Research on High-voltage Inverter Controlling System Based on Wave Algorithm

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***Abstract*- High-voltage inverter designed in accordance with the principle of voltage serial stacking is adopted and controlling for the high-voltage electric motor with high-power is realized by the method of low-voltage series connection. Besides, distributed control system overcomes the shortcomings of traditional controlling system, such as bad reliability and difficulty in maintenance. Using ARM processor as the central controlling system can reduce the system cost; using DSP processor as the controlling unit can make the controlling method more flexible and also can gain more preciseness. The experiment in the principle of voltage serial stacking verifies that the method of voltage serial stacking is correct. What's more, AC asynchronous motor hauling experiment, adopting the method of low-voltage simulating high-voltage, verifies that the idea of voltage serial stacking and distributed control system based on the field bus are correct and realizes the function of the system.**

***Keywords*- superposition waves, high-voltage inverter, CAN bus, distributed control system, ARM processor**

I. INTRODUCTION

The inverter was invented in the 1960s and it was widely used in most industrialized countries in the 1980s. Since the 1990s, the awareness for protecting the environment has been strengthened and invter plays a more and more important role and it has been frequently used in various fields of national economy and people's daily life[1 2]. In the field of high power AC-AC variable frequency speed adjusting technology, Alstone company in France is able to provide electrical drive device with 30,000 KW power per machine for ship propulsion system. In the field of medium power AC-AC variable frequency speed adjusting technology[3], Simovert Aspeed control equipment of current type thyristor frequency converting of Siemens company in Germany, which is with 10~2600kVA per machine, and its controlling system has been digitalized and it is mainly used in electric locomotive, fan and water-pump driving device[4]. In the field of low power AC-AC variable frequency speed adjusting technology, the BJT frequency converting of Fujitsu in Japan is with 700kVA per machine and IGBT frequency converting is applied in kinds of products[5 6]. The control system is digitalized.

Traditional high-voltage frequency conversion controlling system mainly adopts the method of centralized control and main control computer adopts industrial control computer or PLC controller to gain the data and output the controlling signals, besides, through controlling FPGA chip, PWM sequence is gained to change the speed of controlling motors. The controlling technique of high-voltage is widely used on the site owing to its stability on the work. However, the controlling function of PLC controller is simple, in addition to that, all the gathering and controlling signals are gained through centralized controlling method, but PLC and industrial control computer can not fulfill the instant requirements of the controlling system since they are slow in processing. For a large controlling system, its controlling functions are too limited[7 8]. As the high-voltage frequency conversion technique is developing rapidly, the centralized controlling method has done a bad job in fulfilling the verifying requirements of the market.

Resources of this article are from the cooperating program with Beijing Sunsing Co.,LTD.The company has promoted new high-voltage inverter and now , it is prepared to improve its system controlling structure and adopt embedded distributed control network method, so that the system can be automatically controlled and also automatic supervising system is added, including the function of problem alarming, data collecting on the site and distancing transmission . Through the method of network node, the controlling system can be automatically operated. The plan of the controlling system is the fruit of investigation on the working site with the customers for more than one year and the new controlling method is advance. Perfect combination of the new controlling idea and the high-voltage frequency conversion technique is realized through ARM embedded controlling system and DSP intelligent controller. In this condition, two partners cooperate in the technique to develop the new high-voltage inverter distributed control system.

II. THE STRUCTURE OF HFI CONTROLLING SYSTEM

A. The principle of HFI

The principle of HFI system high-voltage frequency conversion is showed in Fig. 1. High-voltage inverter mainly consists of input isolating transformer and power transformer. Input isolating transformer secondary-side transforms three-phase power into 24 separate cutting voltage and supplies electricity for 24 separate power units. Each power transformer consists of 8 low power units in series, which is as three-phase output in Y connection. each power unit, which consists of four

1200V IGBT modules, composes three-phase input and uniphase output pulse-width modulation inverter and provides 0~540V voltages individually. With waveform continuous transformation superposing voltage of all power units, each power transformer can provide high-voltage output whose frequency and voltage can be continuously adjusted. The phase voltage is 0~420V and the corresponding line voltage is 0~7500V.

