Calculation of pulse voltage stabilizer

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Abstract. This scientific article is devoted to one of the priority issues in electronics, namely the implementation of the engineering task of designing a power source. In my case, according to the terms of reference, which includes: the main parameters of the network, efficiency, a structural electrical circuit of a switching power supply was developed. In the process, the main functional units (blocks) were calculated and the choice of radio components from which they were built on the basis of: current values, reverse voltage, gain, operating frequency and other parameters of diodes, transistors, integrated circuits, Zener diodes, operational amplifiers was justified. In the "Methods" section, calculations will be made for the device blocks: a network rectifier, a push-pull transformer converter, a pre-amplifier circuit with a transformer input, an error signal comparison and amplification circuit, a sawtooth voltage generator, and a secondary power source. The information presented in the text is recommended to a narrow circle of specialists, priority in the field of power electronics, as well as in the field of communication systems.

1 Introduction

Switching voltage stabilizer - a voltage regulator in which the regulating element is in the cutoff mode (R_{max}) or under saturation (R_{min}), hence can be considered as the key [1,121]. Smooth change of voltage occurs due to the presence of integrating elements: the voltage rises as you accumulate them energy and decreases its impact in the load. This mode reduces energy loss and improves weight and overall dimensions, however, has its own characteristics.

Essential elements of a switching power supply are: integrator, which voltage can not change instantly, but gradually increases according to the accumulation of energy and then slowly drops as it returns to the load (for example a capacitor, to which included some non-zero resistance, which can be, for example, the internal resistance of the power source) and a device able to change the resistance to the passage of current from minimum to maximum and Vice versa.

2 Methods

This simulation was carried out at the Department of Electronics and Communications. During the calculations, the Mathcad program was used, as well as the development environment of electronic circuits Multisim.

3 Materials

Has been provided by the technical specification (requirements) regarding the network conditions for which it is planned to produce the product. Input the following:

Power supply voltage: Ups = 36 V; the Relative change in supply voltage: δUps = ± 20 V; Frequency mains current: F = 400 Hz; Type of mains supply: three phase with a "0" output star; Diagram of the network rectifier: three-phase half-wave; load Voltage: U load = 12 V; load Current max: I l max = 5 A; load Current min: I l min = 1 A; ambient Temperature: t = + 50 C; ripple Factor: Kr = 1.5 %; The switching frequency of the Converter: fs = 25 kHz; Diagram of converters: push-pull; efficiency: η = 92 %.

3.1 The calculation of the network rectifier

Depending on the number of phases supply rectification circuit may be a three-phase bridge, three phase half-wave, single-phase bridge.

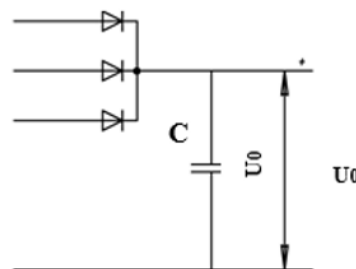In (Fig.1) shows a diagram of a network rectifier "three phase half-wave rectified".

Fig. 1. Scheme of three-phase half-wave rectifier.

Calculate the main parameters:

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The average value of the rectified voltage for three-phase half-wave circuits:

$$U_{0 \text{ rated}} = 0.95 U_{ps} \sqrt{2} = 0.95 \cdot 36 \cdot \sqrt{2} = 47.9 \text{ V}$$

The maximum value of the rectified voltage:

$$U_{0\text{max}} = U_{0 \text{ rated}} \cdot \left(1 + \delta_{U_{ps}}\right) = 47.9 \cdot (1 + 0.2) = 57.46 \text{ V}$$

The minimum value of the rectified voltage:

$$U_{0\text{min}} = U_0 \cdot \left(1 - \delta_{U_{ps}}\right) = 47.9 \cdot (1 - 0.2) = 43.08 \text{ V}$$

The capacitance value:

$$C_1 = 1.3 \frac{P_{load}}{\eta} = 1.3 \frac{I_{load \, max} \cdot U_{\text{H}}}{\eta} = 1.3 \cdot \frac{5 \cdot 12}{0.92} = 84.15 \text{ μF}$$

Taken on a table e24: $C_1 = 100 \text{ μF}$.

