Study of the standard sine wave frequency conversion power supply based on analog and digital integrated control

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Abstract: In this article, a standard sine wave frequency conversion power supply based on analog and digital integrated control is proposed. First of all, the article introduces the topology structure and principle involved in this frequency conversion power supply. The system of frequency conversion power supply was designed based on the DSP2812[1] made by TI company. Next, it is stated that the method of analog-digital combination control simplifies the inexact algorithm, under the digital control, of calculating the carrier wave and the PWM driving signal of power device generation at the point of modulation wave intersection. In addition, it is also stated that the analog-digital integration control is equipped with a good performance in dynamic control response and a harmonic content that can effectively drop down the output voltage of the controller; the analog-digital integration control can realize the required motor control performance at a low cost, improve the operation efficiency of the motor, and suppress various secondary harmonic currents of the motor. At the end, the voltage and the input waveform of the electric currents of the system are under analyzed through a test simulation experiment on the power source of the variable frequency power supply system; at the same time, the input voltage waveforms corresponding to different frequencies are also involved in discussion, while the corresponding harmonic waves are analyzed.
1. Introduction
Between countries, the state grid standards vary to a certain degree, due to which a large-scale promotion is conducted for the application and development of power supply with variable frequency. And the power grid state in each country is simulated by means of power supply. Thus, it is required for the equipment and power supply to provide such frequency integrated with purity, reliability, low harmonic distortion, and high stability, and such a sine wave power output with a regulated voltage.

In this article, the focus is attached to the introduction of the general development of the power supply technology and the common control methods for power supplying, which comes up with the significance of this subject. Besides, the foreign and domestic research status, and the working principles, the current development state and application of the variable frequency power supply, as well as the systemic structure of this article are also summarized by this paper. In combination with the actual needs of this research, the scheme to achieve a power supply with variable frequency and variable voltage is demonstrated on the basis of the technology of power supply with variable frequency and variable voltage and its development trend; additionally, the control principle--the basic principle of PWM control--is also elaborated in detail. The power supply with variable voltage and variable frequency is designed by both software and hardware, and put into stimulation analysis, system debugging, and experiments by Simulink. For the waveform of each constituting circuit of the system, a comparison study is performed to control the voltage amplitude and output frequency of the test power supply, and to deeply analyze the harmonic waves of the output voltage of the system at the same time.

2. System structure and control method of variable frequency power supply

2.1 AC/DC circuit
In the conversion of alternating current to direct current, the relevant functional requirements can also be accomplished by dint of the APFC. The APFC circuit can output a stable voltage under the control of the grid voltage waveform. Generally, the output voltage is set to 400V. Combining with the loss of the line and the device, it is possible to complete an output of 220V AC and also to increase the power factor and to reduce the effects of harmonic currents. For this end, it is determined by the system to adopt an APFC circuit. For example, Figure 2-1.

![Figure 2-1. Structure diagram of the system used in this paper](image1)

![Figure 2-2. Triangle wave circuit principle](image2)
2.2 Principles of analog and digital integrated control

In the Figure 2-2 of the principle of triangular wave circuit, on the left side of the circuit is a square wave generator that serves to generate a square wave, and concurrently, on the right side is an integrator system via which the square wave forms a triangular wave. At time t, the positive input of the op amp is higher than the negative input, and thus the op amp outputs a high-level of current (the positive peak of \( U_Z \)). The positive input voltage of the operational amplifier is \( U_Z \cdot \frac{R_z}{R_z + R_z} \).

The high electric level charges the C1 through R3, so as to slowly increase the capacitor voltage; not until the negative input of the op amp is higher than the voltage of the positive input terminal, is the output of the op amp inverted, that is, the current output is low (negative peak - \( U_Z \)). The electric level on the positive input end is \( -U_Z \cdot \frac{R_z}{R_z + R_z} \) which is still lower than that of the negative input voltage. Capacitor C1 discharges the output of the op amp through R3, and its voltage is gradually reduced. Till the capacitor voltage drops below the positive input terminal, the output of the op amp is flipped again; through multiple times of recycling and repeating, the square wave is formed by oscillations. The frequency of the square wave depends on the product of R3 and C1.

Principle of the integrator yielding a triangular wave. The circuit on the right is an integrating circuit. According to the virtual ground principle, the positive and negative input voltages of the op amp should be the same, that is, zero at the same time. If the square wave voltage is added to resistor R5 as a load and it is an electricity at high level, the current on the R5 is a constant current (\( U_Z / R5 \)) that also charges for the capacitor C2. In this state, the constant current of charging causes the voltage across the capacitor C2 to increase at a constant rate. After a half square-wave period, the input flips into a low-level electricity. The C2 discharges through R5, and the current stays constant (\( U_Z / R5 \)). In such a condition, the constant current of the discharge causes the voltage across C2 to decrease at a constant speed, and the voltage input and output values across the capacitor C2 are equal. By repeating the above steps in a recycling manner, a triangular wave output will be produced accordingly.

