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ALTERNATING CURRENT EXCITATION CONTROL OF ASYNCHRONIZED SYNCHRONOUS GENERATOR BASED ON DSP

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ABSTRACT:

Design alternating current excitation system based on TMS320LF2407 in terms of characteristic of Asynchronized Synchronous Generator after thoroughly studying control thoery and control strategy of alternating current excitation. This paper emphasis on the method of implementing excitation current with low harmonic, quick adjusting speed, wide adjusting range and high control precision of frequency. Experimental results are given in the paper.

KEY WORDS: Asynchronized Synchronous Generator, AC excitation, TMS320LF2407

1. INTRODUCTION

The stator's winding structure of Asynchronized Synchronous Generator (ASG) is the same as that of traditional synchronous generator. However ASG's rotor has multi-phase wounded winding structure. The adjustable quantities of excitation in ASG is excitation current's magnitude, frequency and phase. The angle (i.e. power angle) between generator's electromotive force (EMF) E and terminal voltage U will be changed when excitation current's frequency or phase is varied. Hence ASG's excitation adjustability will not only regulate generator's reactive power, but also change generator's active power, which is a new approach to enhance available electric system's steady and dynamic stability, extend generator's operating range.

The reason that alternating current (AC) excitation ASG has much nicer adjusting traits, running reliability and mobility is ASG must have a excitation control system to exert ASG's running characteristic, besides multi-phase alternating current (AC) excitation in ASG's rotor. At present, the AC excitation control systems are almost based on microcontrollers, which improve on PWM wave production, deadband control etc. to suit motor control. However microcontrollers' low speed in signal processing is not improved. It is more suitable for the system with implementing simple algorithm and requiring not high dynamic performance. This paper proposed a new scheme of AC excitation based on TMS320LF2407 (for short, thisafter calling 'LF2407'), and emphasizes on the controlling and calculating method about implementing excitation current with low harmonic, quick adjusting speed, wide adjusting range and high control precision of frequency.

2.SYSTEM DESIGN

Fig. 1 is the block diagram of ASG AC excitation system. System's main circuit is AC-DC-AC voltage source inverter (VSI), which contains rectifier, filter with large capacitor and inverter. The diode rectifier can be used simply when inverter is controlled by PWM technique. However system requires excitation voltage's magnitude has large changing range and generator exists especial operating situation such as "strong excitation", hence the silicon controlled rectifier is used in the system. The DC voltage can be controlled by changing thyristors' trigger angle. System control unit contains rectifier control module, inverter control module, generator's rotor speed and rotor position measuring module, information exchange module. This four modules are all controlled by LF2407. The relations among modules are linked through LF2407's program. The whole control system controls the main circuit to produce excitation current with low harmonic, quick adjusting speed, wide adjusting range and high control precision of frequency based the references of excitation voltage frequency f_{ref}, magnitude V_{ref} and initial phase θ_{0ref} received from PC.

Rectifier control module includes typical feedback controller, whose feedback signal is DC voltage from DC voltage transformer. The reference of controller V_{DC_ref} is little greater than excitation voltage magnitude reference V_{ref}. It is commonly chosen as $V_{ref}/0.9$. The controller outputs thyristors' trigger angle signal V_{OUT} to control the magnitude of DC voltage through D/A IC MAX5121 interfaced with LF2407's SPI module. The core algorithm of rectifier control module is position PID control algorithm. Parameters used in the algorithm are acquired through experiment with engineering method.

Inverter control module controls the inverter to transform DC voltage to AC voltage with referenced frequency, magnitude and initial phase. The control strategy of inverter switch device IGBT is SPWM (Sine Pulse Width Modulation). The SPWM wave is generated by using regular sampling method, which is widely used in engineering and easily carried out by LF2407's program. In other words, LF2407 must timely calculate three-phase duty cycle in term of formula (1) and update LF2407 PWM compare registers respectively during each PWM period T_C (The modulating frequency is 5KHz, T_C is 200us).

$$D_i = \frac{1}{2}[1 + a\sin(\frac{2\pi}{N}i + \theta_0)] \qquad (i=0,1\ldots N-1) \qquad (1)$$

In formula (1), D_i is the duty cycle of the ith PWM period. $N = \frac{F_C}{F_R}$, of which F_C is the frequency of triangle carrier wave and F_R is the frequency of sinusoidal modulating wave. θ_0 is the initial phase of sinusoidal modulating wave. a is tune-in scale, $0 \le a \le 1$.