The value of current-limiting (to limit charge current) resistance:

$$R_0 = \frac{U_{stabil \, max}}{I_{varib}} = \frac{60}{6} = 10 \, Ohm$$

Taken on a table e24: $R_0 = 12 \, Ohm$.

For selecting the rectifier diode, the required values:
The average current through the valve:

$$I_{1,2,3} = \frac{I_0}{3} = \frac{0.313}{3} = 0.104 \text{ A}$$

$$P_0 = I_0^2 * U = 0.9 W$$

$$I_0 = \frac{P_0}{U_{0\text{min}}} = \frac{13}{43.08} = 0.313 \, A$$

The magnitude of the reverse voltage to the idle valve:

$$U_{reverse} = U_{ps} \sqrt{2} \sqrt{3} = 36 \cdot \sqrt{2} \cdot \sqrt{3} = 87.19 \text{ V}$$

According to the data selected diode KD209B with the following parameters:

Table 1. Parameters of the Diode KD209B.

Diode	Ipr.cp, A
KD209B	0.5
U rev., V	I variable, A
600	6

3.2 Calculation of transformer push-pull converter

In this popular scheme (Figure 2), the performance is a combination of electric energy conversion and its regulation through pulse width modulation. Characteristic for them is the presence of a relatively strong smoothing LC filter [2, 63].

In half-bridge scheme of transformer push-pull converter, when the transistor VT1 is opened at time γ

T/2, and VT2 is closed, energy transfer occurs from capacitor C1 through a transformer T to the cumulative LC choke and the load [3,51]. At the same time, the capacitance C2 is charged through the circuit: +U0, U1 winding, the capacitance C2 and –U0. In the next half cycle the process repeats: the S2 is open, C1 is charged. During the pause, the filter capacitor C is discharged to the load through the diode VD5. Capacitance C1, C2 form a capacitive divider.
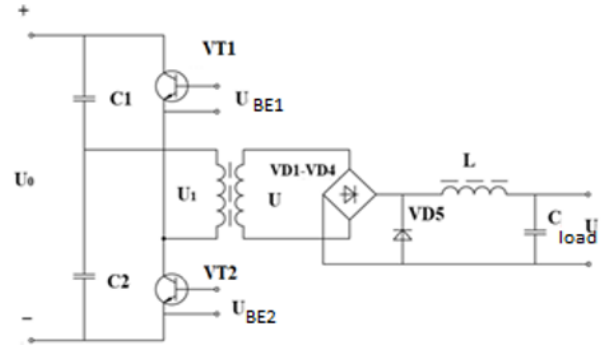

Fig. 2. Schematic diagram.

Capacity C_1 and C_2 form a capacitive divider:

$$U_1 = \frac{U_0}{2} = \frac{47.9}{2} = 23.95 V$$

The fill factor of the pulse: $\gamma_{\text{max}} = 0.7$
The output voltage of an RF rectifier:

$$U'_{2 \, min} = \frac{U_{load}}{\gamma_{max}} = \frac{12}{0.7} = 17.1 V$$

$$U'_{2 \, rated} = \frac{U'_{2 \, min}}{\left(1 - \delta U_{ps \, max}\right)} = \frac{17.1}{(1 - 0.2)} = 21.4 \text{ V}$$

$$U'_{2 \, max} = U'_{2 \, rated} \cdot \left(1 + \delta U_{ps \, max}\right) = 21.4 * (1 + 0.2) = 25.6 \text{ V}$$

$$\gamma_{min} = \frac{U_{load}}{U'_{2 \, max}} = \frac{12}{25.6} = 0.5$$

The voltage at the secondary winding of the transformer:

$$U_2 = U'_2 + U_{ddv} = 17.1 + 1 = 18.1 V$$

where U_{ddv} - forward drop voltage of the diodes an HF bridge.

The value of the output inductor:

$$L = (5 \div 10) \cdot \frac{R_{load} \cdot \left(1 - \gamma_{min}\right)}{2 \cdot f_s} = 7 \cdot \frac{12 \cdot (1 - 0.5)}{2 \cdot 25 \cdot 10^3} = 84 \, \mu H$$

Taken on a number e24: $L = 100 \text{ μH}$.
Load resistance (R_{load}):

$$R_{load} = \frac{U_{load}}{I_{load \, min}} = \frac{12}{1} = 12 \, Ohm$$

Taken on a number e24: $R_{load} = 12 \, Ohm$.

