DESIGN AN AUTOMATIC VOLTAGE COMPENSATION DEVICE USING AN AC CHOPPER CIRCUIT

THIẾT KẾ THIẾT BỊ BÙ ĐIỆN ÁP TỰ ĐỘNG SỬ DỤNG MẠCH AC CHOPPER

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ABSTRACT

This paper proposes an automatic voltage regulator (AVR) based on series voltage compensation mechanism by AC chopper. The proposed AVR consists of a pulse-width-modulated (PWM) AC chopper and a transformer for series voltage compensation. The AC chopper circuit provides direct AC power without the need for an energy storage element, thus reducing the size and cost of the AVR. Simulation results demonstrate that the proposed AVR responds quickly to changes in input voltage.

Keywords: *Automatic voltage regulator, AC chopper, Dynamic voltage restore*

TÓM TẮT

Bài báo đề xuất một bộ bù điện áp tự động (AVR) dựa trên cơ chế bù điện áp nối tiếp bằng AC chopper. AVR được đề xuất bao gồm một bộ AC chopper điều chế độ rộng xung (PWM) và một máy biến áp để bù điện áp nối tiếp. Mạch AC chopper cung cấp nguồn điện xoay chiều trực tiếp không cần phần tử lưu trữ năng lượng, do đó kích thước và giá thành của AVR giảm xuống. Kết quả mô phỏng chứng minh rằng AVR đề xuất phản ứng nhanh với sự thay đổi của điện áp đầu vào.

Từ khóa: *Thiết bị bù điện áp tự động, mạch điều chế AC chopper, khôi phục điện áp động.*

1. INTRODUCTION

Most modern electrical equipment has to deal with voltage drop, which significantly affects electricity quality. The connection of non-linear loads in the system and short circuit events are considered the main causes of voltage drop. This problem can crash the entire system causing malfunction or equipment failure [1]. Currently, on the market there are many devices that use voltage compensation such as: Uninterruptible power supply (UPS) keeps important electronic systems operating during short-term power outages and prevents damage due to sudden power outage. Dynamic Voltage Recovery (DVR) is a type of FACTS device used for series compensation in distribution networks [2]. DVR can minimize voltage drop and improve system power quality [3]. Automatic voltage regulator (AVR) has been used as AC voltage regulator and voltage drop compensation as proposed in [4]. In particular, researching and manufacturing an AC chopper alternating voltage converter is still a difficult problem, attracting the attention of many scientists. To meet fast voltage compensation for AC choppers, this paper develops an AVR based on power electronics devices, providing a solution for long-lasting voltage drops and deep attenuation amplitudes at grid. AVR has the advantages of UPS and DVR, overcoming the short compensation time of UPS and DVR.

2. DESIGN AUTOMATIC VOLTAGE REGULATOR

The voltage compensation device consists of a series transformer, a filter, an AC chopper and a series compensation capacitor shown in Figure 1.

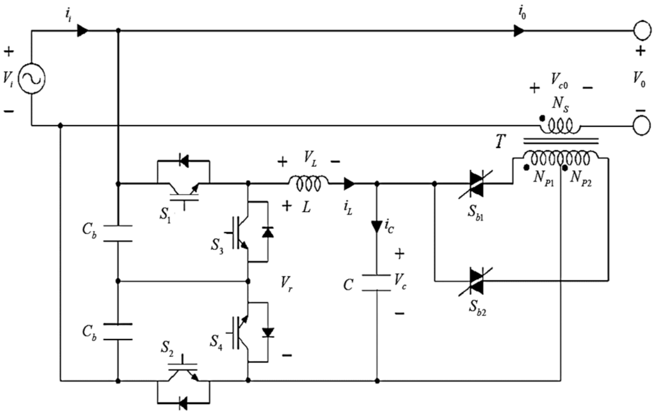

Figure 1. Principle diagram of voltage compensation circuit

The compensation voltage V_{c0} generated by the single-phase AC-chopper is used for voltage compensation. S_1, S_2, S_3, S_4 are thyristers; T is a transformer to compensate the input voltage V_i and stabilize the output voltage V_0. $N_{P1} = N_{P2}$ is the number of primary winding turns, N_S is the number of secondary winding turns. The filter capacitor voltage V_c is converted to V_{c0} through T. V_r is the filter modulation voltage and V_L is the inductor voltage. This AC chopper circuit consists of four switches S_1, S_2, S_3, S_4, an inductor and a capacitor. A low pass filter is used to filter harmonic components at the output. The AC-chopper converts AC power directly without the need for energy storage

