Journal of Electrotechnology, Electrical Engineering and Management (2023)
Clausius Scientific Press, Canada
DOI: 10.23977/jeeem.2023.060501
ISSN 2560-6697 Vol. 6 Num. 5

Simulation Study on Conducted Emission from Power Line of Three-phase Three-level Inverter

Guanghao Wu[1,*], Meiyuan Chen[2], Chunlei Wang[2], Yiyi Liu[2], Yang Teng[1], Qionggang Luo[1]

[1]*Chengdu Hezong Nuclear Power Engineering Company Limited, Chengdu, 610000, China*
[2]*Science and Technology on Reactor System Design Technology Laboratory, Nuclear Power Institute of China, Chengdu, 610041, China*
[*]*Corresponding author*

Keywords: Electromagnetic Compatibility Test, Power Line Conducted Emission, Three-Phase Three-Level Inverter, DC Input Bus Current

Abstract: Inverters are widely used in various I&C equipment. According to equipment qualification requirements, I&C equipment needs to pass Electromagnetic compatibility test. The commonly used two-level inverters are difficult to pass the power line conducted emission test items in electromagnetic compatibility tests. Compared to two-level inverters, three-level inverters have the advantage of low harmonic content. In order to quantitatively evaluate the power line conduction and emission performance of three-level inverter, according to the test requirements, this paper takes a typical three-level inverter as an example, combining the Electromagnetic compatibility test methods and test conditions specified in the standard, starting with LISN, cables, DC input, inverter main circuit, filter and load, etc., gives the circuit structure, parameters and solution methods of each link in detail, and establishes the simulation model of each link. By setting typical parameters and operating conditions, the time-domain waveform of the DC input bus current, as well as the frequency domain waveform of CE101 and CE102 segments, were obtained through simulation. Through the analysis of the simulation results, it is clear that the power line conducted emission level of the three-phase three-level inverter meets the Electromagnetic compatibility test requirements, and has sufficient margin.

1. Introduction

Inverter is one of the commonly used equipment in all kinds of equipment, the current commonly used inverter is two-level structure, there are problems such as high output voltage harmonic content, poor electromagnetic compatibility and so on, it [1] is difficult to pass the electromagnetic compatibility test requirements of the power line conduction emission test. [2] In theory, the three-level [3-4] structure of the inverter is conducive to reducing the output voltage harmonic content and improving electromagnetic compatibility, but its effectiveness needs to be further verified and evaluated.

GAMOUDI R, CUI K E, Gao Ying et al. compared the influence of different modulation modes of three-level NPC converter on EMI noise, and used random period modulation technology to effectively suppress EMI noise. Random carrier frequency mode can also reduce [5-7] EM noise.

However, at present, there are few conducted emission studies on the combination of three-level inverter and electromagnetic compatibility test, which cannot achieve effective quantitative evaluation. Therefore, this paper establishes a detailed simulation model of three-phase three-level inverter in use to study whether the conducted emission level of its power line meets the requirements of electromagnetic compatibility test.

2. Three-phase Three-level Inverter Structure

Figure 1 shows the structure of the main circuit of the three-phase three-level inverter, which is mainly composed of 12 controllable power devices, 2 midpoint balance capacitors, 6 midpoint clamp diodes, DC power supply, output LC filter and load. C1, C2 can make the DC side to get two of the same voltage, for one phase, two diodes Dz1, Dz2 to achieve level clamp, 4 switching tubes from top to bottom of the 1, 3 tubes and 2, 4 tubes are complementary on, each phase has Udc/2, 0, −Udc/2 these 3 switching states [8-9]. Take phase a as an example: when S1 and S2 are switched on, the output voltage Udc/2 relative to the midpoint O; the output voltage is 0 when S2 and S3 are switched on; Output voltage −Udc/2 when S3 and S4 are switched on.

