A Study on Micro-Grid Power Quality Management and Simulation Based on RTW Toolkit

Zhiqiang Gao, Zhongji Sun, Liang Meng, Xiao Yang, Lingming Meng and Peng Luo

Abstract For improving micro-grid power quality, this paper elaborates a method of using energy storage system to stabilize power and active power filter (APF) to govern harmonic. The control principle of energy storage system and APF is introduced, and the simulation model of the micro-grid is established, which can generate C code automatically through MATLAB real-time code generation tool RTW (Real-Time Workshop). The code is applied to the running real micro-grid system. By comparing APF simulation results and actual running results, the effectiveness and practicability of the simulation based on RTW were verified. At the same time, it shows that the application of APF has a positive role in micro-grid power quality improvement.

Keywords Micro-grid · Power quality · Battery · Active power filter (APF) · Real-time workshop (RTW)

1 Introduction

Micro-grid is increasingly attended in society as an effective means to achieve the diversification of new energy utilization. For a mature micro-grid, the good power quality is one of its essential characteristics [1]. However, due to the volatility of distributed power factor and a large number of power electronics devices, micro-grid power quality issues cannot be ignored [2]. For power fluctuations and harmonic pollution, the energy storage system and APF are, respectively, used to stabilize

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power fluctuations and to compensate harmonic. Simulation in MATLAB can verify compensation effect and provide help for the improvement of control strategy.

In order to carry out the further research, establishing accurate simulation system is an urgent demand of the study technology. In order to build a more accurate model, we use the RTW digital simulation tool as the actual system control system uses a digital control system. The RTW tool generates real-time C code based on the micro-grid simulation model which can be applied to the actual system control. This method not only avoids the tedious process of hand-written programs, but also ensures the accuracy and efficiency of the program code, and achieves the organic combination of simulation and real control system [3–5].

2 Structure of the Micro-Grid

The micro-grid studied in this paper, shown in Fig. 1, consists of photovoltaic cells, an energy storage system, an active power filter (APF), inverters, loads, and other means. Among them, the energy storage system is a hybrid energy storage system which is composed of a battery and super capacitor. As an energy storage device with high energy density, the battery can achieve a large-capacity storage, but is not suitable for frequent charging and discharging. On the other hand, the super capacitor, as power-type energy storage device, has a high power density, long cycle life, charging time is short, high reliability, and low energy density characteristics. According to these characteristics, the energy storage system combined by the two devices has complementary advantages, which can stabilize power in micro-grid comprising intermittent power supply. The APF can compensate harmonics and reactive power in micro-grid. Both of the energy storage system and the APF is used to ensure higher power quality in micro-grid. The breaker K is used to make the micro-grid run in grid operation or island operation.

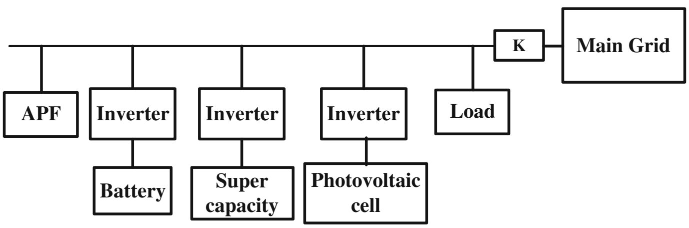

Fig. 1 The micro-grid system

3 Control Principle of the Energy Storage System

Micro-grid has flexible modes of operation, it can work in grid operation and in island operation. In different modes of operation, the control principle of the energy storage system is different.

3.1 Control Theory of Grid Operation

The voltage and frequency is guaranteed by the grid when it operates in the grid-connected mode. Both of the batteries and the super capacitors are controlled with PI double loop control strategy which is composed by outer loop power control and inner current control, as shown in Fig. 2.