The maximum current of the inductor:

$$I_{L\,max} = I_{load} + \Delta i_1 = 5 + 3.42 = 8.42 \text{ A}$$

Ripple current through the inductor:

$$\Delta i_1 = \frac{U_2' \gamma_{max}}{2 \cdot L \cdot f_s} = \frac{17.1 \cdot 0.7}{2 \cdot 84 \cdot 10^{-6} \cdot 25 \cdot 10^3} = 2.85 \, A$$

The capacity of the smoothing filter:
When $K_r = 2\%, get$:

$$C_{load} = \frac{(1 - \gamma_{min})}{8 \cdot L \cdot f_s^2 \cdot K_r} = \frac{(1 - 0.5)}{8 \cdot 84 \cdot 10^{-6} \cdot 25^2 \cdot 10^6 \cdot 0.02} = 50 \text{ μF}$$

Taken on a number e24: $C_{load} = 50 \text{ μF}$.
Average current of the diode VD5 and its voltage:

$$I_{a\,VD5} = I_{L\,max}(1 - \gamma_{min}) = 8.42 * (1 - 0.5) = 4.21 \text{ A}$$

$$U_{rev\,VD5} = U_{2\,max}' = 25.6 \text{ V}$$

The average value of the currents and reverse voltage for diodes HF bridge [4]:

$$I_{am} = \frac{I_{load}}{2} = \frac{5}{2} = 2.5 \text{ A}$$

$$U_{reverse} = U_{2\,max} = 19 \text{ V}$$

As the diode bridge is used KD213A with the following parameters:

Table 2. Parameters of the Diode bridge KD213A.

Diode bridge	$I_{direct.average}$, A
KD213A	10
$U_{rev.}$, V	I_{direct}
200	100
F, kHz	
100	

The maximum current value I_2 of the secondary winding:

$$I_2 = I_{L\,max} = 8.42 \text{ A}$$

For half-bridge circuits:
The collector current $I_{load\,max}$ and the max value of $U_{CE\,max}$ to pick VT:

$$I_{C\,max} = \frac{U_2 \cdot I_2}{U_1 \cdot \eta} = \frac{18.1 \cdot 8.42}{23.95 \cdot 0.92} = 6.87 \text{ A}$$

$$\eta_{H} = (0.9 \div 0.98)$$

$$U_{CE\,max} = U_{0\,max} = 57.46V$$

Selects the transistor VT1 – KT812A:

Table 3. Parameters of the transistor KT812A.

Type	H_{21e}	$U_{BE.saturation}$, V	
KT812A	30	2.2	
$U_{CE.saturation}$, V	f_{cutoff}, MHz	U_{CEmax}, V	I_{CEmax}, A
1.35	6.5	400	8

$q = (1.3 \div 2) -$ the coefficient of saturation,
The value of the base currents of the control:

$$I_{B\,2,3,4} = \frac{I_{C\,max} \cdot q}{h_{21\,min}} = \frac{6.87 \cdot 1.5}{30} = 0.34 \, A$$

3.3 The calculation scheme of the pre-amplifier with transformer input
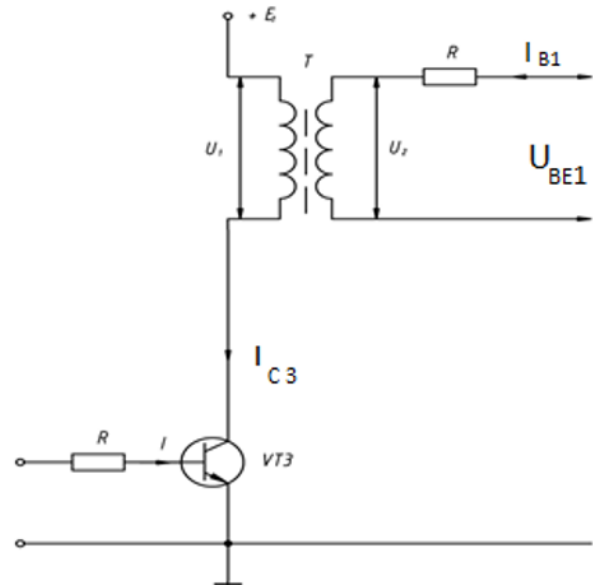
In (Fig.3) shows a diagram of a pre-amp.

