Study of a secondary power source with hysteresic control, comparison of theory and practice

A D Ivanov

1Yaroslav-the-Wise Novgorod State University, 41, ul. B. St. Petersburgskaya, Veliky Novgorod, Russian Federation
2JSC “OKB-Planeta”, ul. Bolshaya Moskovskaya, 13A, 173004, Veliky Novgorod, Russia

E-mail: antonio15@mail.ru

Abstract. This article presents the comparison of the operation of the model and the prototype of a secondary power source with hysteresic control. The principles of operation of this type of control are considered. Timing diagrams and oscillograms of the model and prototype are presented. Comparison results are presented. On the basis of the prototype, theoretical principles of the operation of hysteresic control are confirmed.

1. Introduction

Modern sources of secondary power source differ in a variety of circuitry solutions, topologies and types of control. There are three main types of control of secondary power supplies. Current control, voltage control and hysteresic control. The first two types of control are widespread and have been studied in depth [1], and the most popular source models are based on these types of control.

The principles of hysteresic control were developed back in the 90s of the last century. Its properties are described in publications by Davoodnezhad R. A., Shukla A., Gupta R. [2–4]. Unlike voltage and current control, hysteresic control is implemented on a two-threshold comparator located in the feedback circuit of the source. This type of control is distinguished by increased stability of the feedback operation, which does not require the introduction of correction. Unlike other types of control, such as voltage and current control, a hysteresic controlled source has the best response to load changes. This is achieved by minimizing the feedback circuit delay.

When developing a secondary power source, it is important that the designed device meets the customer's requirements, has the best parameters and works without failures. During production, the spread of parameters of manufactured products must remain within acceptable limits. Power supplies must maintain stable operation under various operating conditions and external physical influences. Computer simulation helps to identify the causes of possible failures in the operation of the device, to analyze the process of an emergency situation leading to the failure of a secondary source. It is important that the source model accurately simulates the operation of a real device [5].

Based on the source model, it is possible to develop a real prototype of the secondary power source with hysteresic control. When developing a prototype, controller is the main element. The choice of the controller is the main component of the diagram of the prototype.

The disadvantages of hysteresic control include an increase in the output ripple of the source. The permissible ripple value is ensured by a careful choice of the element base when designing a secondary
source. The difficulty of achieving the required parameters of the secondary source with hysteresic control restrains their widespread use.

In this article, a model of a secondary power source with hysteresic control is implemented in the LTspice simulation environment [6], a prototype of this source based on the LM3485 controller is developed, and the model's operation is compared with a real prototype of the source. Based on the comparison, the theoretical foundations and principles of operation of the hysteresic type of control are proved on the real operation of the prototype of the secondary power source.

2. Schematic representation of the model and the prototype of the secondary power source with hysteresic control

In the LTspice simulation environment, a hysteresic-controlled secondary power source model was implemented. The secondary power source has a step-down topology. The input voltage is 12 V. The output voltage level is set by the voltage divider at R3 and R4 in the feedback circuit, as well as by the threshold voltage $V_t$ of the comparator A2 operation according to the expression:

$$U_{\text{Вых}} = \frac{R_3 + R_4}{R_4} V_t$$

(1)

The required voltage at the source output, for example, $U_{\text{out}} = 3$ V, is provided at $V_t = 1.242$ V by resistors $R_3 = 29$ kOhm and $R_4 = 20$ kOhm.

Figure 1 shows a diagram of a model of a secondary power source with hysteresic control in the LTspice simulation environment.

![Diagram of a model of a secondary power source with hysteresic control](image)

**Figure 1.** Diagram of a model of a secondary power source with hysteresic control.

The prototype diagram in the figure 2 has the same components as the model of the source. The difference lies in the fact that the prototype uses a controller that also uses a two-threshold comparator in its operation, but additionally contains blocks for limiting the current.
Figure 2. Diagram of a prototype of the secondary power source with hysteresic control.

Figure 3 shows a functional diagram of the controller of the LM3485 prototype [7].

Figure 3. Functional diagram of the controller of the LM3485 prototype.

The principle of constructing the diagram of the model and the prototype and of building the diagram of their operation have an identical structure, the differences are only in the functional plan of the controller in the prototype of the secondary power source.

Hysteresic control used in the LM3485 controller hysteresic control does not require an internal generator. The switching frequency is determined by external components and operating conditions. The operating frequency is automatically reduced at low loads, which ensures high efficiency.

It is possible to simulate the controller in the simulation environment.

3. Comparison of the operating modes of the model and the prototype of the secondary power source with hysteresic control

The principle of operation of the secondary power source model is shown in figure 4 and is as follows. The output voltage through the divider \( R_3 - R_4 \) is fed to the input of the comparator, when triggered, the source feedback loop is closed. Switching the output of the comparator A2 from low to high and vice versa occurs at two different operating thresholds: \( V_t \) and \( V_{t+h} \) respectively, where \( V_h \) is the hysteresic voltage.
In the steady state, when the threshold $V_t$ is reached, a high voltage level appears at the output of the comparator A2, which opens the transistor M1 (figure 1), which leads to an increase in the current in the coil L1, and, consequently, in the voltage at the source output. As soon as the output voltage supplied through the divider $R_3 - R_4$ to the input of the comparator A2 reaches the operation threshold ($V_t + V_h$), the transistor M1 closes, and the current in the coil L1 begins to decrease, charging the capacitor C1.

![Diagram of secondary power source in steady state](image)

**Figures 4.** Timing diagrams of the model of the secondary power source in the steady state operation mode. a) 1 – signal at the output of the comparator A2; 2 – signal at the input of the comparator A2; b) the current in the inductance coil L1.