In Figure 2-3, the DSP controller generates a modulated wave, and the triangular wave circuit forms a carrier. With these two parts, a PWM output waveform is formed via a comparator to supply for the driving circuit, and then to ensure the reliability of the inverter bridge and guarantee its stable operation through driving the inverter circuit.
3. Circuit design of the hardware of frequency conversion power.

3.1 Principle schematic of main circuit of variable frequency power supply

In the whole circuit, for example, shown in Figure 3-1, the functions of each part of the main circuit are as follows: (1) APFC circuit: The grid input power is converted into pulsating DC power through the APFC circuit and input to the next intermediate filter segment. The circuit is started and the capacitor in the initial state needs to be charged. Thanks to the high capacity of the capacitor, the charging current will be increased within a short time. Thus, if no treatment is performed, the rectifier bridge and the input side fuse will show errors, and a trip will be brought up even on the input side. For this end, R3 should be linked in parallel to control the charging current in the case where the main circuit is connected. And the touch point of RT should be short-circuited so as to enable the R3 to short-circuit and save the electricity. (2) Rectifier circuit: The input electric energy is converted into direct current by means of three-phase bridge type uncontrollable rectification, and is input to the next intermediate filtering section. (3). Intermediate filter circuit: On the strength of capacitive filtering, the AC component in the output current of the rectifier circuit is filtered out, while the DC component is retained only. Because the grid impact and the output will affect the input current, causing the input side voltage and current to fluctuate, the capacitors C1 and C2 should be connected in series to increase the rectifier bridge capacity and reduce the occurrence of circuit problems resulted from this state. By the aid of R1, R2 series grading resistors, the capacitor is subjected to voltage equalization. R11 and HL are connected in parallel to detect the performance of the circuit. (4). Inverter circuit: By feat of the three-phase inverter bridge formed by the MOSFETs of V1-V6, the DC power output from the filter circuit is converted into an alternating current at a predetermined frequency and voltage. Six sets of RCDs constitute a snubber circuit MOSFET [3] which can be effective in small power inverters; however, an over-high switching frequency of the switch tubes will give rise to the error of excessive voltage or excessive current in the process of transition, thereby affecting the safety of the switch tube. Corresponding to the possible problems, it is supposed to adopt the DRC adsorption circuit [4] to protect the tubes. (5) Output filter circuit: The distortion of the output waveform is reduced as much as possible to resemble it a sine wave with the help of LC output filter circuit.

3.2 Design of control circuit

The core of the DC/AC inverter control circuit falls down to the DSP2812. The circuit contains three branch circuits, which are a sampling signal conditioning circuit, an output voltage and current feedback circuit, and an optocoupler isolation driving circuit, respectively, as shown in Figure 3-1.

The most important function of the DSP2812 is ascribed to its capability of generating a good SPWM [5] signal. And the four MOSFETs of the two bridge arms can be switched under the action of the driver circuit.

With the action of the transformer and signal conditioning circuit, the output voltage and output current can pass through the DSP2812 and enter the AD sampling module. The applicable SPWM signal is outputted by a voltage feedback modulation. According to the current [6] that is fed back, is
the need of initiating a current protection determined.

Figure 3-2. Diagram of the control circuit principle

4. System experiment and results analysis

4.1 Simulation results

Figure 4-1. Output voltage waveform after rectification and filtering

Figure 4-2. Inverter output voltage waveform
To sum up, in this subject will a variable voltage frequency conversion system based on the digital and analog integrated control for variable voltage frequency conversion system be designed, and an effective simulation model will be established to match the software and hardware corresponding to the DSP design, by which the intelligent control method will be more practical and conducive to the design and development of a control system with high performance, as shown in Figures 4-1 to 4-4.