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elements such as L and C, so the size and cost of the AVR is reduced. When a voltage drop is detected, the AVR operates as follows: S_{b1} turns on and S_{b2} turns off. Now the compensation voltage V_{c0} is in phase with the input voltage, so V_{c0} is added to the input voltage:

$$V_0 = V_i + V_{c0} \tag{1}$$

Therefore the output voltage compensates for the voltage drop. When the device detects a voltage increase, S_{b1} turned off and S_{b2} turned on. At this time, the compensation voltage V_{c0} is in opposite phase with the input voltage, so the output voltage has the value:

$$V_0 = V_i - V_{c0} \tag{2}$$

From (1), (2) it shows that the AVR can stabilize the output voltage.

The average V_r Chopper modulator output voltage is

$$v_L(t) = v_i(t) - v_c(t) \tag{3}$$

The average value during a switching cycle is calculated:

$$v_L(t) = Dv_i(t) - v_c(t) \tag{4}$$

$$i_c(t) = i_L(t) - ni_o(t) \tag{5}$$

Where, $n = \frac{N_s}{N_{P1}}$ is the ratio of the number of turns of the secondary coil to the primary coil; i_c, i_L are the current flowing through capacitor C and inductor L, respectively; i_0 output current; D is the opening time ratio of S_1 and S_2.

According to (4), (5) have:

$$L\frac{d}{dt}i_L(t) = Dv_i(t) - \frac{(v_o - v_i)(t)}{n}\mathbb{S} \tag{6}$$

$$C\frac{d}{dt}\frac{(v_o - v_i)(t)}{n} = i_L(t) - ni_o(t) \tag{7}$$

Substituting (7) into (6), we get the following differential equation:

$$nLC\frac{d^2}{dt^2}(v_o - v_i)(t) + n^2L\frac{d}{dt}i_o(t) = (nD+1)v_i(t) - nv_o(t) \tag{8}$$

Transforming equation (8) we have:

$$\frac{V_o(S)}{V_i(S)} = \frac{s^2LC + 1 + nD}{s^2LC + 1 + sn^2L / Z_o} \tag{9}$$

V_0/V_i is the voltage gain of the compensation device, Equation (9) is rewritten as follows:

$$\frac{V_o}{V_i} = \frac{1 - \omega^2LC + nD}{\sqrt{(1-\omega^2LC)^2 + (\omega n^2L / Z_o)^2}} \tag{10}$$

Because $\omega L \ll \frac{Z_o}{n^2} \ll \frac{1}{\omega C}$ so approximately we have:

$$\frac{V_o}{V_i} \simeq 1 + \frac{nD}{1 - \omega^2LC} \tag{11}$$

Next to that watch because $\omega^2LC \ll 1$ so:

$$\frac{V_o}{V_i} \simeq 1 + nD \tag{12}$$

Similarly, when the input voltage increases, the output voltage of the compensation device has the following value:

$$\frac{V_o}{V_i} = \frac{1 - \omega^2LC - nD}{\sqrt{(1-\omega^2LC)^2 + (-\omega n^2L / Z_o)^2}} \tag{13}$$

Inferred

$$\frac{V_o}{V_i} \simeq 1 - nD \tag{14}$$

The turns ratio of the output transformer depends on the maximum value of the input voltage variation range, calculated according to the following formula:

$$n = \frac{N_S}{N_{P1}} = \frac{N_S}{N_{P2}} = \frac{100 - P_{co}}{P_{co}} \tag{15}$$

Where, P_{co} is the percentage of compensation voltage;

The bias of the inductor current is calculated by the formula:

$$\Delta i_L = \frac{v_c(1-D)}{Lf_s} \tag{16}$$

Deviation of capacitor voltage:

$$\Delta v_c = \frac{\Delta i_L}{8Cf_s} = \frac{v_c(1-D)}{8LCf_S^2} \tag{17}$$

The AC chopper circuit is the core part of the entire voltage compensation device and is the basis for realizing the voltage compensation function.

$$\begin{aligned} V_o(t) &= V_i(t) \times S(t) \\ &= U_m \sin\omega t[D + \frac{2}{\pi}\sum_{a=1}^{\infty}\frac{\sin\varphi_a}{a}\cos(a\omega_c t - \varphi_a)] \\ &= U_m D\sin\omega t + \frac{U_{Nm}}{\pi} \times \sum_{a=1}^{\infty}\frac{\sin\varphi_a}{a}\{\sin[(a\omega_c + \omega)t - \varphi_a] \\ &\qquad - \sin[((a\omega_c - \omega)t - \varphi_a]\} \end{aligned} \tag{18}$$