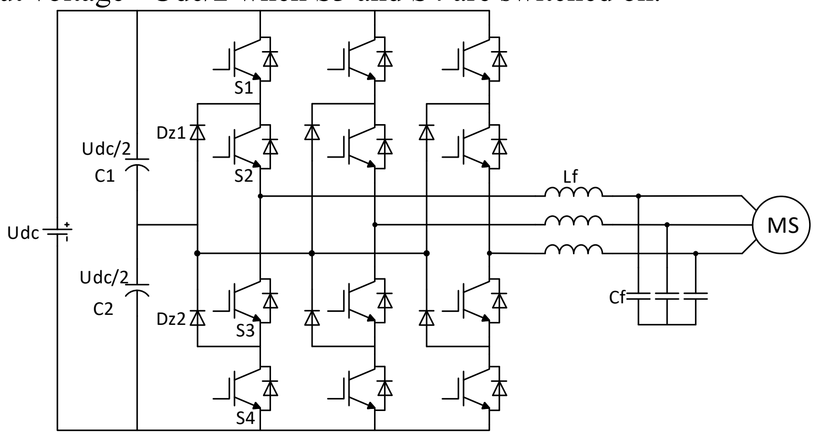

Figure 1: Main circuit structure diagram of three-phase three-level inverter.

3. Simulation Model Establishment

According to the test method of GJB 151B-2013 "Electromagnetic emission and Sensitivity Requirements for Military Equipment and Subsystems", when three-phase and three-level inverter conducts the power Line conduction emission test, the main links involved include Line Impedance Stabilization Network, LISN), cable, DC input, power main loop, filter and load. First establish a simulation model for each part, and then combine to form a complete simulation model [10].

3.1. LISN

The LISN is a necessary device in the conducted emission test of the power line, which is used to isolate radio wave interference, provide a stable test impedance, and play the role of filtering. According to the circuit diagram and parameters required by the standard, the simulation model of LISN is established, as shown in Figure 2. The input end of LISN is DC input voltage, the amplitude is 150V, and the output end is Equipment Under Test (EUT).

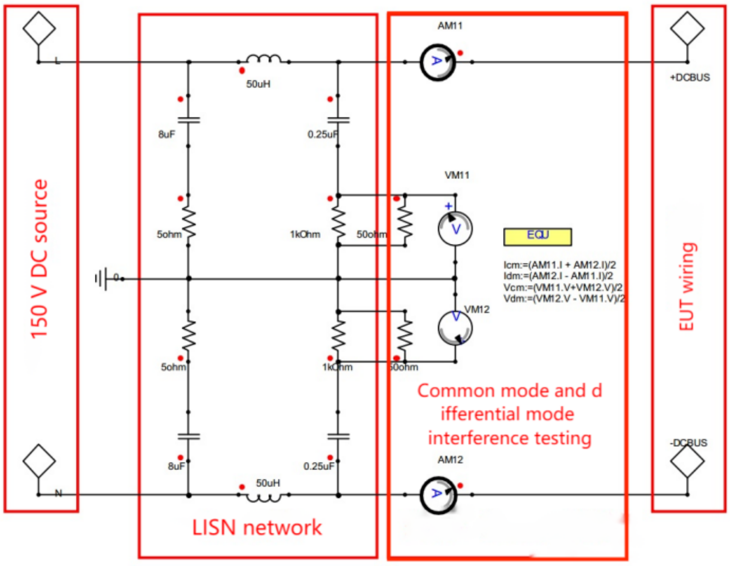

Figure 2: LISN simulation model.

3.2. Cables

Using unshielded cable model can reflect the most severe EMI situation, two-phase input cable and three-phase output cable, both using PI type transmission line model, as shown in Figure 3.

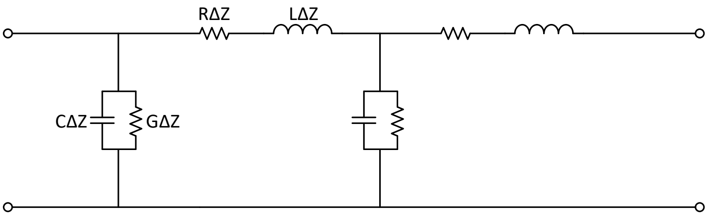

Figure 3: π type transmission line model.

The model in Figure 3 contains four parameters of resistance (R), conductance (G), inductance (L) and capacitance value (C) per unit length of the cable. The conductance of a cable containing an insulating layer is generally negligible, so the cable model is obtained by solving R (by analytical method), L, and C (by numerical method) per unit length.

3.2.1. Resistance R Per Unit Length

Low frequency current is approximately evenly distributed on the conductor cross section, but high frequency EMI has obvious skin phenomenon, and its skin depth can be expressed as:

$$d = \sqrt{\frac{2}{2\pi f \mu \gamma}} \tag{1}$$

Unit length resistance can be expressed as:

$$R = \frac{1}{\gamma\left[\pi r^2 - \pi (r-d)^2\right]} \approx \frac{1}{\gamma 2\pi r d} (d \ll r) \tag{2}$$

Where f is the current frequency, μ is the conductor permeability, γ is the conductor conductivity; When the EMI frequency reaches MHz, the skin depth d is much less than the conductor radius r.

