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Research on output frequency of linear phase-shifting transformer

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Research on output frequency of linear phase-shifting transformer

Shuheng Zhang*, Jinghong Zhao, Yangwei Zhou and Mei Wu

Electrical engineering, Naval University of Engineering，Wu han ，430033，China

*Corresponding author's e-mail: 1577785934@qq.com

Abstract. The article briefly introduced the basic structure of linear phase-shifting transformer and the working principle of inverter system. After the previous work of the research group，based on the maxwell simulation software, the high-frequency output of the linear phase-shifting transformer is subjected to finite element simulation analysis, and an improved design is proposed for the high-frequency output. Finally, the feasibility of simulation analysis is verified through experiments, which provides strongly support for subsequent prototype optimization.

1. Introduction

In recent years, as a kind of professional transformer[1-3], phase-shifting transformer can be used in various occasions such as electrical equipment and precision instruments. At present, it is mainly divided into Phase-shifting transformer with self coupling topology and Circular phase-shifting transformer.The traditional phase-shifting transformer has some problems such as single phase-shifting angle, complicated winding, and difficult to control the air gap magnetic field. The design and connection of traditional phase-shifting transformer windings are difficult, and the volume and weight of the transformer are greatly increased. To make the structure of phase-shifting transformer more simple, and make phase-shifting more various, according to the structural principle of the linear motor, the literature proposed a new type of linear phase-shifting transformer, which can realize the accurate winding ratio of transformer and has the advantage of expansion.This article introduces the basic principles of linear phase-shifting transformers first. Based on the research by Jinghong Zhao et.al. of Naval University of Engineering, the high frequency output of the transformer is simulated and analyzed, and verified by experiments, and the improved high frequency output design scheme is proposed.

2. Principle of linear phase-shifting transformer

The linear phase-shifting transformer is a new type of transformer based on the operating principle of linear motor,the length and width of the core on the primary side and secondary side of the transformer are the same,the iron core groove of the primary and secondary sides (corresponding to the stator and rotor in the motor) corresponds to each other,keep relatively motionless.Install adjustable air gap between primary side and secondary side[6-8].When symmetrical three-phase alternating current is connected to the three-phase winding on the primary side,the three-phase alternating current is controlled by 24 IGBT tubes to synthesize 24 step waves,there is a translational sinusoidal magnetic field in the air gap, is also called traveling wave magnetic field.When the traveling wave magnetic field moves in the sequence of phase A, B and C ,as shown in the figure below,sinusoidal magnetic field generates electromotive force by cutting secondary coil,three phase step wave current is obtained at the secondary side,No load output is 24 step wave,DC ripple factor can be guaranteed within 5%.

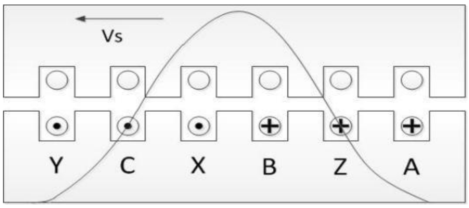

Fig.1 Structural diagram of linear phase-shifting transformer

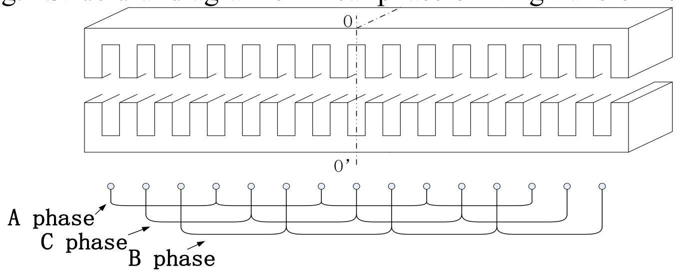

Fig2 Structure of linear phase-shifting transformer

3. Inverter system of linear phase-shifting transformer

The inverter system of the linear phase-shift transformer employs the technology of multi overlap and inverter: stacking and synthesizing 2N echelon wave by N square waves of phase shift **π**/N in turn.

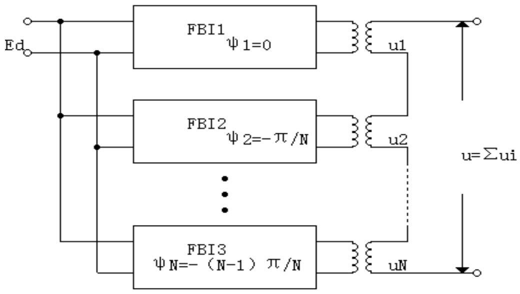

Fig.3 Phase-shifting multi overlap inverter

Four groups of three-phase half bridge inverters consistsof 24 IGBT switch tubes,control output voltage wave form by controlling 24 IGBT switches.The switches on the same bridge arm lag each other by 180 degrees,the three-phase output of the same group of inverters lags 120 degrees in turn, while the switches corresponding to each group of inverter circuits lag 15 degrees in turn.The output phase voltage of three-phase inverter is six step wave.Four groups of six step waves lag 15 degrees in turn,The superposition is composed of 24 step waves, and the waveform is close to the sine wave[9].

