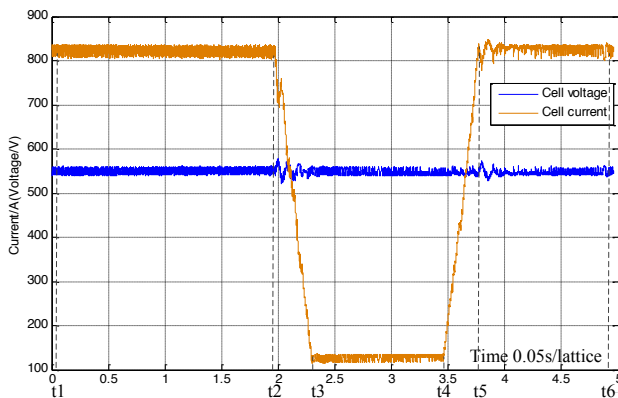


Fig. (9). Simulation waveform of changing intensity of illumination.

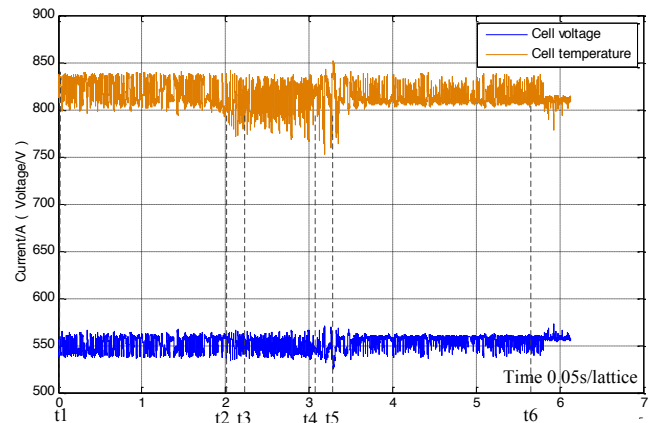


Fig. (10). Simulation waveform of changing cell temperature.

MPPT algorithm. When the intensity of illumination and the cell temperature change, the system can operate at the maximum power point quickly and accurately with optimized controller parameters, which will meet the demands of rapidity and accuracy, and it is fundamental to verify and optimize the control algorithm.

CONCLUSION

- (1) In this paper the advanced real-time simulation system RT-LAB is introduced in detail, including hardware structure, flow of simulation implementation and rules of software modeling. Two special modules, ARTEMIS and RTEVENTS applied to power electronics are introduced.
- (2) Seamless connection between real-time simulation system RT-LAB and MATLAB/Simulink can be realized. MPPT control strategy of photovoltaic system can be modeled together with Simulink, ARTEMIS and RTEVENTS, which is significant to verification of MPPT control algorithm. It can solve the problem that simulation waveform is accurate while the actual hardware has much errors. Furthermore, the code of simulation can be generated automatically, which can reduce the development cycle of controller.
- (3) In this paper, RT-LAB is applied to photovoltaic power system firstly, which can offer some reference for the field of new energy even for the micro grid. These fields commend high real-time performance, which can get reference in this paper. Further study remains to be carried out for the application of RT-LAB in complex power systems.

CONFLICT OF INTEREST

The authors confirm that this article content has no conflict of interest.

ACKNOWLEDGEMENTS

This work was financially supported by the Natural Science Foundation of Jiangsu Province (BK20130742), the Nanjing Institute of Technology Fund (YKJ201107).

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