As shown in Fig. 2, the AC bus voltage (*u*) and current (*i*) of the outlet of the inverter are collected. Via the Park transformation (as formula 1), they are divided into the direct-axis component and the quadrature-axis component respectively. Then active component (P) is obtained by multiplying the voltage direct-axis component and the current direct-axis component. In the same way, we can get reactive component (Q) by the calculation of the quadrature-axis component of voltage and current. By calculating the difference between the measured value and the set value, $i_{\_ref}$ which is the setpoint of inner current control is got after the adjustment of PI link and Park inverse transformation. In the inner current control, i calculated by $i_{\_ref}$ minus i is put into PWM generator to control the inverter bridge after filtering, clipping, and other links.

$$P = \frac{2}{3}\begin{bmatrix} \cos\theta & \cos(\theta - 120^\circ) & \cos(\theta + 120^\circ) \\ -\sin\theta & -\sin(\theta - 120^\circ) & -\sin(\theta + 120^\circ) \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \end{bmatrix} \quad (1)$$

3.2 Control Theory of Island Operation

The voltage and frequency of the micro-grid need to be supplied by the energy storage device, so the control method is different from the grid operation mode. In

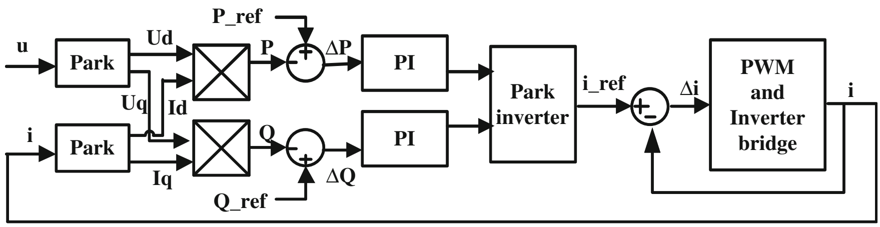

Fig. 2 Principle of power−current control

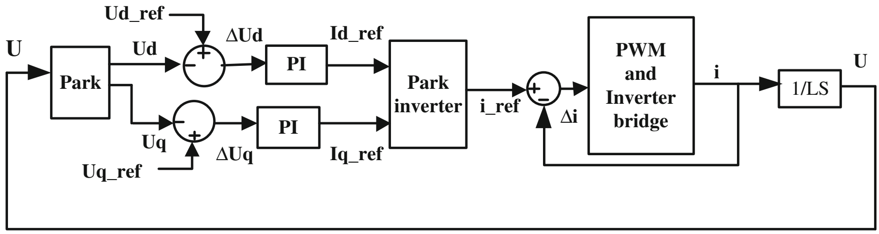

Fig. 3 Principle of voltage−current control

this paper, the voltage and frequency support are provided by the battery which is controlled by outer loop voltage control and inner current control. Then the super capacitors are still controlled by outer loop power control and inner current control.

The U-I double loop control strategy of the battery is shown in Fig. 3. The AC output voltage of the inverter is decomposed into U_d and U_q after the Park transform. Compare U_d and U_{d_ref} which is the set value and input the difference into the PI link, then the output is i_{d_ref}. In the same way, i_{q_ref} can be calculated. Through the calculation of the Park inverse transformation, i_{d_ref} and i_{q_ref} are transformed into $i_{\_ref}$ which is the setpoint of inner current control. Then achieve the control of the battery after the current loop control.

4 Control Principle of the APF

The control strategy of APF is designed to compensate the harmonic according to different harmonic orders. For example, to compensate the fifth harmonic, the APF is controlled to output the reverse fifth current waves until the fifth harmonic is disappear. For any other orders of harmonic, add the input to the control loop can do it. The control diagram is shown in Fig. 4.