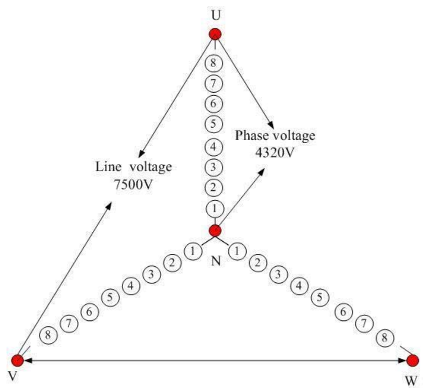

Fig. 1 The principle of HFI system

With input transformer, the output voltage can suits voltage grade on power network well. The output voltage quantity is controlled by the mounts of serial power unit and can satisfy the need of motor voltage. In addition, the secondary-side coil which provides power for each power unit has a phase difference and realizes multiple inputs. Therefore it can eliminate harmonic wave and get satisfied sine-wave current and sine-wave voltage in kinds of speed range.

1) The principle of uniphase series multiplex overlapping invter

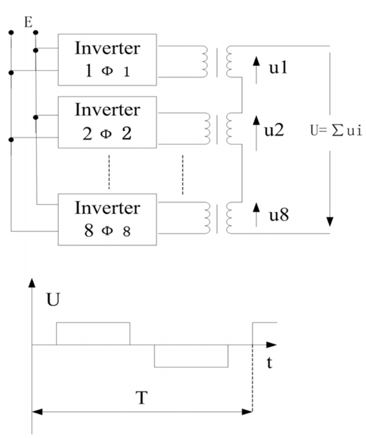

Fig.2 Uniphase series multiplex overlapping invter

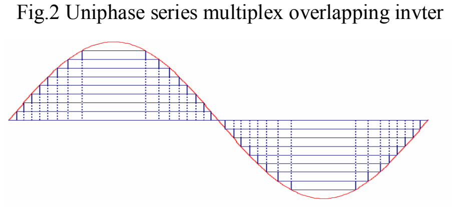

Fig.3 Overlapping of uniphase output voltage

Uniphase series multiplex overlapping invter is built by connecting the output transformer secondary circuits of N(means the quantity) uniphase square wave invters (H bridge inverse circuit can be adopted if voltage adjustment is needed). If N uniphase square wave invters adopt bridge inverse circuit, uniphase series multiplex overlapping invter can adjust and improve the voltage wave, as well as output voltage.

As shown in Fig.2, rectified by bridge circuit, three-phase input voltage a, b and c produce volts DC: V = Vc-Vd = 540V. and then V passes 4 IGBT insulated gate electrode bipolar transistors. When the diagonal IGBT insulated gate electrode bipolar transistors T1 and T4 are connected, V is +540V and when T2 and T3 are connected, it is -540V. In the situation of assuring the up bridge circuit and down bridge circuit are disconnected, the connection of T1 and T3, or T2 and T4 provides flow-wheeling for whole power unit following current and protects the capacitors from damage because of quick charge. The output of each power unit is shown in Fig.2. The overlapping of synchronous eight power unit modules is +/- 4320V phase voltage. The overlapping of unique multi-units output voltage is shown in Fig.3. The output wave of unique phase voltage is close to sine wave. The whole high-voltage frequency conversion speed adjusting system realizes variable voltage and variable frequency (VVVF) by adjusting PWM

B. The structure of HFI

1) The structure of HFI high-voltage variable frequency speed-adjusting system

HFI high-voltage speed-adjusting function module mainly consists of high-voltage isolating part, power unit part, signal controlling driving part and signal examining and protecting part. As Fig. 4 shows, it can be divided into over-current protecting unit, cutting unit, full-bridge rectifying circuit, voltage examining and DC brake, voltage superposition unit and protecting unit, controlling power unit, examining transforming unit, protecting unit, voltage transforming and isolating driving unit, output examining unit, digital/analogy output unit and digital input. Function of every part is as follows:

