SIMULATION OF AN ACCELERATOR PULSE POWER SUPPLY WITH AN ACTIVE RECTIFIER USING SIMPLORER

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Abstract

In this paper, a simulation model of an accelerator pulse power supply with an active rectifier (voltage-type SVPWM rectifier) was set up based on the C-Model function in SIMPLORER 8.1, which is a simulation software belonging to the ANSOFT corporation. We introduce a SVPWM rectifier into an accelerator pulse power supply to solve its problems such as low input power factor, a large number of AC current harmonics and instable DC bus voltage due to the diode or thyristor rectifier used in it now. Components of control strategies developed in C language were built up and inserted into the simulation project. The simulation results indicate that an accelerator pulse power supply with a SVPWM rectifier can solve the problems above well. For all the control strategies were developed in C language, they can be transplanted into the digital signal processor (DSP) nearly without change for the prototype controlling. So it provides a basis for development of the experimental prototype.

INTRODUCTION

SIMPLORER is an intuitive, multi-domain, multi-technology simulation program, which enables engineers to simulate complex power electronic and electrically controlled systems. Within SIMPLORER, engineers can analyze all aspects of large-scale systems, from detailed component analysis to system performance. Multiple system-based modeling techniques (circuits, block diagrams, state machines, equation level) and modeling languages (VHDL-AMS, C/C++, SIMPLORER Modeling Language) are integrated in SIMPLORER. All of them can be used in a simulation project concurrently, which makes SIMPLORER an ideal systems modeling tool [1].

We have used SIMPLORER in the early stages of design and optimization for several years. It allows us to identify problems before the prototype being built up, and the parameters from SIMPLORER are basically close to the actual ones. In recent years, many new technologies were used in accelerator power supplies to improve their performance, which make the simulation models of them become more and more complex. Together with the application of digital chips in accelerator power supplies, we need to build up our own simulation components with modeling languages (particularly C language) in SIMPLORER for reducing the simulation mass and prototype development cycle.

Heavy Ion Research Facility in Lanzhou-Cooler Storage Ring (HIRFL-CSR) is the first dedicated heavy ion synchrotron facility in China [2]. Such a big synchrotron needs a lot of switching pulse power supplies to provide high precision and low ripple current for magnet loads. The AC/DC parts used now in the pulse power supply are usually diode/thyristor rectifiers, they inject a large number of reactive power and AC current harmonics into the grid and can't keep a stable DC bus voltage due to the energy from the inductance load during the current falling section of the output waveform. A SVPWM rectifier can be a good solution to these problems [3].

Therefore, a simulation model of an accelerator pulse power supply with a voltage-type SVPWM rectifier was set up in SIMPLORER to prove its good performance at improving the input power factor, reducing AC current harmonics and keeping a stable DC bus voltage. Due to the advantages of C language such as high flexibility, high efficiency and good transportability, we selected C-Model editor to develop our own components.

SIMULATION MODEL DESIGN

The topology of an accelerator pulse power supply with a SVPWM rectifier is shown in Fig. 1. It is made up of a SVPWM rectifier and a four-quadrant H-bridge. The simulation model will be set up according to this topology in SIMPORER [3].
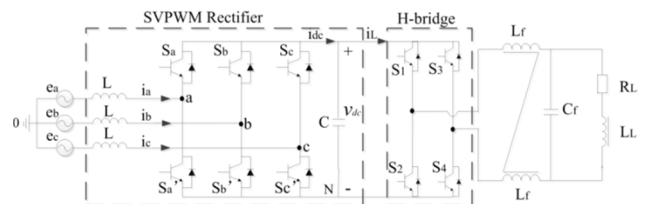

Figure 1: Topology of an accelerator pulse power supply with a SVPWM rectifier.

Control Strategy

To the SVPWM rectifier, we applied Kirchhoff's law of voltage and current at Fig. 1, Equation (1) can be easily got.

$$\begin{cases} \vec{V}_L = L\dfrac{d\vec{I}}{dt} = \vec{E} - \vec{V} \\ C\dfrac{dv_{dc}}{dt} = \vec{I}\vec{S}^T - i_L \end{cases} \tag{1}$$

Here, $\vec{E}$ is grid side voltage vector; $\vec{I}$ is grid side current vector; $\vec{V}_L$ is inductance voltage vector; $\vec{V}$ is AC side voltage vector of the SVPWM rectifier; $\vec{S}$ is switch state vector.

Then, we can get a vector relationship of the SVPWM rectifier at AC side (Fig. 2).
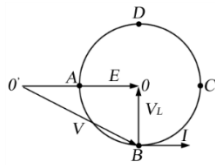
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Figure 2: Vector relationship of the SVPWM rectifier at AC side

When the SVPWM rectifier works at point B and D, the power supply get a unit power factor (B means rectifying with unit power factor, D means inverting with unit power factor). We can control the inductance voltage vector $\vec{V}_L$ by controlling AC side voltage $\vec{V}$, and then $\vec{I}$ can be controlled.