Fig. 3. Diagram of the preamplifier with transformer input.

$$U_2 = (3 \div 4) \cdot U_{BE\,saturation1} = 3.5 \cdot 2.2 = 7.7V$$

Balanced resistance is needed to limit the base current of the power transistor of the Converter (after replacing the transistor) due to the variation of parameters h21e, U_{BE} [5].
Balanced impedance:

$$R_b = \frac{U_2 - U_{BE\,saturation1}}{I_{b1}} = \frac{7.7 - 2.2}{0.27} = 20.4 Ohm$$

Is selected by row e24: $R_B = 22 \, kOhm$.

$$I_{C3} = \frac{U_2 \cdot I_2}{U_1 \cdot \eta} = \frac{7.7 \cdot 0.34}{(15 - 1) \cdot 0.92} = 0.2 \text{ A}$$

$U_1 = E_1 - U_{CE\,saturation} -$ the amplitude of the voltage of the primary winding of the transformer;
Select transistor VT5-6:

Table 4. Parameters of the transistor KT630E.

Type	H_{21e},	$U_{BE\ saturat}$, V	$U_{CE\ saturat}$, V
KT630E (n-p-n)	300	0.85	0.11
f_{cutoff}, MHz	U_{CEmax}, V	I_{CEmax}, A	
300	60	1	

Current control I_{B3}:

$$I_{B3} = \frac{I_{C3} \cdot q}{h_{21}} = \frac{0.2 \cdot 1.5}{300} = 1\ mA$$

The resistance value R:

$$R = \frac{U_{out}^1 - U_{BE\ saturation}}{I_{B3}} = \frac{14 - 0.85}{1 \cdot 10^{-3}} = 13\ kOhm$$

Is selected by row e24: $R = 15\ kOhm$.
, U_{1out} - voltage logical units on the I_{ps} output of the logical element "and" [6,124].

3.4 The calculation of the comparison circuit and the gain error signal

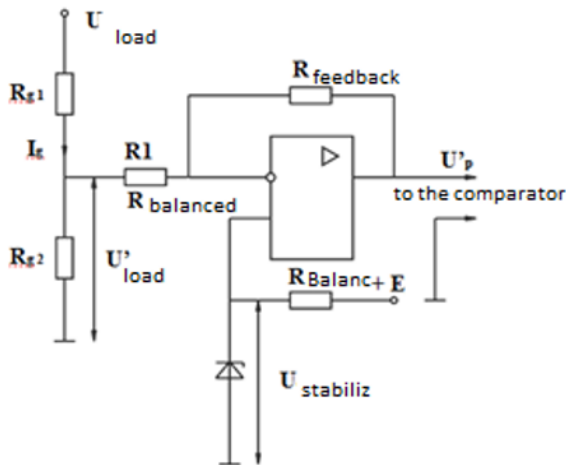In (Fig.4) shows a diagram of the circuit built on the operational amplifier.

Fig. 4. Comparison Circuit and the gain error signal.

The voltage U_{st} on the stabilizer is selected from the conditions: $U_{st} < U_{in\ max}$, if $U_{in\ max}$ - is the maximum value of the input voltage of the operational amplifier [7,20].
Set the value $U_{st} = 4.7$ B, equating it to the voltage U'_{load}, t.e. $U'_{load} \approx U_{st} = 4.7$ B.
The value of the current divider choose: $I_d = 1$ mA.
Ballast resistance of reference voltage source:

$$R_b = \frac{E - U_{st}}{I_{st\ min}} = \frac{15 - 4.7}{3 \cdot 10^{-3}} = 3.4\ kOhm$$