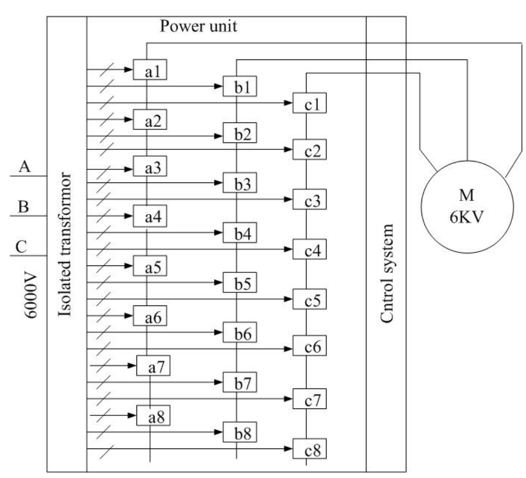

Fig. 4 HFI speed adjusting system structure

High-voltage isolating switch and over-current protecting unit are responsible for the transforming and cutting of input and output high voltage so that the system can work in the condition of online, offline or bypass (invter bypass, motor network power source);segmentation unit: cutting unit is responsible for cutting input three- phase AC 6000V into several middle AC output. In order to decrease the disturbance for harmonic wave in the input side of electrical network, cutting unit adopts phase shifting technique so that equivalent electricity can be gained in 144 wave mount, full-bridge rectifying circuit transforms middle voltage signal outputted by the cutting unit into DC voltage signal output. Voltage examining and DC brake are responsible for examining DC voltage signal; phase overlapping and protecting unit make use of overlapping wave technique and waveform continuous transformation technique to overlap all the middle DC voltage signal so that three-phase AC signal can be outputted on the side of output and the volume changes between zero and a certain number; protecting unit is responsible for protecting the

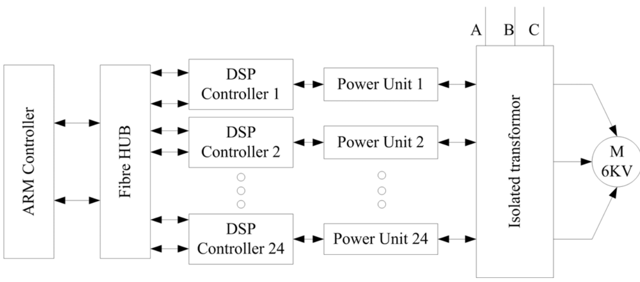

Fig. 5 HFI controlling system structure

device and load from over-current or over-load. detecting and detecting unit: examining transforming unit is responsible for transforming the output signals from every examining unit and then send them to the central controlling unit to manage; voltage transforming and isolating driving unit are responsible for voltage conversion and isolated drive the controlling signals from the central controlling unit so as to control the work or operation in the main circuit of the controlling system.

2) The structure of HFI high-voltage variable frequency controlling system

HFI controlling system consists of the central controller, CAN bus, fiber optics communication and unit controller. The structure of the system is showed in Fig. 5. The central controller works with embedded controlling system ARM controller as its center and IO module, AD data-gathering module, LCD display module, GPRS remote communication module and CAN Bus module as its outside function modules. CAN bus, fiber optics communication mainly consists of fiber optics driving circuit, fiber optics and fiber optics(HUB). Since the working environment on the site is complex and there is EMI(Electromagnetism Interruption), fiber optics are used to transmit the signals between the central controller and every controlling unit so that signals can be isolated and decrease EMI and the system can work more stably. The controller of power unit is TMS320LF2407 which is used by an American TI company as its CPU of their system, and main function modules include CAN Bus communications module, I/O input and output module, A/D data-gathering module and PWM output controlling module and etc.