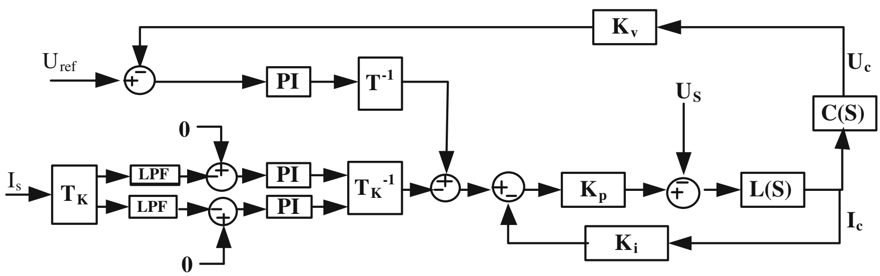

Fig. 4 Principle of APF control

I_s is the high-order harmonic current, it can be decomposed into direct-axis component I_{s_d} and quadrature-axis component I_{s_q} through conversion matrix T_K and low pass filter (LPF). Let set value (0) minus I_{s_d} and I_{s_q}, respectively, and input the answers to the PI link, then the harmonic current signal is got after inverse conversion matrix T_K^{-1}. After proportion and integral control link, this signal controls APF to output compensation current. The function of the voltage control loop is to stabilize the fundamental voltage.

$$T_K = \frac{2}{3}\cdot\begin{bmatrix} \cos(k\omega\cdot t) & \cos\left(k\omega\cdot t-\frac{2}{3}k\pi\right) & \cos\left(k\omega\cdot t+\frac{2}{3}k\pi\right) \\ -\sin(k\omega\cdot t) & -\sin\left(k\omega\cdot t-\frac{2}{3}k\pi\right) & -\sin\left(k\omega\cdot t+\frac{2}{3}k\pi\right) \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \end{bmatrix} \quad (2)$$

$$T_K^{-1} = \begin{bmatrix} \cos(k\omega\cdot t) & -\sin(k\omega\cdot t) & 1 \\ \cos\left(k\omega\cdot t-\frac{2}{3}k\pi\right) & -\sin\left(k\omega\cdot t-\frac{2}{3}k\pi\right) & 1 \\ \cos\left(k\omega\cdot t+\frac{2}{3}k\pi\right) & -\sin\left(k\omega\cdot t+\frac{2}{3}k\pi\right) & 1 \end{bmatrix} \quad (3)$$

5 Establishment and Analysis of Simulation

According to the control theory, a micro-grid working in island mode of operation, as an example, was established in MATLAB/Simulink environment which is shown in Fig. 4. In this model, the Pv module consists of photovoltaic cells and inverter, the battery module is a combination module which contains battery and inverter, the EDLC module is a combination of super capacitors and inverter, the APF module is active power filter and the load module is loads of the micro-grid. Design simulation parameters are as follows: micro-grid bus voltage of 100 V, battery and super capacitor DC voltage are both 700 V, super capacitor rated power 50 W, PV power 20 W, and parameters of loads depend on the specific set of simulations.

In addition, the simulation model can be compiled by using RTW into executable C language code which can be accessed directly downloaded to the target

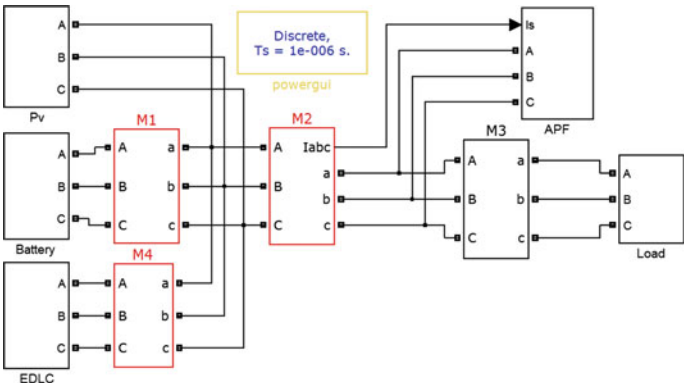

Fig. 5 Simulation model of micro-grid system

machine and run in the actual system. It is of great meaning which will integrate the control system simulation and practical system to achieve real-time semi-physical simulation [4–7] (Fig. 5).

5.1 Simulation of Load Mutation

The value of phase resistance of the load which is connected in triangle connection mode is 40 Ω. Run this simulation and test voltage dynamic characteristics of the main inverter in AC side. In order to observe the dynamic process, this article will invert direct-axis voltage through the DA per unit of output (at 100 V line voltage direct-axis voltage DA output by 1 V). The load capacity is mutated In 0.304 s, Figs. 6 and 7 show the simulation result.

