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Power Electronic Transformer Control Technology Based on DSP

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This paper aims to analyze the control technology of Power Electronic Transformer (PET) using DSP software. With two-stage cascaded power electronic transformer as study case, the H-bridge grid parallel is used to analyze the control conditions of the back stage inverter, prime and intermediate separator. It is found by experimental simulation analysis that the H-bridge parallel method proposed in this study has a certain applicability and can play a useful control effect on power electronic transformer. In the end, we conclude that the DSP-based control technology for PET has a certain exploration and application value.

1. Introduction

The PET operates as a core part of the power grid system, it is a kind of power grid equipment developed by American scholars. In terms of power grid operation, the PET plays a more apparent role. As the PET controls more flexibly and can adjust the power factor, etc., such equipment has a greater impact on the stable operation of the power grid. As such, many scholars at home and abroad have been exploring the control strategies over the equipment. Although there have been many findings on the control of PET, most of them lack the availability. Today, the scale of power grid construction expands day by day, the poor effect of power grid system operation control increasingly worsens the normal power consumption of users. This paper primarily explores the PET control technology with DSP software in order to guarantee the stability of electricity consumption for inhabitants. This paper first launches the analysis on the DSP software design with two-stage cascaded PET as the study case. Next, it is discussed what the control effect ensues. In the specific PET control technology, a physical experiment is cited for analysis on the study case and to explore whether the H-bridge grid parallel control is workable.

2. Literature review

A circuit topology named the high frequency chain power converter, which is proposed by the McMurray of the United States Ge Corp, is an AC/AC transform circuit with high frequency link. After that, Prasai and many other foreign staff improved the basic circuit by using the principle of high frequency conversion. The topology of power electronic transformers mainly includes the following kinds (Prasai et al., 2014). The first kind if single stage structure without DC link, which is directly reduced from HVAC to LVAC; the second kind is two-level structure without DC low voltage bus bar; the third one is two-level structure with DC high voltage bus bar; the last is a three-stage structure with high voltage DC bus bar and low voltage DC bus bar. Among them, the last kind, the three-level structure with high voltage DC bus bar and low voltage DC bus bar has become the main direction of power electronic transformer applied to energy Internet. In this topology, the high frequency conversion circuit is DC/DC transform circuit, the AC/DC transformation level is connected to the front of the high frequency conversion circuit, and the DC/AC transformation level is connected to the high frequency conversion circuit. The power electronic transformer is composed of the topology structure, which not only has high voltage and low voltage AC side, but also has high voltage and low voltage DC side. She and others, based on the comparison of the three-stage structure of back to back converter with AC-AC type, found that it had better control characteristics. This topology could be connected to a variety of voltage levels, and could also

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achieve voltage drop compensation and reactive compensation (She et al., 2013). The topology could be widely applied in the energy Internet.

The FREEDM centre of North Carolina State University in the United States has done a lot of research on the advanced control strategy and topology structure of power electronic transformers and has made great achievements. The researchers at the University of North Carolina designed an experimental prototype of a high-voltage power electronic transformer, and described how the power electronic transformer operates as an active network interface in the smart grid architecture. In order to make the operation of the system more efficient, She and others put forward a more advanced control strategy. At the same time, the key technology of the integration of power electronic transformer and DC micro network was explained in detail, and the reactive power compensation capability, voltage regulation ability and the test of the fusion capability with DC micro-network were carried out on the main functions and characteristics of power electronic transformers under different environmental conditions (She et al., 2014). There are also a series of explorations on the single-phase power electronic transformer. The front-stage high voltage rectifier level of the topology is made up of a cascade of multilevel AC/DC rectifiers. It is beneficial to improve the rated power of the system. At the same time, the voltage level of the system can be improved, and the intermediate isolation level is a modular double active bridge (DAB) current and DAB module has higher efficiency and power density. However, the bus voltage and power of each module are unbalanced, which will lead to the unstable operation of the power electronic voltage apparatus, and it will aggravate the difficulty of the design of the power single transformer and increase the probability of various bad conditions of the system. In order to balance the DC voltage and power of each module, a single phase DQ control method is proposed by Shi and so on. This scheme balances the power and DC voltage of each module by using a dual feedback voltage control to the dual active bridge module. The control method can effectively reduce the distortion of the network side current waveform and get the same power factor. The simulation and experimental results of the literature verify the effectiveness of the control scheme (Shi et al., 2011).

She and others put forward a cascade power electronic voltage transformer topology, which mainly provided interface for 7.2kV distributed system. The traditional voltage balancing control strategy based on PI regulation, because the voltage balancer is more, will lead to the closed-loop control effect of the system cannot achieve the desired results. In this case, a new 3D space modulation strategy is proposed. The modulation strategy can realize the DC side voltage balance of cascaded multilevel converters. At the same time, the scheme can also control capacitance and inductance better. In the end, the prototype is built, and the simulation and experiment are carried out to verify the effectiveness of the method (She et al., 2011).