III. THE FUNCTIONING SYSTEM OF HFI CENTRAL CONTROLLING SYSTEM SOFTWARE

The article chooses a multiple-task system μC/OS-2 as ARM operating system. The controlling software of ARM operating system mainly consists of HMI (human interface) management, data processing, logic controlling, problem solving, file management , Can communications and GPRS communications. Now, we are going to give an introduction about main modules:

HMI management: It is the media of the customers and HFI controlling system. HFI controlling system relies on LCD to tell the operating condition of the system and the customers can control HFI system by touching operation. HMI mainly consists of system main, testing interface, parameter setting interface and historical curve interface, Data processing: Data processing module consists of A/D sampling, synchronization with DSP and online back-up, Logic controlling: Logic controlling module consists of switch controlling logic, frequency changing logic, closed-loop controlling logic and user authority logic. Problem solving: Problems of the system include ARM system problem, DSP system problem and communications problem. Attention must be paid to the problems occurring when beginning the system and when the electricity is cut. ARM system and DSP system make the judgment about the problems according to the data collected. Further operation is allowed only when everything goes well.

A. Function realization of the software system

High-voltage variable frequency controlling system realizes HFI distributed control network owing to ARM central controlling unit and 24 DSP controlling driving unit based on CAN bus communications method.

Since there is difference in DSP controller crystal, various hardware IC(Integrated circuit) and circuit, the count bias will occur after DSP controller works for some time so that signal output from every DSP controller system may not occur at the same time. Therefore, ARM central controlling unit of HFI controlling system, when fulfilling the requirement of daily communication, give some synchronization orders for all DSP controllers. The management module of DSP controller has 4 timer/counter in all. According to design of the system, when timer T2 works in the condition of counting as the counting standard of the whole system, while timer T1is mainly used to provide system period interrupt(The frequency of HFI changes between 5Hz and 50Hz). When timer T1 provides system middle interrupt, the count register of timer T2 is restarted so that counting starts from zero in every period. When DSP controller receives synchronization orders from ARM central controlling unit every one minute, it immediately returns the present counting numberT2CNT of T2. After ARM system receives all the counting number of DSP, at first, it selects counting standard of A, B and C. According to the principle of 120 difference degree for three phases, it has a final counting standard and then gets the counting difference of these 24 DSP controllers; finally, it gives the result to every DSP controller to make some improvements for T2 counting. Detailed processes are showed in Fig. 6: When working properly, if within one minute, synchronous signals are not received.

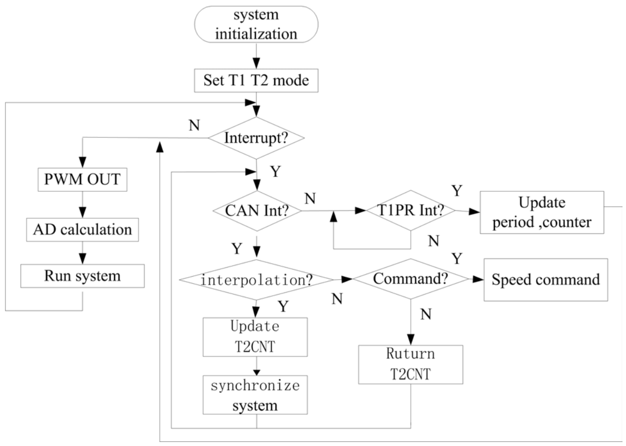

Fig.6 Synchronization arithmetic flow chart

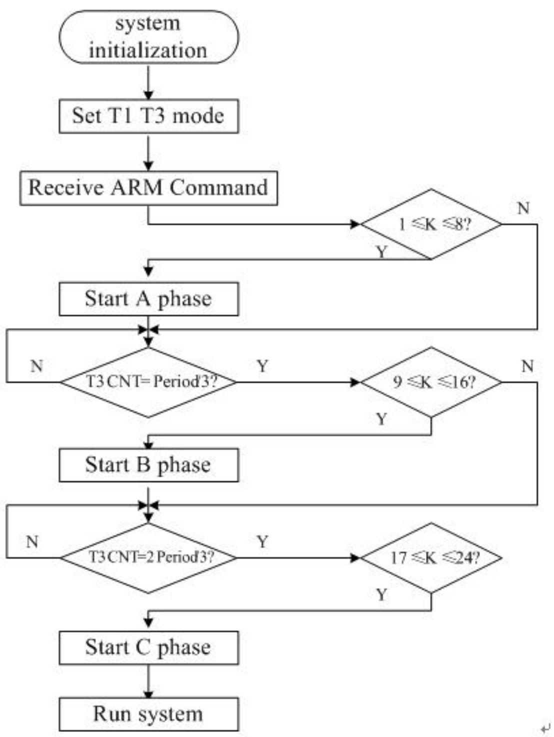

Fig. 7 Phase shift arithmetic flow chart

Then there must be some problem in network communications. At this time, DSP controller opens 1,3 of H bridge and closes 2,4 and locks PWM output from DSP system to prevent that there are some waves error output under the influence of system desynchrony destroying power unit module.