3.2.2. Capacitance C and Inductance L Per Unit Length

According to the boundary conditions of electromagnetic field and the Laplace equation of electromagnetic field energy, the boundary value problem of electromagnetic field is constituted; the distribution of the electromagnetic field in the solving region is obtained by using the numerical method of solving the electromagnetic field. The amount of electromagnetic energy is calculated, and then the capacitance C per unit length and the inductance L per unit length are obtained.

The relationship between the static electromagnetic field energy and the inductance and capacitance parameters of the conductor in the cable can be expressed as:

$$\begin{aligned} W_m &= \frac{1}{2}\sum_{p=1}^{N}\left(l_{pp} I_p^2 + \sum_{q=1, q\neq p}^{N} l_{pq} I_p I_q \right) \\ W_e &= \frac{1}{2}\sum_{p=1}^{N}\left(c_{pp} U_p^2 + \sum_{q=1, q\neq p}^{N} c_{pq} U_p U_q \right) \end{aligned} \tag{3}$$

Where: Wm static magnetic field energy of a multi-conductor transmission line system, Ip and Iq are the current flowing through the conductors in the two cables, lpp is the conductor's self-inductance to the ground, lpq is the mutual inductance between the two conductors; We is the static electric field energy of the multi-conductor transmission line system, Up and Uq are the voltage flowing through the conductors in the two cables, cpp is the capacitance of the conductor to the ground, cpq is the capacitance of the conductor to another conductor.

Through model simulation, the inductance parameter matrix is estimated under the condition of given size and current, and the capacitance parameter matrix is estimated under the condition of given size and voltage.

3.2.3. Cable Simulation Model

The transmission cable is segmented, and then the cable parameters can be obtained by R, L and C per unit length. The simulation model of the cable is shown in Figure 4.

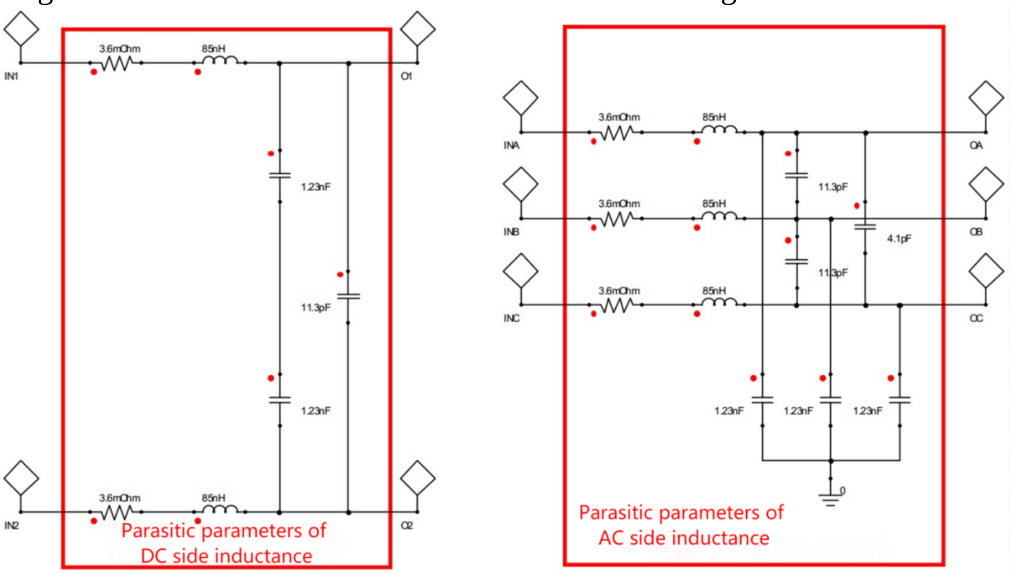

Figure 4: Cable simulation model.

3.3. DC Input

The DC input busbar of the inverter generally includes the DC busbar and the DC busbar capacitor. The simulation model of the DC input side mainly includes the DC busbar parasitic inductance and the equivalent resistance and inductance of the DC busbar capacitor, as shown in Figure 5.