Researchers at the University of North Carolina proposed a new solid state transformer system, which included three control levels: master control of local controllers, secondary control for DC mini smart grid bus voltage recovery control, and third level control to control and manage battery charge state. Yu and others described the proposed system structure and corresponding control schemes. On this basis, an experimental prototype was built to verify the effectiveness of the proposed system and its control scheme. The experimental results verified the effectiveness of the system and the distributed power management strategy (Yu et al., 2014).

Gu and others proposed a multi-port PET topology, which contained multi winding intermediate frequency transformers. The topology was modelled and the control method was proposed. The main purpose of this method is to balance the power between different ports, which is controlled by the coupling flux linkage. In addition, the problem of multi-terminal active bridge (MAB) is also explained, and a new nonlinear solution for power decoupling problem is presented, which can achieve power balance (Gu et al., 2015). On the other hand, Zhao and others used advanced components to build SST, which was more practical than the traditional one. A new type of silicon carbide power device and iron based nano soft magnetic materials are used to build SST. The high voltage rectifying stage of the SST system is cascaded, and the intermediate isolation stage uses a dual active bridge. In order to reduce the circulation and improve the efficiency isolation level, the dual phase shift control was adopted (Zhao et al., 2015).

To sum up, the above research work mainly studies the advanced control strategy and topology of power transformer, but the traditional transformer distance meets the requirements of the energy Internet, and there are still a lot of areas to be improved. Therefore, based on the above research status, this paper takes the two-cascade power electronic transformer as the research object, and puts forward a new method of grid connection for the grid connection problem of the H Bridge. Moreover, it puts forward the control strategy for the front stage, the middle isolation level and the postverter level of the power transformer.

3. Methodology

3.1 Control strategy

In relation to the three-phase grid parallel converter, the main circuit of the single-phase grid parallel converter cannot directly exercise the vector control due to lack of a freedom degree. In general, imaginary quadrature voltage and current signaling is adopted to realize coordinate transformation. Such an idea that a virtual three-phase system is captured using fiction approach is analogous to the principle of single-phase voltage sag detection, so that there will be a delay in the event of a signal mutation. For the fiction of voltage signals, the traditional approaches for constructing a virtual system include a transient voltage decomposition for building a virtual three-phase voltage and αβ detection method by which a virtual dimension orthogonal to the physical quantity is further available. These two programs are 1/6 and 1/4 grid cycles the actual physical quantity delays, respectively. To address the delay of traditional fiction method, this paper proposes a new solution which can further improve the timeliness, and implement the process without involvement of system parameters. (The coordinate transformation is shown in Figure 1 below.) The a-phase voltage mode is given as follows:

$$u_a = \sqrt{2U}\cos(\omega t + \psi)$$

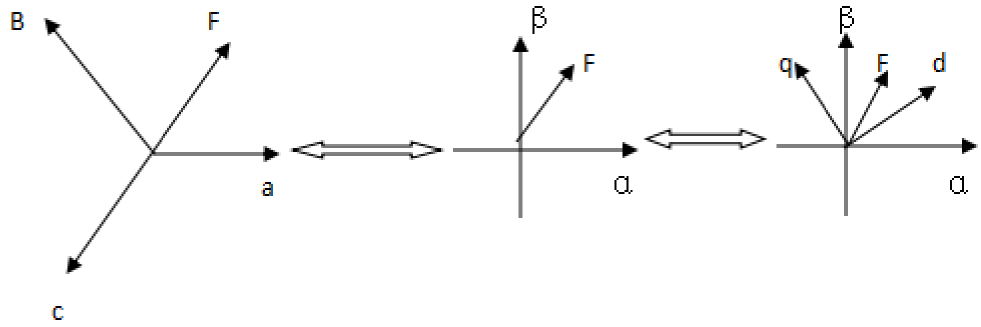

Figure 1: schematic diagram of coordinate transformation

After high-speed sampling, signals stored in data buffer are constantly cycling. Conventional fiction method considers signal fiction based on phase-lag process. This paper, based on the idea of phase lead implementation, proposes a new type of virtual signal vector control method that further improves the real-time control performance of grid parallel converters. The single-phase AC voltage Wa is advanced by 30° to get the virtual voltage W|. The relationship with phase voltage phasor is used to capture the c-phase voltage MC and the b-phase voltage wb. (The relationship among three-phase system voltages is shown in Figure 2)