According to equation (18), the modulated device output voltage consists of the fundamental wave and higher harmonics. Harmonics present in the output voltage include:

$$\sin[(a\omega_c + \omega)t - \varphi_a]\ ;\ \sin[(a\omega_c - \omega)t - \varphi_a] \tag{19}$$

With $\omega_c = \frac{2\pi}{T_c}$ determined by the cycle T_c. Therefore, it is necessary to filter out high-order harmonics, then the output voltage $V_0(t) = DV_i(t) = U_m D\sin\omega t$ can be directly adjusted by adjusting the parameter D, that is, the output voltage can be linearly adjusted.

3. SIMULATION RESULTS

Simulate the proposed AVR device using Matlab-Simulink software, AVR is designed for capacity 3kVA; 3-phase input voltage 50Hz; switching frequency 15kHz;

$L = 0.02H$; $C = 50\mu F$; $C_b = 0.02\mu F$; $n = 1$. The AC chopper circuit diagram is shown in Figure 2.

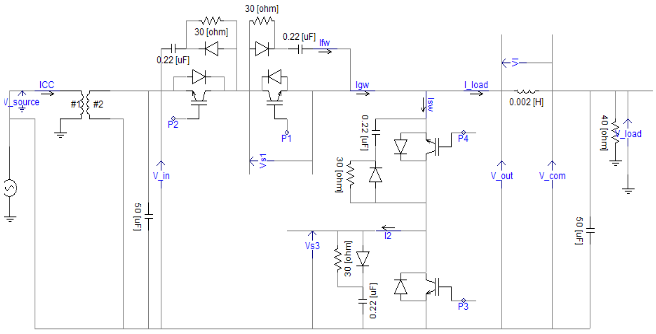

Figure 2. AC chopper circuit designed on Proteus software

Case 1: The input voltage increases at 0.13s to 0.3s.

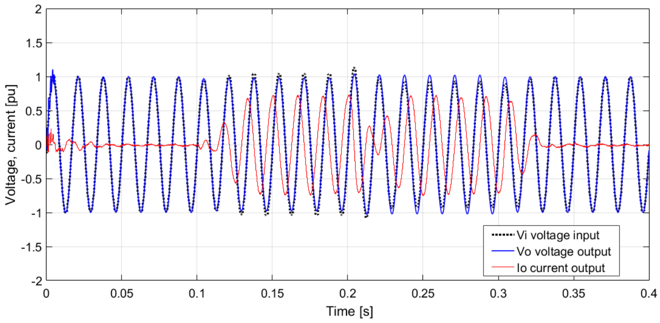

Figure 3. Output voltage and current response when input voltage changes from 0.13s to 0.3s

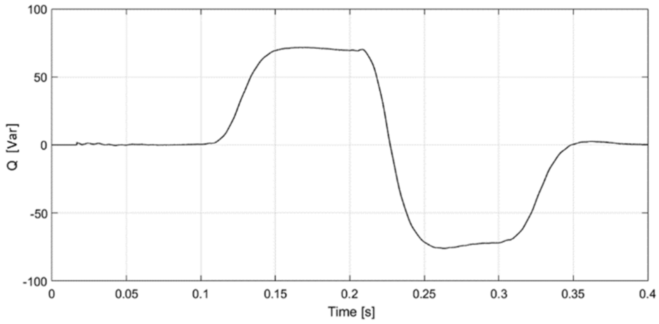

Figure 4. Respond to the reactive power generated by the capacitor

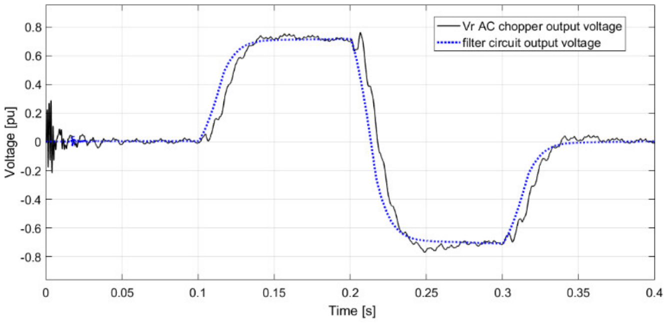

Figure 5. Respond to the reactive power generated by the capacitor

When the input voltage increases, the AVR reacts by drawing in an amount of reactive power of 65Var. When the supply voltage decreases, the AVR switches from inductive to capacitive and compensates the reactive power to the system by an amount of 62Var, helping for stable output voltage.