The full charge of the capacitor C1 corresponds to the moment when the current in the coil decreases to zero. At this moment, the output voltage reaches its maximum value. After that, the capacitor begins to gradually discharge, the output voltage decreases until the second operation of the comparator A2.

The principle of operation of the controller of the prototype is based on a two threshold comparator with hysteresis of about 10 mV. This value is fixed for this particular controller. When designing, it is possible to change the value depending on the parameters of the required source. Depending on the voltage at the FB pin, the gate (PGATE pin) turns the external PFET transistor on or off. With an increase in the inductor current, the protection is triggered, which turns the transistor on and off for 9 μs.

Also, hysteresis control does not require an internal generator. Control frequency is adjustable.

Figure 5 shows the oscillogram of the operation of the key of the prototype of the secondary power source with hysteresis control.
Figure 5. Oscillogram of operation of the key of the secondary power source with hysteresis control.

Figure 6 shows an oscillogram of the LM3485 controller operation.

From the presented results of the operation of the model and the prototype of the secondary power source with hysteresis control, it is clear that the principle of construction and the mode of operation in the oscillogram data is identical. The waveforms in the model and the prototype are absolutely the same. Characteristics of input and output voltages and currents for the model and the prototype are matched as closely as possible.

4. Representation of pulse frequency modulation and load response in the model and the prototype of the secondary power source with hysteresis control

One of the main positive features of the hysteresis type of control is the fast response to load changes. This feature is well suited for devices that require uninterrupted voltage in their operation. In hysteresis control, pulse frequency modulation is implemented. In contrast to current and voltage modes of operation, which use pulse width modulation. This type of modulation, when changing the operation mode does not change the width of the working pulse, but their number.

Figure 7 shows the changes in the number of comparator pulses when the load changes.
Figure 7. Changes in the number of comparator pulses when the load changes.

From this timing diagram, it can be seen that when the load changes, the number of pulses increases, therefore, the frequency of operation of this power source increases.

Figures 8, 9 show oscillograms of changes in the operating frequency of the prototype of the secondary power source with hysteresis control.

Figures 8. Oscillograms of changes in the operating frequency of the prototype of the secondary power source with hysteresis control.
Figures 9. Oscillograms of changes in the operating frequency of the prototype of the secondary power source with hysteresic control.

These oscillograms show the change in the frequency of the secondary power source well, and therefore they also show the pulse-frequency modulation mode. The model and the prototype of the secondary power source show identical results of work, the only difference is that the model shows the mathematical calculation of the signal, and also does not introduce inaccuracies, unlike the prototype. The presence of inaccuracy is present in the oscilloscope probes, prototype PCB layout, real components in the prototype diagram.

Figures 10, 11 show a comparison of the output voltage of the model and the prototype of the secondary power source with hysteresic control.

Figure 10. Output voltage of the model of the secondary power source with hysteresic control.
From the data obtained in figures 10, 11 it can be seen that the output voltage in the model of the source is more detailed, and the capacitor discharge time constant, as well as the energy accumulation, are clearly visible. This characteristic arises due to the absence of inaccuracies in the model. The duration of the first comparator impulse is determined by the rise interval of the output signal to the voltage \((V_t + V_h)((R3+R4)/R4)\), at which a low level will appear at the inverse output of the comparator. As a result, the transistor is open for a long time, the current in the inductor increases. The capacitor charge also has a high voltage. Reducing the voltage to a steady state takes a long time until the voltage in the feedback circuit is equal to the threshold for switching on the comparator A2. After this, the power supply goes into the steady-state operation mode.

As a rule, converters with any type of control have changes in the output voltage value depending on the change in the load value, the so-called response. Changing the load value causes the output voltage to decrease or increase. In turn, the voltage change indicates how quickly the control circuit can respond to the change in output current. At the point of maximum voltage dip, the regulator delivers maximum current to the inductance. As a result, the current in the inductor has a great influence on the load, which in turn allows the charge and voltage of the output capacitor to be increased. Voltage converters with hysteretic control have the fastest response, since the voltage reaches its minimum value earlier than in the case of other types of control. To establish the response of the output voltage, the load value in the prototype varied from 0.1 to 1 A.

Figures 12, 13 show the response of the output voltage to load changes.
Figure 12. Output voltage response when the load current increases.

Figure 13. Output voltage response when the load current decreases.

The ripple range of the prototype of the secondary power source is 67 mV. In this case, the voltage recovery with a change in load is 8.4 ns.

The value of the decrease in the output voltage depends on the capacity of the output capacitor: the larger the capacitance, the smaller the decrease in the value of the output voltage. The capacity of the output capacitor for hysteresic control has the lowest value in comparison with other types of control. The reason for this is that hysteresic controlled converters provide minimal feedback delay. For hysteresic control, the rate of response to a load change is only the rate of change of the current in the LC filter choke. In turn, in converters with a different type of control, the system reacts to load changes in two stages. First, a signal must be generated at the output of the error amplifier. Second, the control
system must correct the control signal at the output of the pulse modulator. As a result of the above, the speed of the hysteresis control turns out to be significantly higher than converters with other types of control.

5. Conclusion
This article discusses the principles of operation of the hysteretic control of the secondary power source. The model and the prototype of the source with this type of control is presented. Based on the results obtained, the theoretical foundations of this type of control are proved. A comparison of the model and the prototype of the secondary power source with the same voltage and current parameters is made.

The presented oscillograms and timing diagrams of operation show the positive aspects of this type of control and its use in real devices.

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