The detail of adjusting strategy of excitation voltage is explained as follows: In steady state, the measuring value of DC voltage $V_{DC} \approx V_{DC\_ref} = V_{ref}/0.9$ because of the function of PID, so the tune-in scale of SPWM wave is a=0.9. However during dynamic adjusting processing, the tune-in scale will be limited between 0.8 and 1 through the program chopping. If V_{DC_ref} changes within ±10%, inverter control module will keep V_{DC_ref} constant and directly adjust tune-in scale to implement quick response. As PID modulation needs some time and the function of capacitor filter causes system's response delay. All above steps will ensure inverter working under high tune-in scale, which guarantees to control the output AC voltage magnitude with high resolution and reduce the harmonics.

Rotor speed and rotor position are the necessary parameters in motor control algorithm such as vector control and dual-channel control. Moreover, in order to improve the control precision, these parameters must be measured accurately. The generator's rotor speed and rotor position measuring module timely provide rotor speed and rotor position information for the algorithm running at PC.

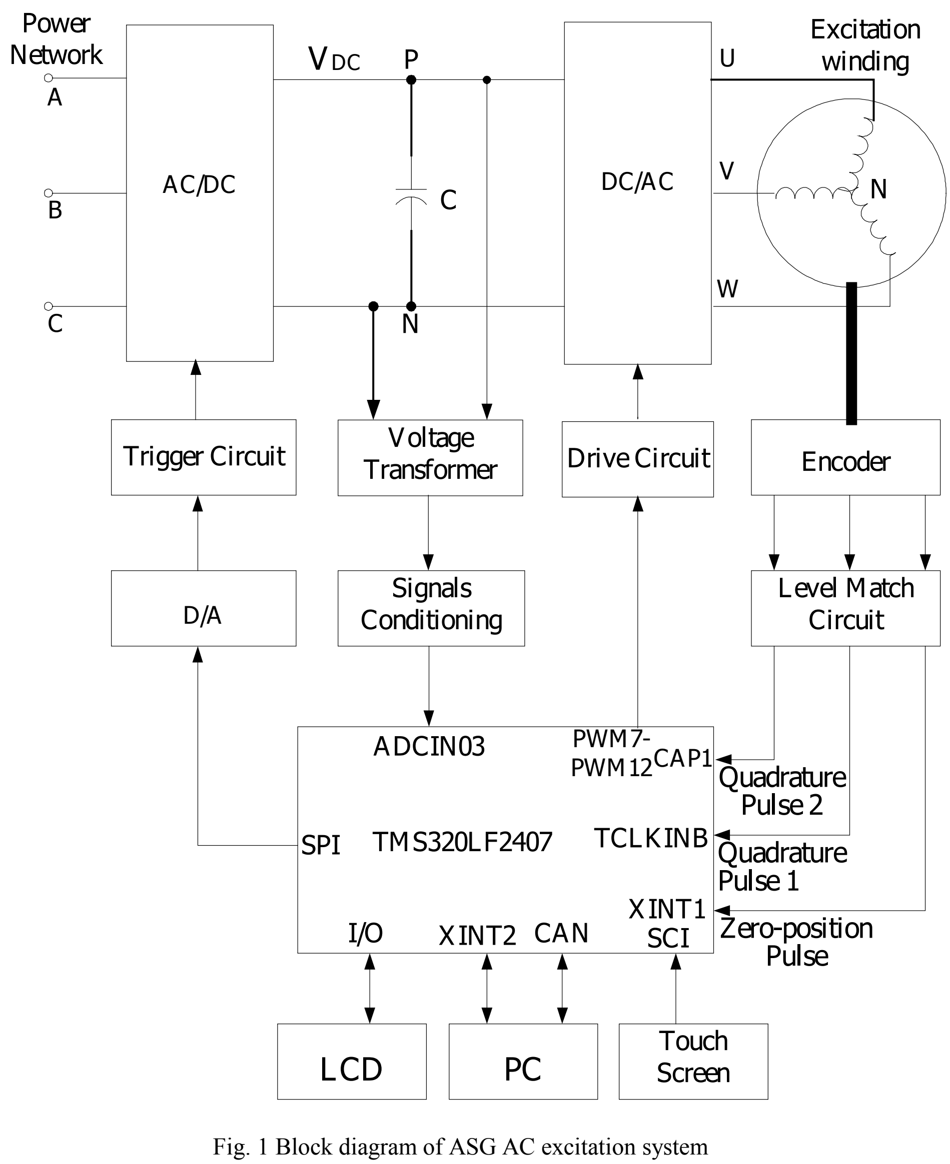

Fig. 1 Block diagram of ASG AC excitation system

Rotor speed signal measured by encoder, which outputs two quadrature pulse and one zero-position pulse. The two-quadrature pulse's frequency is proportional to rotor speed, so it is used to rotor speed measurement. The zero-position pulse is produced one time each loop of rotor rotation and it can be used to identify rotor's zero position and measure the rotor position after the encoder is equipped and calibrated on the rotor.