B. Implement of phase shift algorithm

Generally, the speed-adjusting range of high-voltage variable frequency controlling system varies from 6KV to 10KV, but for different motors, the range of output voltage can be changed with the change of the number of serial power unit. According to the design of this system, 24DSP driving controlling unit is divided into three phases A,B, and C, and every phase is combined by 8 DSP driving controlling units. A, B and C phase have the difference of 120^0 between each other. In high-voltage variable frequency controlling system, how to ensure A, B and C phase have the difference of 120^0 between each other, is a problem of great importance for synchronizing output of the whole system and stabilizing operation. In the process of design of the system, the requirement of phase shift can be fulfilled with the cooperation of timer of the DSP controller. A, B, C three-phase shift arithmetic flow chart is showed in Fig. 7, timer T1 plays a role of period interrupt timer. Only after T1 starts, DSP controller can work properly, producing PWM output, so controlling the starting time of T1 can assure A,B,C three-phase phase difference, and the starting time of T1 can be realized by timer T3,which is set in counter module. When receiving starting orders from ARM central controlling unit, T3 counter is started to count. When T3 counter: T3CNT=0, 8 DSP controllers of A are started. When T3CNT=T1_Period/3, 8 DSP controllers of B are started. When T3CNT=2*T1_Period/3, 8 DSP controllers of C are started. In this way, phase shift of HFI controlling system has been realized.

C. Implement of system wave overlapping and voltage reconstruction

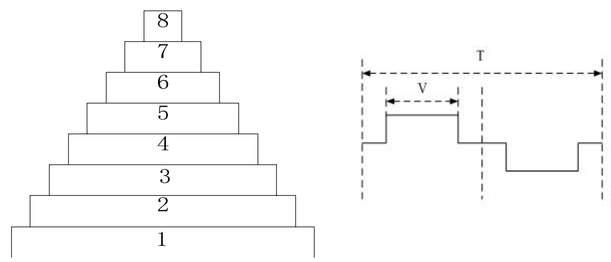

Fig.8 Phase voltage overlapping wave output in half period and power unit output voltage overlapping wave

High-voltage inverter is consisted of dividing device, transform device and control device. High level to high level transform style is used for the design of the system. By full-bridge rectifying circuit, three-phase input voltage a, b and c are transited to DC voltage V=540V, and this voltage go through four IGBTs insulated gate electrode bipolar transistors then output +/- 540V voltage. Eight in-phase modular voltages were added to high voltage +/- 4320V. When the four IGBT of H-bridge (H bridge) are connected diagonally, it generates output voltage, but when the IGBT on the same side of H-bridge were connected, it is used for continuing the current not for generating output voltage. G1-G3, G1-G4, G2-G4, G3-G2, G1-G3, ... is the connection order of four IGBT in every power unit of HFI control system. So in one cycle, Fig. 8 showed the output curve of the power unit controlled by every DSP control system and the resulted from the adjusted PWM duty cycle of every phase of 8 DSP controllers.

IV. EXPERIMENTS

After the controlling system is set up, it is necessary to verify low-voltage serial connection which is used to control high-voltage motor, and then we can watch whether wave satisfies the requirement. The idea is to Boolean calculation IO signals of IGBT controlled by DSP and simulate actual connection and disconnection of IGBT.