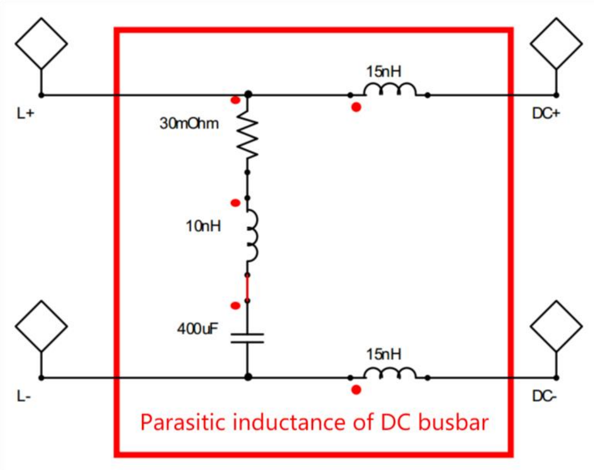

Figure 5: DC input simulation model.

3.4. Power Main Loop

The power main loop mainly includes the power switching device, and the switching device needs to release heat evenly through the heat sink. The heat sink is equipotential grounded with the housing, and the parasitic capacitance between the power switching device and the heat sink is one of the interference coupling paths. The parasitic capacitance is a flat-plate capacitor, and the estimation formula is as follows:

$$C_p = \varepsilon_0 \varepsilon_r A / 3d_p \tag{4}$$

Where A is the contact area, dp is the insulation layer thickness, take A=140x32mm^2, dp=0.9mm, calculated Cp=115pF. Taking the lower half of the main power loop as an example, the simulation model is established, as shown in Figure 6.

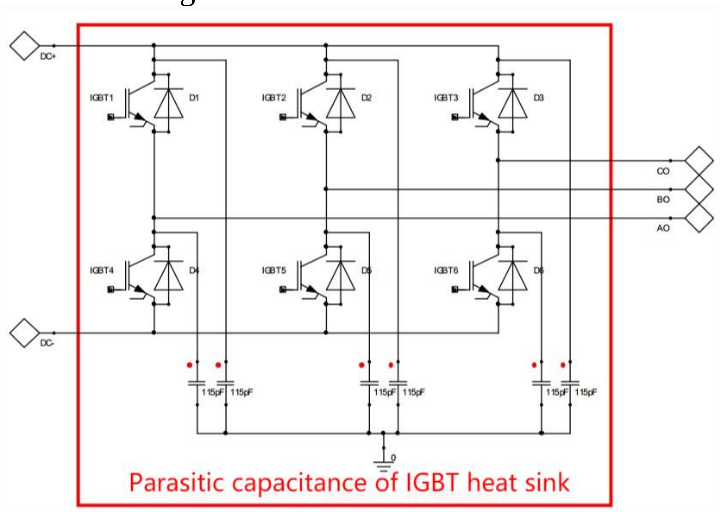

Figure 6: Power main circuit (Lower Half) simulation model.

3.5. Filter and Load

The filter adopts passive LC filter, and the simulation model is shown in Figure 7.

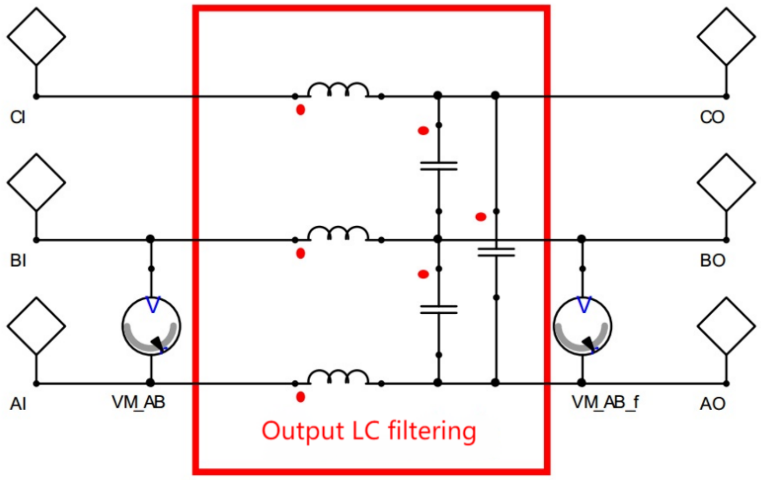

Figure 7: Filter simulation model.