System's information exchange module contains exchanging information with PC and control system's parameters setting, measuring data's displaying etc. LF2407 sends the rotor speed and rotor position to PC and receives the references of excitation voltage's frequency f_{ref}, magnitude V_{ref}, initial phase θ_{0ref} from PC by CAN (Control Area Network) bus. Otherwise, PC synchronizes LF2407's parameters measurement through XINT2 interrupt of LF2407, which starts the rotor speed and rotor position measuring. Control system's parameters setting and data displaying are implemented by LCD and touch screen respectively, which forms rich functions and friendly interface.

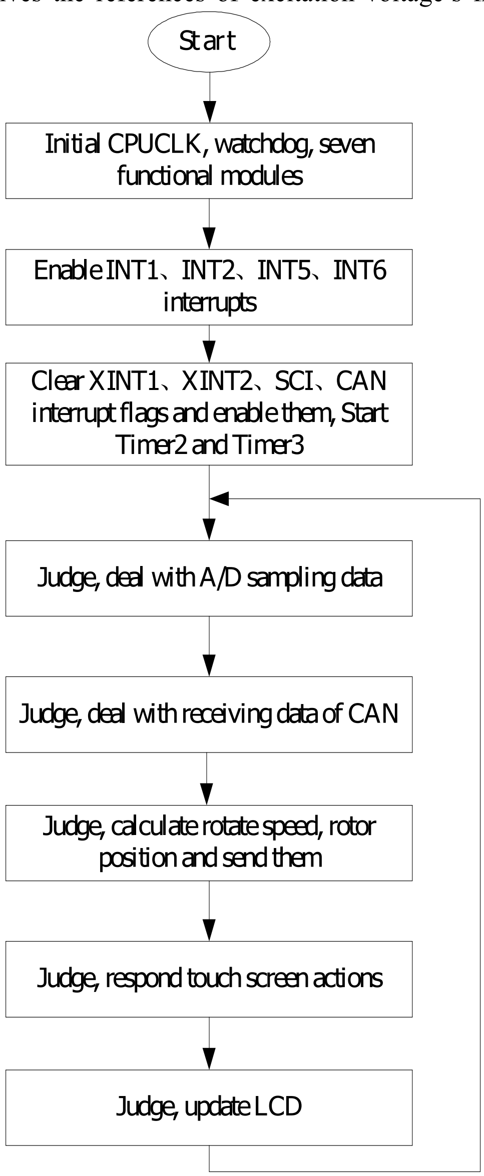

Fig.2 Flow chart of main program

3. PROGRAM DESIGN

LF2407 uses the float point computation to deal with data and control algorithm in order to increase system's control precision. There are several methods to carry out float point computation on LF2407 such as accurate computation, approximate computation, look-up table and interpolation used in some special function program. For example, sine value can be calculated by accurate computation through directly calling TI's floating functions library. The sine function in library includes one floating comparison operation, five floating addition operations, two floating subtraction operations, ten floating multiplication operations and two data-type conversion operations. The function spends about 652us running time under 24MHz CPUCLK and involves about 231 words program space (the space doesn't include the involving space of called subroutine by sine function). Moreover, calling sine function in assemble language must conform to C language calling criterion of LF2407. The criterion requires passing parameters to sine function by stack and fetch results from stack after calculation, which increases additional running time and program space. The program using look-up table and interpolation to calculate sine value is short and only spends about 1.75us under 24MHz CPUCLK. But the sine table occupies large program space and fixed step table causes the different precisions of sine wave at different frequencies. Moreover, this method doesn't suit to non-periodic occasion. Specially, the produced sine wave has many harmonics at low frequency such as 0.05Hz. The detail error analysis is discussed in the reference [3].

Approximate computation is a compromising method, which can complete quite accurate calculation with less program space and running time. The approximate computation of sine wave can use intercepted series formula. The intercepted item lies on required precision. The formula of sine series after intercepting frontal four items is shown as following:

$$\sin x = x - \frac{x^3}{3!} + \frac{x^5}{5!} - \frac{x^7}{7!}$$

$$x \in [0, 2\pi] \quad (2)$$

$$= (((-\frac{x^2}{5040} + \frac{1}{120}) \cdot x^2 - \frac{1}{6}) \cdot x^2 + 1) \cdot x$$

Before calculating, all numbers must be transformed to Qm.n format. Then sine value is calculated in terms of formula (2) through several addition, subtraction and multiplication. In Qm.n format, m presents the integer bits and n presents the decimal fraction bits. In addition, there is one sign bit at the MSB. So the Qm.n number can be shown by (m+n+1) bits binary. Its integer range is （$-2^m, 2^m$）. The decimal fraction resolution of Qm.n number is 2^{-n}. Q.7, Q.15, Q7.8, Q9.6, Q.31, Q15.16 are several typical Qm.n formats.