AC side voltage vector $\vec{V}$ can be got from the voltage and current dual closed loop controlled strategy in d-q coordinate system as equation (2) shows: [4, 5]

$$\begin{cases} i_d^* = (K_{vP} + \dfrac{K_{vI}}{s})(v_{dc}^* - v_{dc}) \\ i_q^* = 0 \\ v_d = -(K_{iP} + \dfrac{K_{iI}}{s})(i_d^* - i_d) + \omega L i_q + e_d \\ v_q = -(K_{iP} + \dfrac{K_{iI}}{s})(i_q^* - i_q) - \omega L i_d + e_q \end{cases} \quad (2)$$

Then, we can decomposed AC side voltage vector $\vec{V}$ in the space vector formed by 8 states of the switch state vector $\vec{S} = [s_a, s_b, s_c]$, which is show in Fig. 3[3].
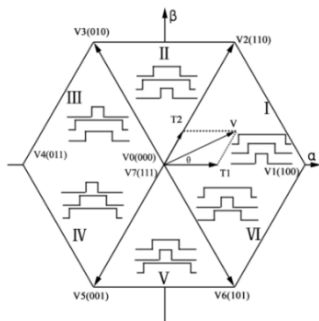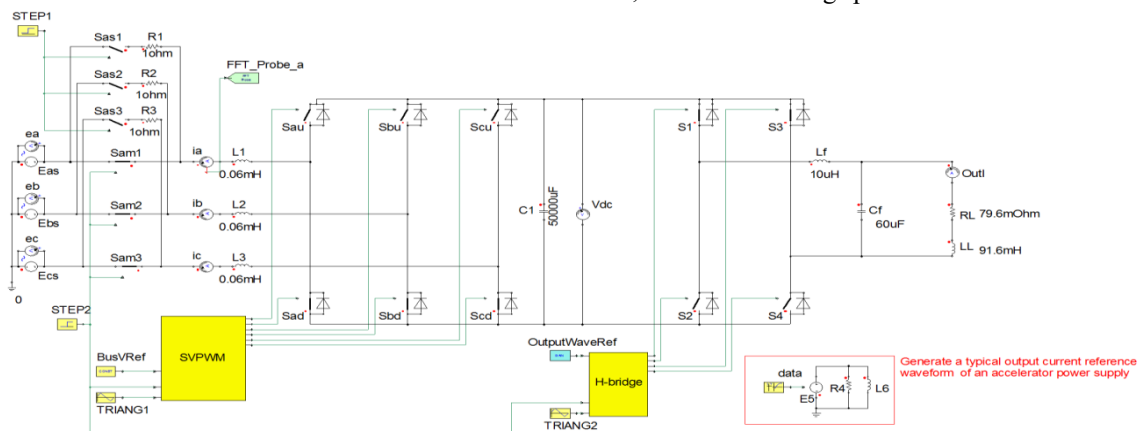

Figure 3: Vector decomposition of AC terminal voltage.

A PI regulator is used to control the duty ratio of the H-bridge, which will be used to generate its turn-on time.

Simulation Model

A simulation model was setup in SIMPLORER 8.1 (Fig. 4). The 'SVPWM' and 'H-bridge' components were developed in C language base on C-Model function in it. The steps of building up a 'SVPWM' component are as follows:

Firstly, we turn on the SIMPLORER and select the 'Tools>Edit Configured Libraries>Models' option on the menu bar. Then the 'Edit Libraries' dialog appears. We click the 'Add Model' button, and we can new a C-Model named 'SVPWM' in the 'Add Model' dialog, three files are generated as: 'SVPWM.cpp', 'SVPWM_define.h' and 'SVPWM_Interface.cpp'.

Secondly, we don't change 'SVPWM_define.h' and 'SVPWM_Interface.cpp' usually, but insert our control strategies into the 'SVPWM.cpp' in C/C++ language. There are five functions in the 'SVPWM.cpp'. We used the inner function 'AddNode_nc' to add input/output nodes and the inner function 'AddNode_State' to set their attributes in the function 'Prepare_SVPWM'; and we developed the control algorithm in C language in the function 'Simulate_SVPWM_TR' [6].

Thirdly, we select 'C Model Editor>Check Syntax' and 'C Model Editor>Update Project' options on the menu bar, a component named 'SVPWM' is generated in 'Definitions>Components' in the project manager. Then we edit the symbol named 'SVPWM' in 'Definitions>Symbols' and add input/output pins on it.

Finally, the 'SVPWM' C-Model component can be inserted into the whole simulation model in Fig. 4.