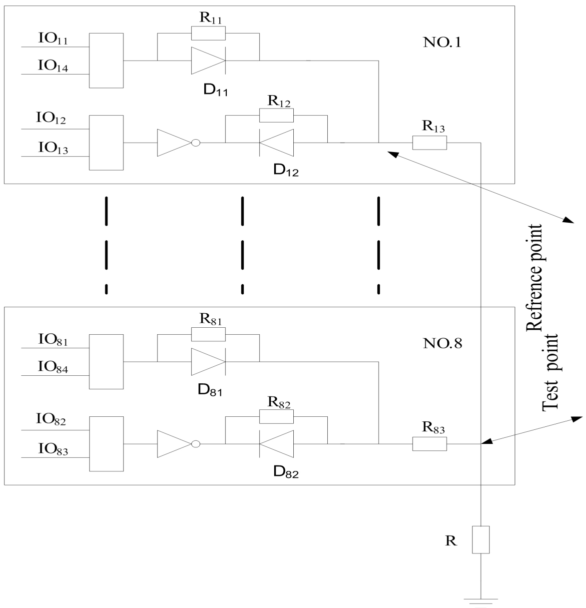

Fig.9 Voltage overlapping principle testing circuit

A. *Experiment on the principle of voltage overlapping*

Experiment principle: as shown in Fig. 9, IOn1~IOn4 are the connection, disconnections logical signal of four IGBT outputted by control power unit of DSP drive unit IO port. The logical relationship is shown in the Fig.9 . When IOn1 and IOn4 are high voltage at the same time, the output is high voltage 5V after going through AND gate. At this time, IOn2 and IOn3 are not forbidden to be high voltage at the same time. The output signal of AND gate and Not gate are high voltage 5V, and neither diode Dn1 nor Dn2 is connected, the reference voltage is 5V; When Ion2 and Ion3 are high voltage at the same time, the output signal of AND gate and Not gate are low voltage 0V. At this time, Ion1 and Ion4 are not forbidden to be high voltage at the same time, the output is low voltage 0V after going through AND gate. Neither diode Dn1 nor Dn2 is connected, and the reference voltage is 5V. When IOn1 and IOn4 are not high voltage at the same time, the output is low voltage 0V after going through AND gate. At this time, IOn2 and IOn3 are not forbidden to be high voltage at the same time. The output signal of AND gate and Not gate are high voltage 5V. Neither diode Dn1 nor Dn2 is connected, and the reference voltage is 2.5V after bleeder circuit by resistance R11 and R12(R11=R12=1K). In conclusion, 2.5V is the zero potential point of output PWM signal. 5V is positive voltage and 0V is negative voltage. The PWM signals outputted by eight units are connected in series. Big value of resistance of Rn3 is used for reducing the effect of the reference voltage, and then detected the signal by sampling resistance R. Result of experiment: As shown in Fig. 10, it is the output phase voltage wave when the system frequency is 50HZ and the corresponding output phase voltage is 6000V. Then, 8 testing unit all have PWM signal output and there are 16 steps of positive and negative voltage which is not the sine wave. As shown in Fig. 11, it is the line voltage wave which is difference of these two phases voltage and is the sine wave.

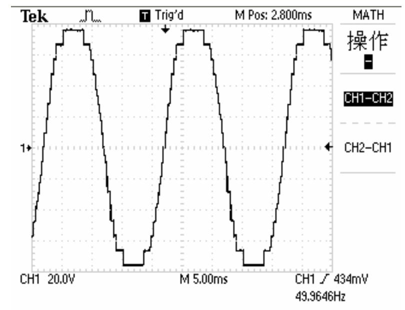

Fig. 10 Phase voltage wave

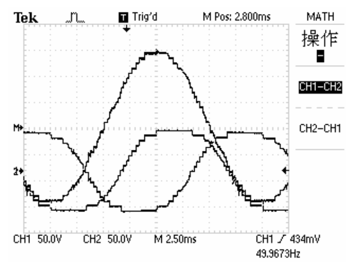

Fig.11 Line voltage wave

Conclusion of experiment: The experiment tells that it is correct to change line voltage amplitude by changing phase voltage shape and amplitude. The correctness is based on CAN bus distributed architecture.