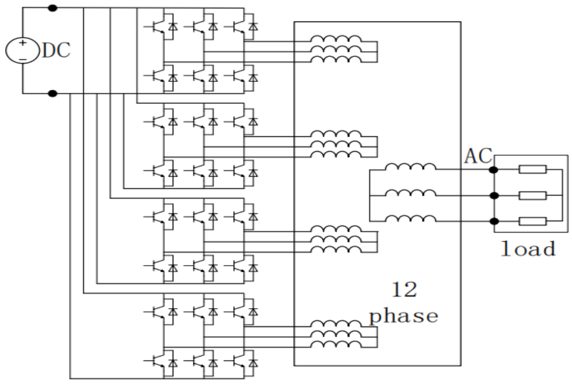

Fig.4 Inverter system circuit

4. Simulation and design of linear phase-shifting transformer

4.1 Parametric design

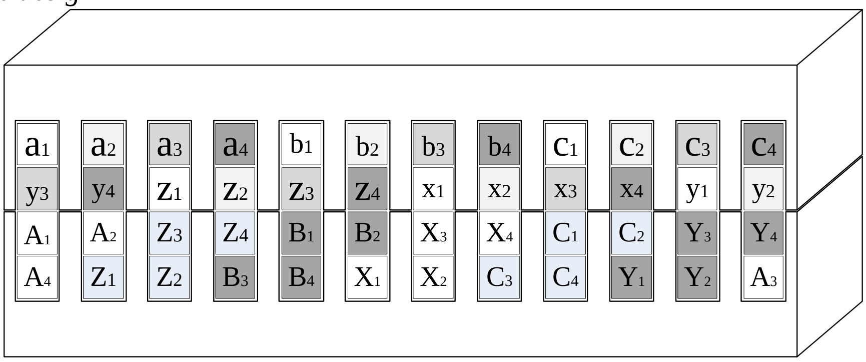

Fig.5 Winding distribution of linear phase shifted transformer

As shown in the figure,there are three dimensional physical model and winding distribution of linear phase-shifting transformer,among the upper section is the primary side of the transformer, and the lower section is the secondary side of the transformer.Based on the previous research of Jinghong Zhao, Ziming Zhang, etc,applying to the best parameter selection for linear phase-shifting transformer.The main parameters are as follows[9-11] :

Output phase voltage： $U_A = U_B = U_C = 200V$；
Output frequency： f=50Hz；
Output power： P=1000W；
Primary phase number： $m_1 = 12$；
Secondary phase number： $m_2 = 12$；
Primary slot number： $Z_1 = 12$；
Secondary slot number： $Z_2 = 12$；
Polar logarithm： p=1；
Groove spacing： d=18mm；
Core length： L=216mm；
Core heighten： H=40mm；
Primary and secondary air gap： 0.3mm；
Core Stack thickness： σ=100mm；

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4.2 Simulation analysis

In this section, the frequency output simulation analysis of linear phase-shift transformer is carried out based on Ansoft Maxwell.Based on the linear phase-shift transformer, the multi overlap plus inverter has the advantages of being suitable for high frequency inverter,The output frequency of simulation experiment is 50Hz.This section mainly compares the inverter effect of the inverter system at different frequencies[12].