The calculation of sine value is the core part of inverter control module and determines system's control performance. In order to achieve excitation current with low harmonic, quick adjusting speed, wide adjusting range and high control precision of frequency, the approximate computation method is used in the system program design because accurate computation method can't complete calculating task within each PWM period (200us), look-up table and interpolation method can't achieve sufficient precision at low frequency. The numbers used in the algorithm are all converted to Q.15 format. The whole sine calculating program spends about 17us and calculating precision reaches 1/10000 at any frequency from 0.05Hz to 50Hz by 0.05Hz step length. In this way, three-phase SPWM duty cycle calculation in terms of formula (1) spends about 59us, which can be completed easily within each PWM period.

Time distribution of control system program is the base of system's program organization. All tasks must be dealt with timely through reasonable task arrangement. The AC excitation control system uses typical foreground/background model. The main program serves as background and interrupts' ISRs serve as foreground. System program responses all measuring, controlling, communicating and displaying tasks in time through switching between foreground and background, queue

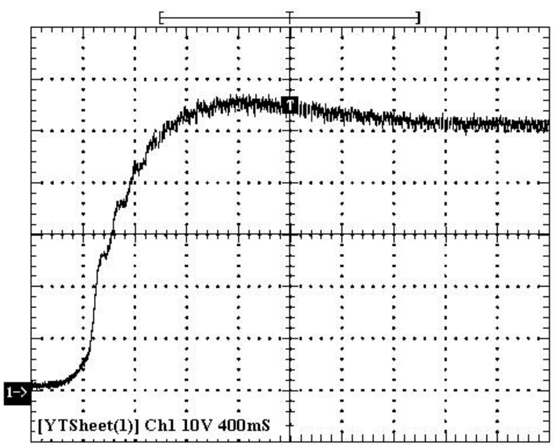

Fig.3 DC voltage adjusting waveform

tasks in terms of priority level.

System runs at 24MHz CPUCLK and uses Timer2, Timer3's timing functions. Timer2 is equal to interval timer of A/D converter. Its period is 10ms/16=0.625ms. Timer2's period match starts A/D converter with no interrupt. However, Timer3 produces interrupt every 200us. In Timer3 ISR, three SPWM's compare registers are updated and new group values used in the next PWM period will be calculated. At the same time, 200us also serves as time benchmark to extend the LCD's updating time (about 3 times per second). SPWM calculation is placed in the Timer3's ISR because of its importance. The required time of whole Timer3's ISR is about 71us. So there is 200us-71us=129us time left for main program and others ISRs in every PWM period. Because all ISRs and data processing program except LCD displaying subroutine are short, they are running out within 129us. Therefore, in general the main program can run one cycle

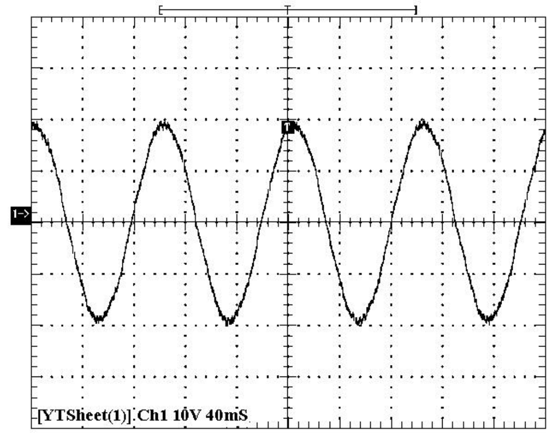

Fig.4 Excitation current waveform

within 200us, which deals data timely.

System program follows structural and modular programming idea. The whole system program is separated into eight modules with rule of module independence: main program, SPWM, PID, LCD, CAN, AD, DA, SPEED.