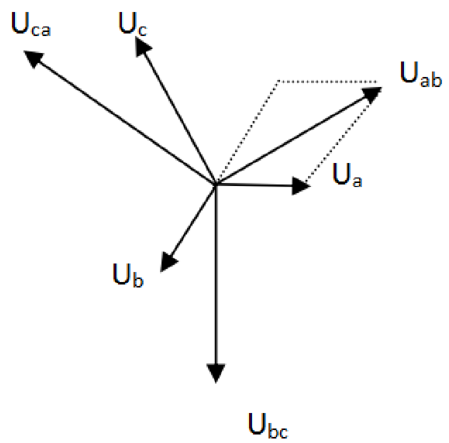

Figure 2: schematic diagram of phase line voltage relation of three-phase system

3.2 Design of system experiment

The main function of the control signal drive circuit is to transfer the PWM pulse signal sent from the DSP to the IGBT module. Since the DSP2812 in the use has a maximum voltage of 3.3V, an optocoupler isolator is required between the DSP and the IGBT. The optocoupler TLP250 is a totem-pole output, so that no pull up resistor is required on the Vcc and Vo terminals. Even it is easier to use. The PWM pulse signal sent from DSP2812 is transmitted to the TGBT's drive circuit via two-stage inverter 4049 and two-stage optocoupler TLP250. As the optocoupler TLP559 is in use, the pull-up resistor with the min resistance is required turning on. However, too low resistance will lead to overcurrent, which will affect the service life of components and parts. The mathematical model for relevant transformer is given as follows:

$$u_s = R_i + L\frac{di_s}{dt} + u_{ab}$$

the rise and the fall of the TLP250 cost much less time than those of the TLP559. It is considered that the TLP250 is chosen here to implement level translator and isolator. The experiment platform built in this paper is a two-stage cascaded PET, where both front stage and middle isolator stage use Infineon's IGBT module F4-100R12KS4. The driver chip is Infineon's 2ED020I12- FI, so that it is required to send the control signal to the input terminal of the driver chip. This paper uses TI's mainstream product TMS320F2812FDSP as the main control chip, a 32-bit fixed-point DSP chip, CPU frequency is 150MHZ, see Table 1 for specific parameters.

Table 1: Dsp2812f parameters

The name	parameter	The name	parameter
Instruction cycle	6.67ms	A/D conversion unit	380V/50Hz
Interrupt level	Level 3	Watchdog timer	1
Input/output voltage	3.3V	On chip RAM	18*16
Maximum AD sampling frequency	12.5MSPS	CPU timer	3
An on-chip Flash	128*16	External interrupt	3
I/O	56	Serial communication interface	2
Time manager	2	Analog/digital channels	16

The main program accesses the main loop after a series of initializations such as system, PE control register, interrupt vector table, EV event manager, and GPIO port is set up and global interrupt is enabled. The main cycle program includes several components, i.e. A/D conversion of electrical (current and voltage) signals timely acquired in the system, computation of electrical signals, determination and protection of faults such as overcurrent and overvoltage in the circuit, control strategy algorithms, and generation and update of PWM wave signals. The control strategy algorithm consists of four parts: normalization processing, computation of trigonometric functions with orientation angle, PI controller and coordinate transformation, while the interrupt unit mainly include TINTO, T1PINT, XINT1, McBSP interrupts, PWM fault and SCI communication interrupts.

When the GPIOF port is set up, leave two I/O pins and set the GPIO register DO bits corresponding to these two pins to zero, that is, these two I/Os are used as universal I/OF port. The two I/OF ports joint to the relay protection circuit board. When there is an overvoltage or overcurrent fault occurred in the circuit, the DSP sends an FO signal to the relay protection circuit board by one of the two I/OF ports. The relay protection circuit is to protect the circuit. The remaining I/OF ports are the fault indication limit number. Normally it is low level and connected with the fault indicator. When the circuit fails, the I/OF port outputs a high-level signal and the fault indicator lights up.

When initiating the EV Event Manager, the TMODE is defined as 1, so that the general-purpose timer T1 turns into continuous addition/subtraction count mode. AD sampling is achieved by the AD7656 chip on the DSP development board. This is a 16-bit successive approximation ADC chip with six channels in total. The resolution of this chip is 0.305mV. Assume that the conversion rate is considered to be u, then the actual input analog voltage value is u×0.305mV. The grid frequency is PF 50Hz. We can know from previous H-bridge control strategy that a single-phase system cannot perform coordinate transform due to lack of freedom degree. The general way is to virtualize a quadrature quantity with a phase difference of 90° in the DSP program. The fictitious voltage quantity as obtained should be realized via the number of historical data that searches from array. It is better to be integer in order to reduce the error sample number. Take the αβ detection method as an example, a 9 kHz sample frequency is used, in this way, the sampling number corresponding to a phase difference of 90° is just 45, an integer. If a sampling frequency is 10 kHz, the phase difference between two adjacent sampling points is 1.8°. The corresponding sample points are decimal, so that there will be a larger error. (the flow chart of main program is shown in Figure 3)