Case 2: When there is a short circuit of the input voltage, phase A goes to ground, the fault occurs when t = 1/60s and ends at time t = 5/60s.

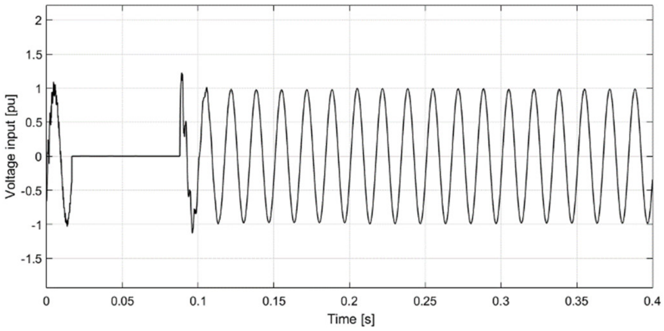

Figure 6. Input voltage short circuit, ground fault

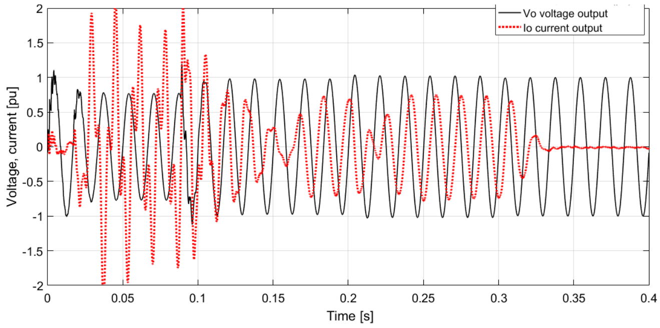

Figure 7. Responds to the output voltage and current when the input voltage ground fault

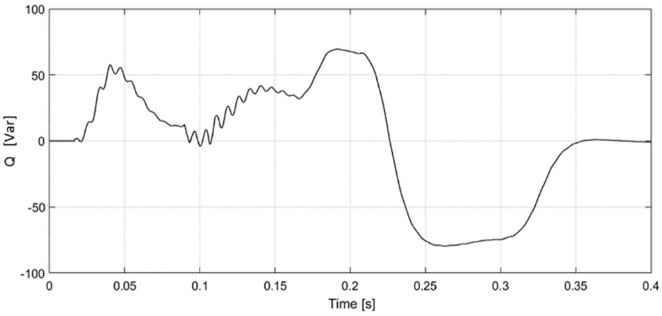

Figure 8. Respond to the reactive power generated by the capacitor

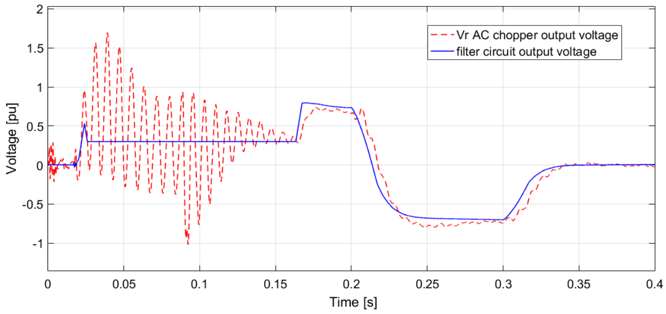

Figure 9. Respond to the reactive power generated by the capacitor

At the beginning of a short circuit to ground fault of phase A, the short circuit current increases to 2.6pu, the system voltage drops rapidly to 0.23pu, the AVR generates an amount of reactive power to compensate for the system.

54Var, after 5/60s the fault ends, the AVR continues to compensate to correct the system voltage until 0.24s.

Comment: From the simulation results, it shows that the proposed AVR operates relatively effectively. Respond quickly to voltage drop incidents during grid operation. Ensure the output voltage for the loads is stable in both frequency and amplitude, without high-order harmonic interference.

4. CONCLUSION

This paper proposes an AVR consisting of an AC chopper and a voltage compensated series transformer. AVRs perform voltage compensation without requiring energy storage components, so size and cost are reduced. Through simulation, it is proven that the proposed voltage compensation device has obvious compensation effects for most loads, less harmonic content, long continuous compensation time and stable performance, suitable for Average power compensation, applied to small production facilities.

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