B. *The experiment of hauling 380V AC Asynchronous Motor*

In order to wholly test the function of the controlling system and decrease the problems occurring on the experiment site, in this article, experiment is done in low-voltage environment. The idea is to replace 6000V AC Asynchronous Motor with 380V AC Asynchronous Motor to do speed-adjusting experiment.

Principle of experiment: the experiment has two parts: MOS power unit is used to replace IGBT power unit and hauling 380V AC Asynchronous Motor to verify the basic function of variable frequency of the system. ARM system fictitious load is used to test the function of the whole system.

The result of experiment: Fig. 12 shows the experiment platform of hauling AC Asynchronous Motor. The experiment platform mainly consists of six parts: the central controlling system based on ARM is responsible for sending controlling orders and present operating condition; drive controlling units based on DSP (24 in all) receive controlling orders from ARM central controlling system and protect controlling power unit and physical level. ARM system fictitious load simulates signals to ARM central controlling system in actual operation. Three-phase realizes power unit to replaces IGBT by MOS for driving AC Asynchronous Motor. Transformer transforms 220V into 24V AC power.380V AC Asynchronous Motor replaces 6000V AC Asynchronous Motor to proceed the experiment. Fig. 13 shows the main interface based on ARM central controlling system and the line voltage (up area) and phase current(down area) are ideal when the 50HZ output voltage is in the maximum amplitude situation. The experiment proves that it is correct to control high-voltage motor in the method of low voltage in series, and also the function of the whole high-voltage transducer controlling system can satisfy the requirement.

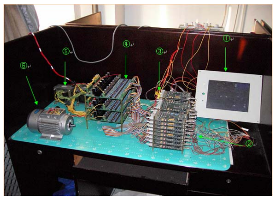

Fig.12 The experiment platform

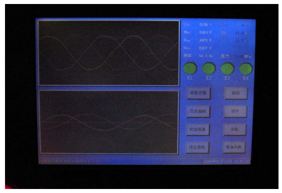

Fig.13 The main interface of the controlling system

C. The experiment of driving power unit

In order to apply the whole controlling system into the actual environment, the article further does the experiment of driving IGBT power unit. The experiment drives one IGBT unit to drive resistance load to verify that the controlling system is able to correctly drive IGBT unit and the newly-added function of over-current protection.

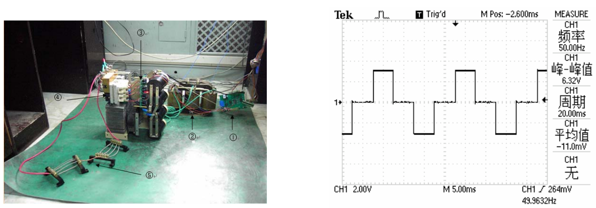

Fig. 14 The experiment platform of driving IGBT power unit and the output wave of power unit

Result of experiment: As Fig. 14 shows, the experiment platform consists five parts. Over-current protection unit is responsible for locking PWM controlling signals when examining that load current are more than the allowed current or IGBT short-circuited; transformer transforms 380V AC into 220V AC and decreases danger of the experiment 20.IGBT driving board mainly consists of IGBT driving IC M57962 and is responsible for driving IGBT. Meanwhile, M57962 is able to judge whether IGBT is short-circuited or not by examining CE voltage drop of IGBT and sends signal DEIN. Low voltage level means short-circuited; power unit mainly consists of IGBT, capacitor and Rectification Bridge and output PWM wave. Power resistance replaces motor to work as load of the experiment. Current sensor examines current here and then decides whether to lock and protect the output. As Fig. 14 shows, it is the output wave of IGBT power unit when 30Ω resistance is used as load. We can see that the designed high-voltage transducer controlling system can correctly drive IGBT power unit. This experiment proves the designed high-voltage inverter controlling system can correctly drive IGBT power unit and it also validates the correctness of the designed over-current module.

V. CONCLUSION

High-voltage inverter designed in accordance with the principle of voltage serial stacking is adopted and controlling for the high-voltage electric motor with high-power is realized by the method of low-voltage series connection. This experiment proves the designed high-voltage inverter controlling system can correctly drive IGBT power unit and it also validates the correctness of the designed over-current module.

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