Fig.2 is the flow chart of main program. After starting, system's running frequency is set as 24MHz and watchdog is configured. Then seven modules are initialized, which includes shared pins and registers configurations, variables used in respective modules initializations. The needed interrupts (INT1, INT2, INT5,

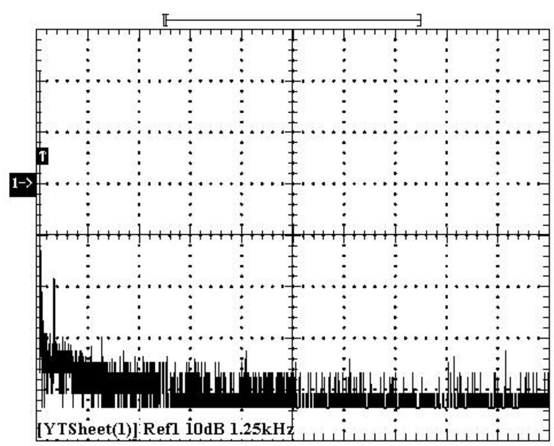

Fig.5 Frequency chart of excitation current

INT6) are opened. The two external interrupts, SCI interrupt, CAN interrupt flags are cleared and these interrupts are enabled thereon. Timer2 and Timer3 are started. Finally, main program enters infinite loop. The loop includes judging and executing of A/D sampling data, CAN receiving data, calculating rotor speed, rotor position and sending these information, responding touch screen, updating LCD display etc..

4. EXPERIMENT DATA AND PERFORMACE ANALYSIS

System experiment uses DC motor-three phases wounded winding asynchronous motor experimental rig. Here DC motor simulates water pump and three phases wounded winding asynchronous motor serves as ASG. The parameters of rig are:

DC motor: Rating power: 7.5kW, Excitation mode: parallel, Rating voltage: 220V,Rating current: 41.1A, Excitation voltage: 220V, Excitation current: 205A, Rating rotor speed: 1000r/min.

Three-phase wounded winding asynchronous motor: Rating power: 7.5kW, Stator rating voltage: 380V, Stator rating current: 18A, Rotor voltage: 220V; Rotor current: 28A, Rating frequency: 50Hz, Rating rotor speed: 940r/min.

The asynchronous motor's excitation winding is supplied and controlled by designed system. Fig.3 and Fig.4 are the DC voltage adjusting waveform and excitation current waveform.

Fig.3 shows the PID adjusting process of DC voltage. It can be seem from the figure, DC voltage appears 5V overshot when it steps from 0V to 50V and it is about 50V in steady state. The transient time is about 400ms. It is the result of globally considering system's responding speed, stability and steady state error.

Fig.4 is the excitation current waveform at f_{ref} =10Hz, V_{ref}=50V and $\theta_{0ref}=0^0$. The frequency of output excitation current shown in the figure is almost equal to f_{ref}. But the magnitude and initial phase of excitation current are only indirectly controlled through excitation voltage. It is the inherent characteristic of AC-DC-AC main circuit.

The waveform of Fig.4 is decomposed with FFT and its frequency chart is shown in Fig.5. Excitation current contains 50Hz and 5kHz harmonic except fundamental from Fig.5. They are introduced by operating frequency and carrier wave of SPWM respectively.

From the experimental results, the designed system attained scheduled standard. The system takes full advantage of LF2407's high speed and earnestly considers in program design to implement excitation current with low harmonic, wide adjusting range and high control precision of frequency. System's quick response is achieved by comprehensive control of rectifier and inverter. On the other hand, there are some advice on mending shortage of the designed system. The frequency, magnitude and phase of excitation current can be directly controlled by AC-DC-AC current source inverter (CSI). The harmonic introduced by operating frequency and carrier wave of SPWM may be effectively reduced by using trapezium PWM technique or new switching strategy such as dual- modulation.

5. CONCLUSION

The designed system takes full advantage of LF2407's high performance core and rich on-chip peripherals, distributes the resources in reason, cooperate well through hardware and software to control ASG's excitation current with low harmonic, quick adjusting speed, wide adjusting range and high control precision of frequency. The system reached control goal by experimental verification. Moreover, the many LF2407's rest resources such as program space, data space and on-chip peripherals etc. can easily carry out extending and optimizing system function. At the same time, the paper puts forward some proposed schemes to improve system performances
Clearly indicate advantages, limitations and possible applications.

REFERENCES

[1] Texas Instruments. TMS320LF/LC240x DSP Controllers Reference Guide: System and Peripherals. April 2001.

[2] Texas Instruments. TMS320LF2407 DSP Controllers Data Sheet. August 2000.

[3] Texas Instruments. Sine, Cosine on the TMS320C2xx. 1997

[4] Yang Shunchang etc. Asynchronous generator. Chongqing: Chongqing University Press, 1991.

[5] Wu Anshun etc. The newest applied frequency conversion technology. Beijing: Machine industry press, 1998.

[6] Huang Jun, Wang Zhaoan. Power electronics technology. Beijing: Machine industry press, 1993.