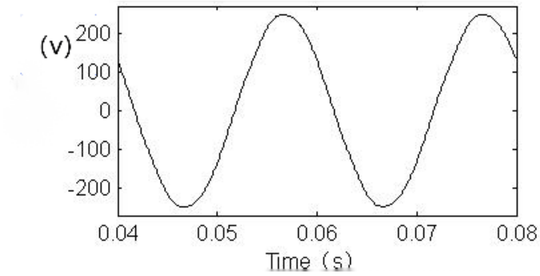

Fig.6 Voltage waveform when output frequency is 50Hz

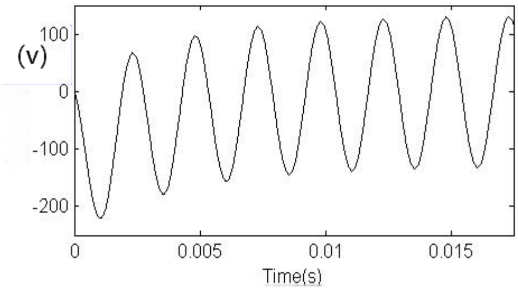

Fig.7 Voltage waveform when output frequency is 400Hz

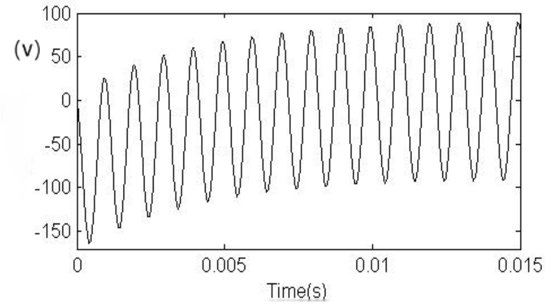

Fig.8 Voltage waveform when output frequency is 1000Hz

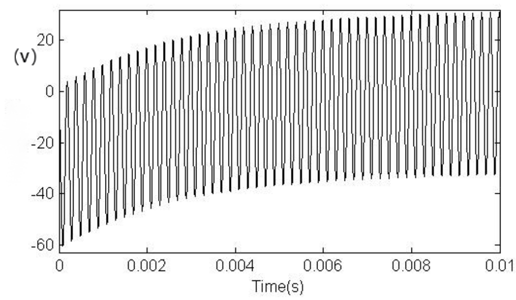

Fig.9 Voltage waveform when output frequency is 5000Hz

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Tab1. Voltage amplitude and efficiency of transformer at different frequencies

Frequency	voltage amplitude	harmonic component	efficiency of transformer
50Hz	233	1.29%	90.24%
400Hz	134	1.08%	65.57%
1000Hz	91	1.23%	41.53%
5000Hz	31	1.09%	12.83%

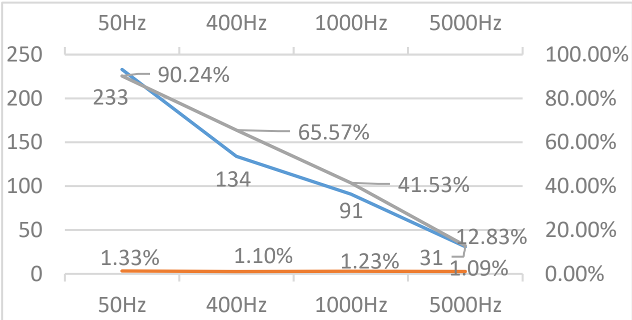


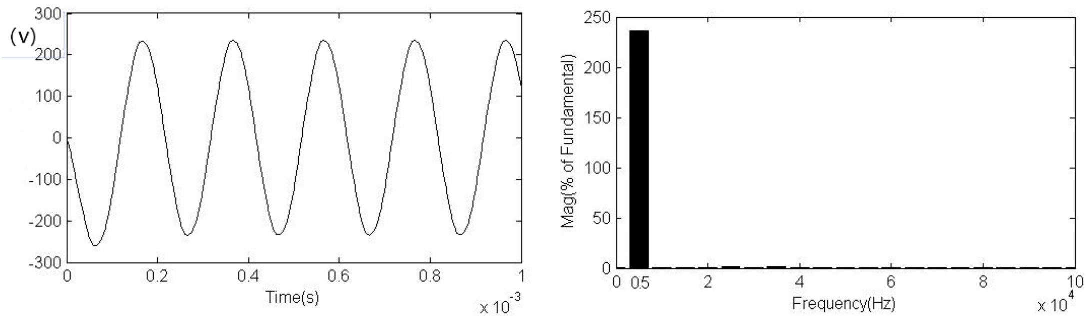
Fig.10 Variation trend of voltage amplitude and transformer efficiency

From the data of simulation results, the following conclusions can be drawn:

(1)When the inverter frequency is higher than the designed frequency，the voltage amplitude will decrease with the increase of frequency.The reason is that as the frequency increases, the inductive reactance of the winding increases proportionally, the partial voltage of the winding increases, the output voltage decreases, and the system efficiency decreases significantly

(2)When the inverter frequency becomes higher, the harmonic component decreases, all of which are about 1%.

(3)For conclusion (1), it can be verified by redesigning the linear phase-shifting transformer: We can reduce core size. At the same time, the number of winding turns is reduced to one tenth of the original, and the frequency is 5000Hz. After reducing the number of turns, the voltage harmonic component is 1.23%, the voltage amplitude is basically the same as the output voltage amplitude of 50Hz before changing the number of winding turns, the efficiency can reach 90.23%, and the inverter effect is good.