SIMULATION RESULTS

We set the RMS value of phase voltage as $E_{as}=E_{bs}=E_{cs}=38.9V$ and the DC bus voltage reference as $BusVRef=120V$ in Fig. 4. A output current reference waveform of an accelerator pulse power supply with 50A's bottom and 700A's top is generated by the circuit in the red rectangle box (Fig. 4) for 'OutputWaveRef'. In order to observe the apparent energy feedback phenomenon, the current falling speed is set to -1400A/s.

Figure 4: Simulation model of an accelerator pulse power supply with a SVPWM rectifier in SIMPLORER.

The simulation results of an accelerator pulse power supply with a SVPWM rectifier are shown in Fig. 5. Figure 5(a) indicates that the DC bus voltage is basically stable with just a little rise during the current falling section due to its bi-direction power flow ability. And we can found that an accelerator pulse power supply with a SVPWM rectifier can make the AC current be sinusoidal and work in unit input power factor (unit rectification in Fig. 5(b) and unit invert in Fig. 5 (c)). The AC current total harmonics distortion (THD) is in a range [1.38%, 1.97%] during the 700A's top, which is detected by 'FFT_Probe_a'.
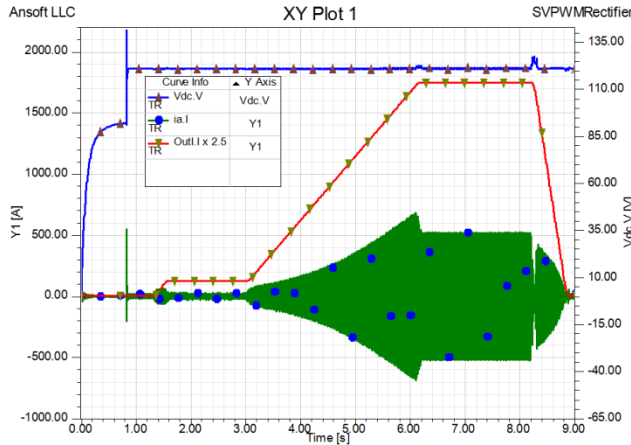

Figure 5(a): Global simulation results graph of an accelerator pulse power supply with a SVPWM rectifier during a complete cycle of the output waveform.
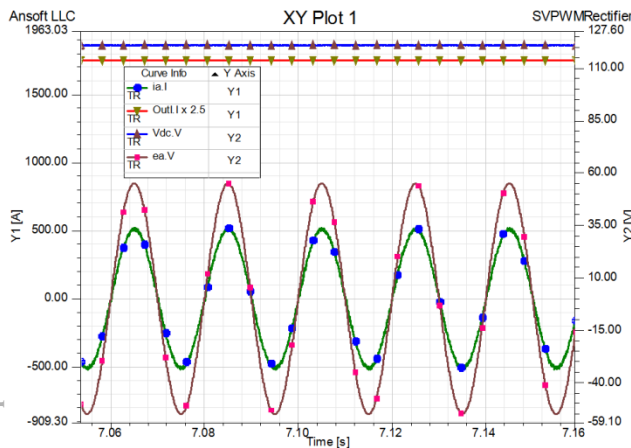

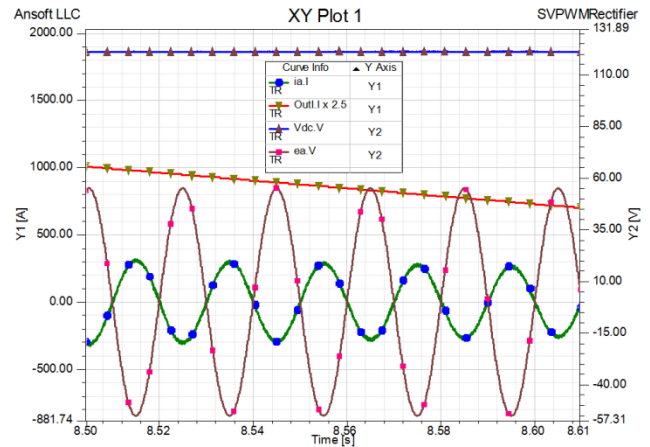Figure 5(b): Unit power factor rectification during the top section of the output waveform

Figure 5(c): Unit power factor invert during the current falling section of the output waveform

CONCLUSION

In this paper, a simulation model of an accelerator pulse power supply with a voltage-type SVPWM rectifier was set up based on C-Model function in SIMPLORER 8.1. The building progress of a C-Model component was introduced. The simulation results show that an accelerator pulse power supply with a voltage-type SVPWM rectifier can efficiently improve the input power factor, reduce the AC current harmonics and stabilize the DC bus voltage. For all the control strategies are developed in C language, they can be transplanted into the digital signal processor nearly without change for prototype controlling. So it provides a basis for development of the experimental prototype.

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