4.2 SPWM drive waveform and spectrum analysis

The equipment used for the system test includes: Tektronix oscilloscope TPS2024B, VICTOR portable multiple-purpose meter VC9807A. As shown in Figure, 4-5, the SPWM driving waveform is displayed under the oscilloscope. Figure 4-6 and 4-7 illustrate the analog and digital integrated control SPWM drive signal boards and their PCB diagrams.
As shown in the following Figures of 4-8 and 4-9, they are respectively the waveform three-phase sine wave modulation signal outputted by the D/A module of DSP, and the waveform of sine wave signal emitted by analog triangle wave circuit.
Next, with an entity construction of the SPWM generation circuit, the analog SPWM, digital SPWM, and digital-to-analog SPWM waveforms are put into a Fourier decomposition analysis, and the designed details of the circuit structure will be described in the Chapter 4. To grant the SPWM parameters with relativity, these parameters are uniformly set as followings: the modulation depth is set to 0.8 and the carrier frequency is rated as 10KHz. Since that the sine analog circuit is fixed by the parameters of RC crystal oscillator circuit, the modulation wave frequency has been set to 54.6 Hz, and the corresponding SPWM wave is analyzed by Fourier analysis as shown below:
As shown in the combo Figure 4-10, the Figure a represents the Fourier analysis of the SPWM waveform generated by the pure analog circuit, the Figure b shows the Fourier analysis of the SPWM waveform sent by the event manager of the DSP [9], and the Figure c refers to the Fourier analysis of the SPWM wave obtained by the sine wave from the D/A of the DSP and the triangular wave generated by the analog circuit through the voltage comparator. In this figure, the horizontal axis coordinate stands for the frequency, the vertical cursor refers to the switching frequency of 10 kHz, and the vertical axis coordinate is on behalf of the decibel that is proportional to the amplitude. The harmonic frequency amplitude distribution of the analog-digital integrated system is similar to the harmonic frequency amplitude distribution of the pure analog system, while the harmonic frequency amplitude of the pure digital method distributed near the switching frequency is larger. Identical with the pure analog approach, the modulation method of digital-analog integration verifies the superiority of the digit-analog integration. In Figure 4-11 is a combination of analog and digital spectrum analysis.

4.3 Analysis of experiment results and summary of experience
Through the above experiment, it has been found in our obtained results that the designed program in this article is feasible and able to reach the designed technical requirement and an output voltage waveform of a better quality. Besides, the dynamic performance and stability of the system has also been verified through tests.
In the process of system debugging, a number of experienced lessons have been also harvested, from which some parts in need of attention have been summed up.

First of all, it should be paid attention to that the oscilloscope needs to be equipped with an isolation probe when the test wave is under debugging. In particular, it is also required to be cautious when one is engaged in a multipath measurement. In case the operation fails to be proper, it may incur burnout to the circuit board, the oscilloscope, and other equipment and materials.

Secondly, the first step of debugging is to debug the control circuit, so as to ensure that the control circuit can work normally, and then to connect the control circuit into the main circuit.

Thirdly, the chip should be located as close as possible to the output feedback voltage resistor. Moreover, the driver chip should be also placed approximately to the switch tube, in order to minimize the driven line between these two.

5. Conclusion
A design of a standard sine wave frequency conversion power supply based on analog and digital integrated control has been completed in this article according to the technical requirements. At the same time, the design of main circuit and the selection of components were introduced in detail, and additionally, the control circuit has also been designed. In the last part of this article, the system is put into test and analysis, through which the designed program of this article is verified. Of this article, the main work listed below has been accomplished, and the following conclusions are also obtained through the experimental demonstration:

(1) The rectification has reached an effect of reducing input harmonics and improving the power factor of the input terminal by adopting APFC technology.

(2) Compared with a pure analog, the digital control and analog control avoided several shortcomings involved in the pure analog, which includes a large demand of discrete components, low circuit reliability, an increase of system cost, the high difficulty in system debugging, the hard troubleshooting for faults, the vulnerability to the ambient temperature, as well as the aging problems.

(3) The combination of digital control and analog control \cite{10} is featured with a good dynamic control response and an effective performance to reduce the harmonic wave content of the controller output voltage. While retaining the advantages of high precision and fast dynamic response of the original analog control, it is also introduced in the flexibility and controllability of the digital control. The modulation pattern of the digital-analog combination possesses an effect which is similar to the one of pure digital system. Furthermore, this combination replaced the triangular wave modulation programme in the control chip, due to the achievement triangular wave modulation by analog circuit, which to a certain extent saved the on-chip resources and improved the running speed of the control chip.

(4) With a good working performance, the power rectification can be put into a stable operation for a long time, which provides a stable voltage for the inverter part and satisfies the power output requirement. The drive circuit can realize the signal amplification well, and can drive the MOSFET to be powered on and off. The wave filtering effect was good. Both of the waveform and amplitude of the output voltage meet the requirement. In addition, a good effect on the frequency modulation and voltage regulation has been realized under the control of DSP \cite{11}.

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