(a) Voltage waveform (b) Voltage spectrum analysis

Fig.11 Voltage waveform and spectrum analysis when turns to 1/10

5. experimental confirmation

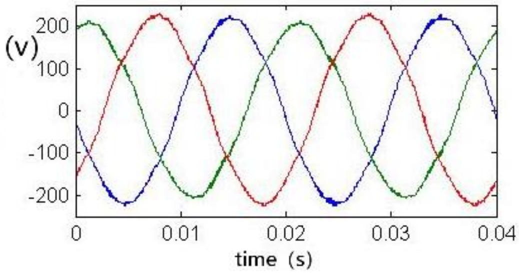


Fig.12 Voltage waveform at 50Hz

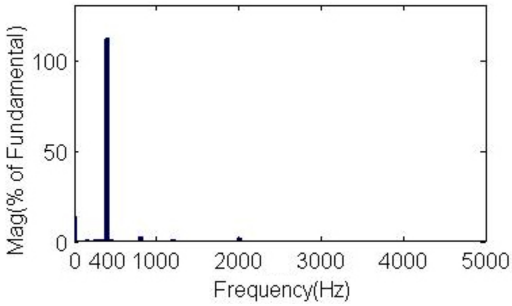


Fig.13 Voltage spectrum analysis at 50Hz

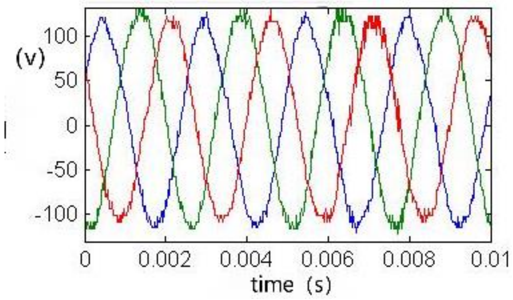


Fig.14 Voltage waveform at 400Hz

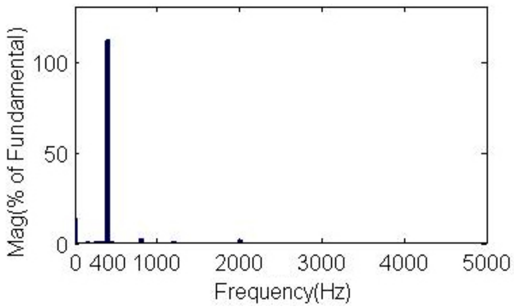


Fig.15 Voltage spectrum analysis at 400Hz

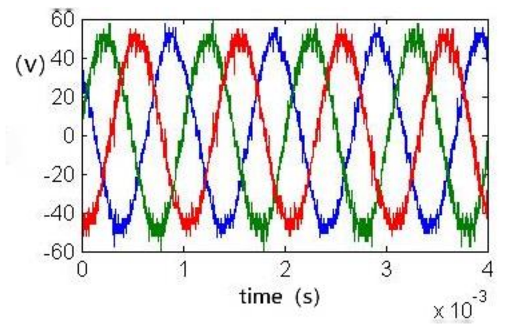


Fig.16 Voltage waveform at 1000Hz

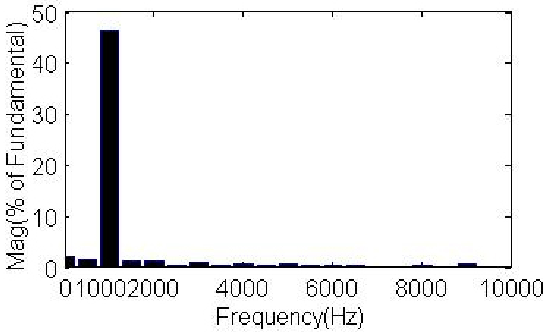


Fig.17Voltage spectrum analysis at 1000Hz

Tab.2 The amplitude and harmonic component of the voltage at different frequencies

Frequency	voltage amplitude	harmonic component	efficiency of transformer
50Hz	230V	2.11%	86.22%
400Hz	125V	4.68%	55.70%
1000Hz	69V	7.77%	32.56%

6. conclusion:

(1)The voltage amplitude decreases with the increase of inverter frequency, and the simulation results are basically consistent with the experimental results.

(2)When applied to high frequency inverter, it can reduce the number of winding turns and at the same time it reduce the volume and weight of linear phase-shifting transformer.

(3)In this paper,the working principle of the linear phase-shifting transformer studied is similar to that of the motor with locked rotor, the starting time of the inverter system is equivalent to the time when the motor stalls, the current value first increases and shifts when the motor is locked, and then slowly stabilize. Because the current in this system also changes according to this rule when it is started and the load of this system is pure resistance, the law of voltage change is the same as that of current change.

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