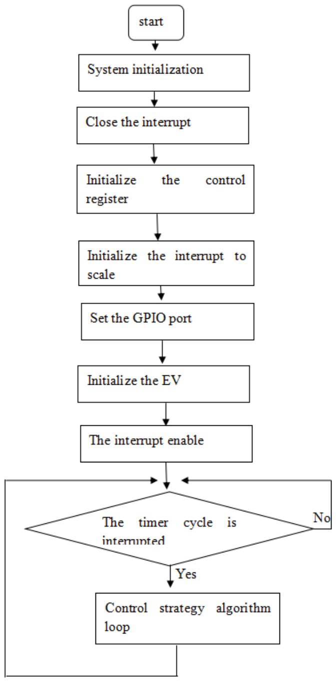

Figure 3: main program flow chart

4. Results and discussion

4.1 Analysis of experiment results

This paper makes the analysis on PET control situation by the physical experiment, the experiment parameters are listed in Table 2 below.

Table 2: Experimental parameters of grid-connected converter

The name of	parameter
Ac side voltage	25V
Dc side voltage	50V
Dc side capacitance	10000μF
Grid-connected reactor	1mH
AD sampling frequency	10kHz
PWM carrier frequency	10kHz
Dead band time	4μs

With reference to the voltage and current waveforms on the DC and AC sides of the two-stage cascaded bridge, the DC side voltages of the upper and lower two H-bridges are all kept in the range of FF30V, which implies that the control strategy can achieve the purpose of voltage equalization. The AC side voltage of two-stage cascaded H-bridges exhibits a five-level gradient wave, which affirms the availability of the CPS-SPWM technology. When the reactive current is -5A, the effects of the reactive current leading grid side voltage and lagging the grid side voltage by 90°can be seen from the voltage and current waveforms, which suggests that two-stage cascaded H-bridge has better reactive power compensation capacity. On the whole, the control strategy of two-stage cascaded H-bridges is feasible. From the experiment results, it can be seen that the topology and control strategies of the two-stage cascaded PET proposed in this study are proven to be effective.

4.2 Simulation analysis

There is an intermediate isolator stage in PET, which mainly isolates the DC side of the front stage from the DC side of the rear stage. The electrical isolation function of the intermediate isolator stage is achieved by a high-frequency transformer. As mentioned above, the intermediate isolator stage rear-mounted the H-bridge only provides the energy for the back stage inverter. Therefore, the value of the capacitor on the DC side of the rear H-bridge at the intermediate isolator stage of PET should allow for the actual load requirements. Here, the capacitor voltage Ucd takes 650V and the maximum active power Pmax is 20kW. If the inertia time takes 0.05s, the maximum fluctuation allowable for DC bus voltage, ΔUdcmax, is 100V, then for rear H-bridge at the intermediate isolator stage, the value of the parallel capacitor on DC side should be greater than or equal to 3800 μF. Concerning the existing hardware in the laboratory determines the corresponding value of the DC capacitor, take C=10000μF. In order to improve the response of the whole control, the filter capacitor and inductor on the AC side of the rear-stage inverter should also take a relatively low value, according to the value of the laboratory hardware equipment, take Z = lmH, C = 47μF. (The main parameters of the system are shown in Table 3 below.)

Table 3: Simulation model parameters

The name	parameter
The grid voltage	380V/50Hz
Power grid side filter inductance	1mH
Front - level HVDC capacitance	1000μF
The forward dc voltage is given	800V
The forward dc side voltage is given	20kVA/1000Hz
Rear - level low - voltage dc capacitance	20μF
Rear load side filter inductance and capacitance	5mH/100μF
RL load (active, reactive)	(10kW, 5kVar)
The second output three-phase ac voltage is given	220V/50Hz

5. Conclusion

The PET as a part of the smart grid has a key impact on grid operation. This paper mainly investigates the new grid parallel method by traditional detection and simulation analysis as well as the analog. It is found by study that the delay time of this method is more short-lived. The simulation analysis of the model reveals that the PET control strategy proposed in this study has a high availability. Then the physical study is made through the experimental platform and DSP software performs design. It is also proven that this control method has certain application value. The experiment environment adopted in this study is low pressure, but experiment in a high-pressure level still requires further study. By studying the H-bridge grid parallel method on experimental platform, it is found that when the H-bridge cascades gradually build up, it is likely that the DSP will be caused to exceed the control range. Therefore, it is required to introduce the FPGA into the experiment platform for the analysis with two software design methods as adopted here, so as to strengthen the PET control.

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