The detailed motor model has high complexity and long simulation time. It is not necessary to use the complex motor model in the simulation of electromagnetic compatibility, and the resistance load and parasitic capacitance models can be used instead of the complex motor model. The parasitic capacitance exists between the motor winding and the housing, and can be estimated by a similar cylindrical capacitance. The expression is as follows:

$$C_q = \frac{2\pi\varepsilon_r h}{\ln\left(R_2 / R_1\right)} \tag{5}$$

Where h is the height of the cylinder, that is, the shaft length of the motor; R2/R1 is the ratio of the outer diameter to the inner diameter of the cylindrical capacitor, and the estimated result is Cq=5nF. The load simulation model is set up as shown in Figure 8.

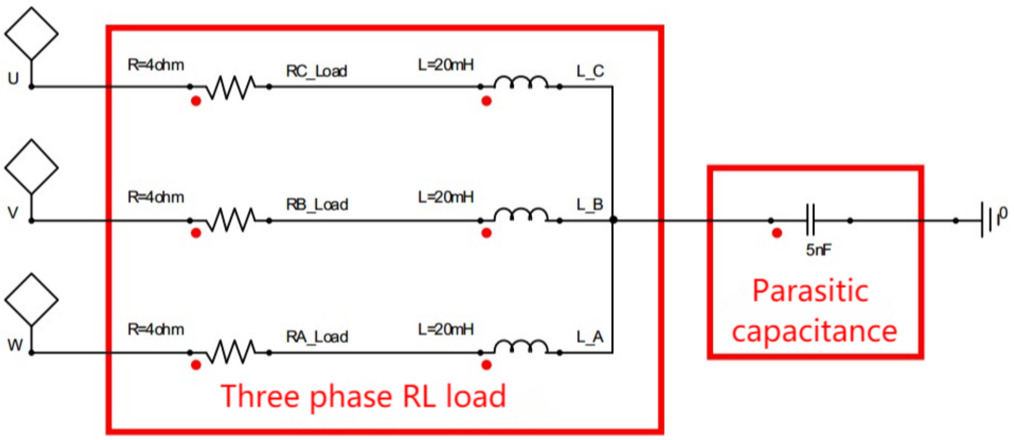

Figure 8: Load simulation model.

4. Detailed Simulation Analysis

Connect each part of the simulation model established in the previous chapter according to the test circuit structure in turn, you can get a complete three-phase three-level circuit simulation model. The simulation parameters are set as follows: SPWM control (modulation wave 2Hz, carrier 18kHz), modulation coefficient 1.0, output filter inductance 0.4mH, output filter capacitance 6.6uF, DC bus capacitance 1000uF.

The power line conduction emission test mainly includes CE101 (25Hz~10kHz) and CE102 (10kHz~10MHz). The time domain, CE101 segment and CE102 frequency domain waveforms of the DC input bus current of the three-phase three-level inverter are obtained by simulation. It is shown in Figure 9~ Figure 11.

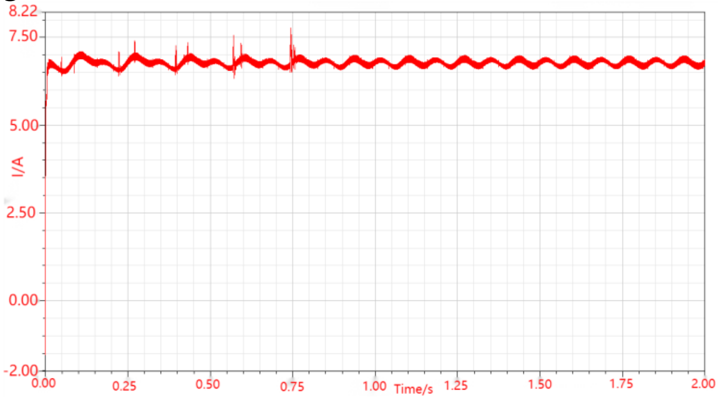

Figure 9: Time domain waveform of DC input bus current.

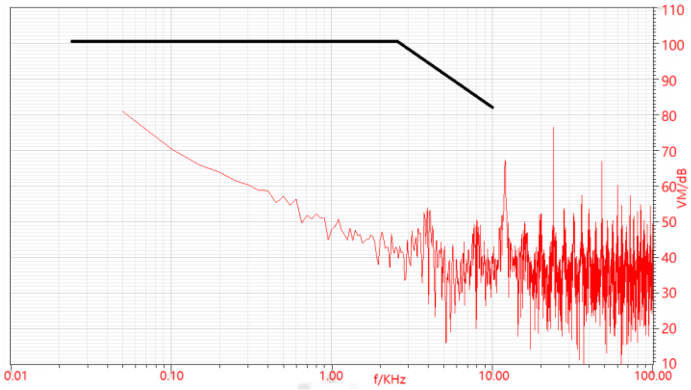

Figure 10: Frequency domain waveform of DC input bus current CE101 section.