In summary, when the load increasing suddenly, the main inverter output voltage has dropped, but the energy storage system control strategy can achieve power

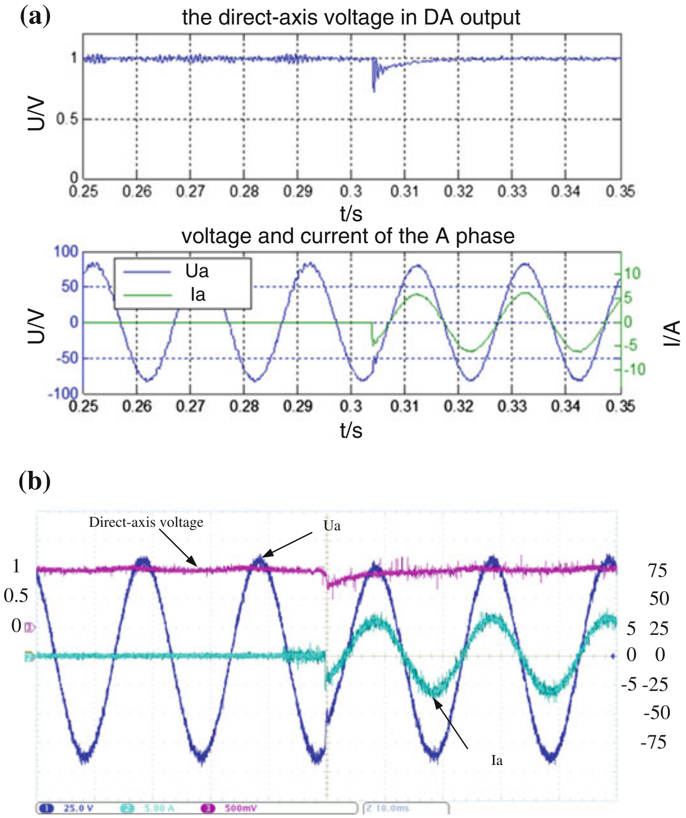

Fig. 6 Simulation datas of increasing load **a** Simulation curves of increasing load (b) Collected curves of increasing load in system

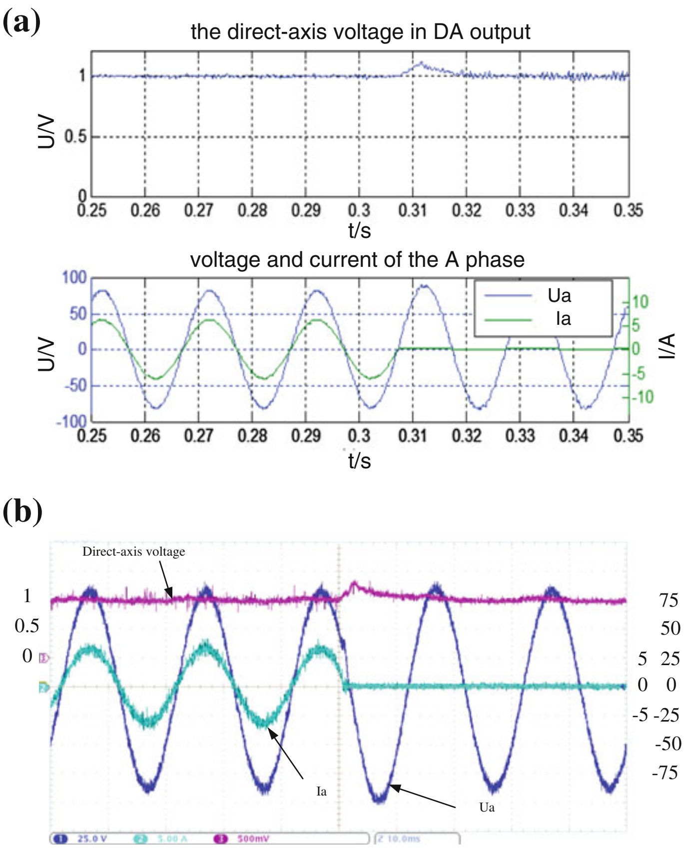

Fig. 7 Simulation datas of reduce load **a** Simulation curves of reduce load **b** Collected curves of reduce load in system

tracking adjustment, the voltage returns to normal in about 0.01 s; when load reduction, the direct-axis voltage sudden rise can be dropped to normalcy in 0.01 s in a very short time. In addition, the simulation is highly consistent with the experimental results, proving the accuracy and practicality of RTW toolkit directly.

5.2 Simulation of Harmonic Compensation

The loads consist of the rectifier and DC load, a DC load RL series impedance, where R is 40 Ω and L is 0.66 mH. To compensate the five-order harmonic and the seven-order harmonic current, for example, simulate the APF harmonic current compensation effect in micro-grid. According to the control principle of the APF, the simulation model shown in Fig. 8, where “5 modules” and “7 modules” are the five-order harmonic and the seven-order harmonic current calculation module.

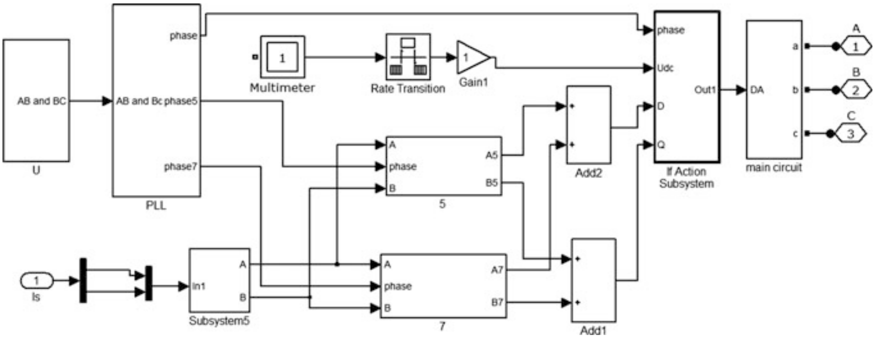

Fig. 8 Simulation model of APF

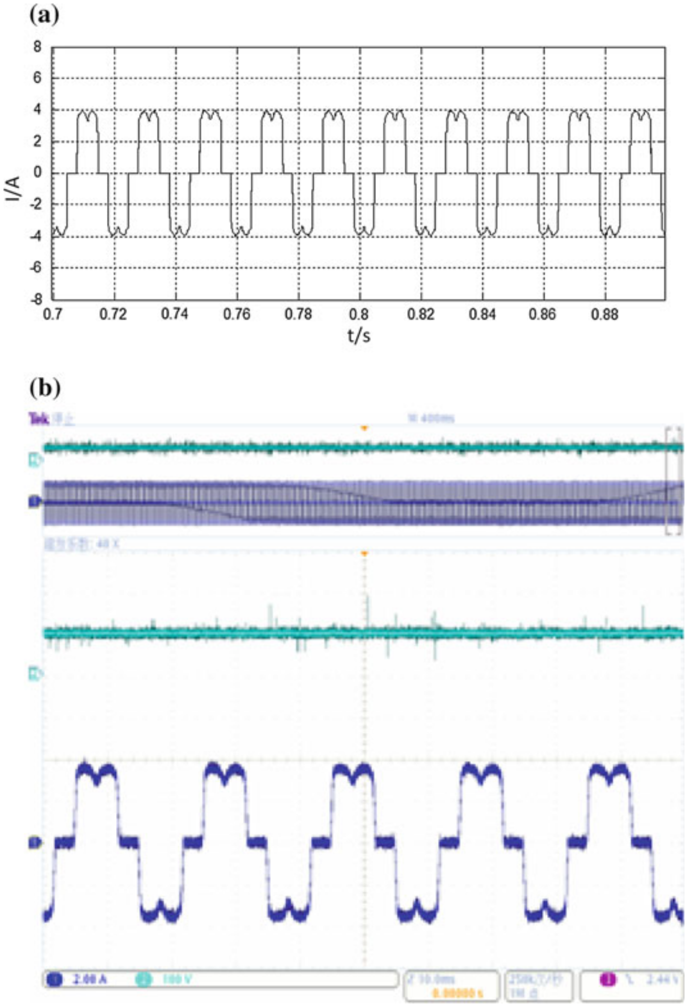

Fig. 9 Simulation without APF compensation **a** Simulation curves without APF compensation **b** Collected curves without APF in system