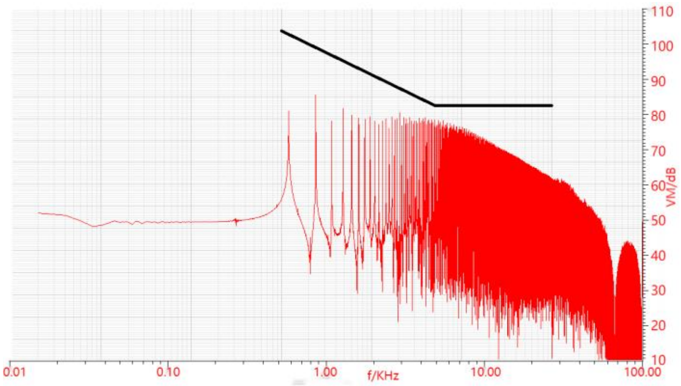

Figure 11: Frequency domain waveform of dc input bus current CE102 section.

As can be seen from the time-domain waveform, the steady state bus current fluctuated less; the black solid line in the upper half of the frequency domain waveform diagram is the selected limit. From the frequency domain waveform, it can be seen that the conducted emission level of the power line of the three-phase three-level inverter in CE101 segment and CE102 segment is lower than the limit value, CE101 segment has a margin of at least 19dB, CE102 segment has a margin of at least 6dB. Therefore, the conducted emission level of the power line of the three-phase three-level inverter is expected to meet the requirements of national J standard.

5. Conclusions

Aiming at the problem that two-level inverters commonly used in instrument control equipment are difficult to pass the electromagnetic compatibility test and require the power line conduction emission test, a detailed simulation model of three-phase three-level inverter is established in this paper, and the quantitative evaluation of the power line conduction emission level of three-phase three-level inverter is realized. According to the simulation results, the conducted emission level of the power line of the three-phase three-level inverter can meet the requirements of electromagnetic compatibility test, and has enough margin. It has important reference significance for the application of instrument control equipment inverter.

References

[1] Liu X. P. (2002) Research on Filter Circuit Design and EMC Simulation of Traction Converter. China Intelligent Transportation Association. Science and Technology Proceedings of the 17th China Intelligent Transportation Annual Conference. Intelligent Transportation Association of China: Intelligent Transportation Association of China, 202: 142.

[2] Pu C. (2019) Research on Active Filter Control Strategy for Aviation Variable Frequency Power System. Nanjing University of Aeronautics and Astronautics.

[3] Meng H. (2022) Modeling and Analysis of Common Mode Interference of Module Units of Photovoltaic Cascade System. Zhejiang University.

[4] Li Z., Jiang C., & Tian B. W. (2021) Optimal Modulation of Harmonic and Electromagnetic Interference Noise in three-level NPC Converter. Journal of Xi'an Polytechnic University, 35 (05), 74-79.

[5] Gamoudi R., Elhak C. D, & Sbita L. (2018) A Review of Spread--spectrum based PWM Techniques--A Novel Fast Digital Implementation. IEEE Transactions on Power Electronics, 33(12), 10292-10307.

[6] Cui K., Adrian V., Gwee B. H. and Chang J. S. (2018) A Noise-shaped Randomized Modulation for Switched-mode DC-DC Converters. IEEE Transactions on Circuits and Systems I: Regular Papers, 65(1), 394-405.

[7] Gao Y., Wang J. J., & Sun J. H. (2019) Study based on SVPWM of All-digital Fuzzy Random Harmonic Spectrum. Control Project 26. 02 (2019), 264-269.

[8] Cao H. D. & Li H. Y. (2016) Research on Tri-level Buck Converter. Science and Technology Vision, (05): 164-165.

[9] Zhu J. J., Wu Z. C., Xu J., Sun X. F., & Han Y. (2022) Multi-constraint IMPROVED Indirect Vector Control Strategy for Electromagnetic Launch linear Induction Motor. Electric Machines and Control, 26(08), 11-20.

[10] Ye S. Z. (2021) Research on Electromagnetic Interference Modeling of Motor Drive System Based on Online Testing. Zhejiang University.