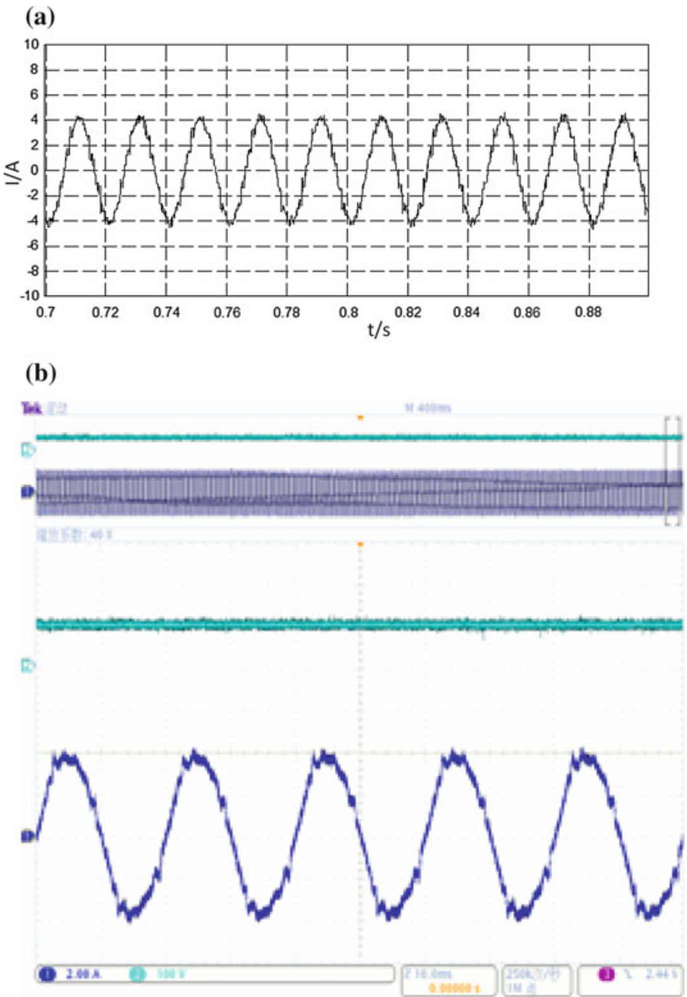

Fig. 10 Simulation with APF compensation **a** Simulation curves with APF compensation **b** Collected curves with APF in system

Table 1 FFT analysis of actual test in micro-grid

	Five-order harmonic (%)	Seven-order harmonic (%)
Without APF	21.56	18.02
With APF	0.23	0.03

Figures 9 and 10 show the simulation current waveform. Visibly, the non-sinusoidal grid current becomes a sine wave after the APF compensation. FFT analysis data of the current waveform is shown in Table 1, the five-order harmonic and the seven-order harmonic wave components are close to zero. In a word, the simulation shows the accuracy of the APF control strategy. Comparing the simulation waveforms and waveforms measured in practical micro-grid, the results are almost identical, proving once again the accuracy and usefulness of RTW toolbox.

6 Conclusion

As an essential part of the promotion micro-grid, the energy storage system plays a crucial role in promoting power quality. The multiple energy storage device used in this paper which consists of batteries and super capacitors can enhance the micro-grid dynamic performance, keep the system power being balance in the load mutation and maintain the normal operation of bus voltage stability. The analysis and simulation verify that the control strategy is effective and practical. Then harmonic pollution is a major threat to the micro-grid power quality, the active power filter (APF) described in this paper can compensate harmonic current effectively and stably which improves the micro-grid power quality. At last, the Real-Time Workshop (RTW) simulation can be achieved in practice micro-grid, which is easy to use, and avoids the manual code written and improves efficiency. It provides feasible and effective research methods for the future micro-grid simulation study.

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