Is selected by row e24: $R_b = 3.9\ kOhm$.
The resistance of the second divider:

$$R_{d2} = \frac{U'_{load}}{I_d} = \frac{4.7}{10^{-3}} = 4.7\ kOhm$$

Is selected by row 24: $R_{d2} = 4.7\ kOhm$.
The division ratio of the divider:

$$K_d = \frac{U'_{load}}{U_{load}} = \frac{4.7}{12} = 0.39$$

The resistance of the first divider:

$$R_{d1} = \frac{R_{d2}(1 - K_d)}{K_d} = \frac{4.7 \cdot 10^3 \cdot (0.61)}{0.39} = 7.4\ kOhm$$

Is selected by row (table) e24: $R_{d1} = 8.2\ kOhm$
As the operational amplifier selected chip LM392:

Table 5. Parameters of op-amp LM392.

Type	Type power supply V, U_{ps}	U_{in}, V	U_{out}, V
LM392	3-32	-0.3-32	U_{ps}-1.5
		0	0.4
I_{in}, nA	I_{out}, mA	K_u	Number of OG on the case
250	6	10^4	OG
250	20	$2 \cdot 10^4$	Comparator

$$R_{feedback} = K \cdot R_1 = 30 \cdot 10 \cdot 10^3 = 300\ kOhm$$

Is selected by row e24: $R_{feedback} = 330\ kOhm$.
Select the Zener KC139A:

Table 6. Parameters of the Zener diode KC139A.

Model	$I_{st\ min}$, mA	$I_{st\ max}$, mA
KC139A	3	70
$U_{st\ Rated}$, V	$U_{st\ max}$, V	
3.6	4.3	

3.5 The calculation diagram of the sawtooth generator

The sawtooth generators find wide application in automation, television, communications technology, measurement technology, power supplies and other applications of electronics [8, 19].
Most often performed with an external control. The duration of the stroke is determined by the duration of the external control pulse of a rectangular shape [9]. If necessary, you can create generators running in sync mode or the oscillatory modex [10].
In the simplest case, when not required high linearity of the working area of the output voltage, they are executed according to the scheme of integrating RC-circuit with the reset of the charge during the return stroke of the saw. The formation of a sawtooth voltage based on the alternation in time of the processes of charge and discharge of the capacitor. The function of the element, creating a circuit to quickly discharge capacitance, performs a transistor in a key mode. Discharge of the capacitor and maintaining the voltage

close to zero, occurs in the interval tp input signal when the transistor is in saturation (fully open). Linearly-varying voltage in the interval of the stroke is formed when the transistor is closed (nonconductive state).

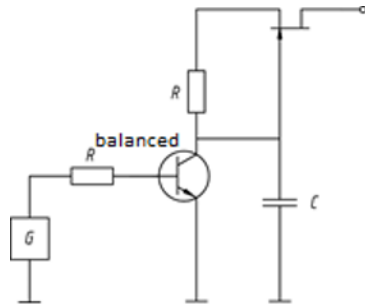In (Fig.5) shows a schematic of the sawtooth generator.

Fig. 5. Oscillator Circuit with a constant current charge.

The pulse period of the sawtooth is calculated according to the formula:

$$T = \frac{1}{f_{sw}} = \frac{1}{25000} = 40\,\mu s$$

The discharge period of the capacitor:

$$t_n = 0.02 \cdot 40 = 0.8\,\mu s$$

The period of charging of the capacitor:

$$t_p = T - t_n = 4 - 0.8 = 3.2\,\mu s$$

The calculation of the capacitance of the capacitor:

$$C_6 = \frac{I_c \cdot t_p}{U_g} = \frac{1 \cdot 10^{-3} \cdot 3.2 \cdot 10^{-6}}{3} = 1\ \text{nF}$$

Taken on a table e24: $C_6 = 1\ nF$

The value of the voltage of the generator is chosen equal to: $U_g = 3$ V.

The current value of the capacitor equal to: $I_{pow.s} = 1\ mA$

The calculation of the resistance of drain circuit:

$$R_9 = \frac{T}{c_6} = \frac{4 \cdot 10^{-6}}{1.06 \cdot 10^{-9}} = 3.77\ kOhm$$

Is selected by row e24: $R_{10} = 3.8\ kOhm$.
Selects the transistor VT1 – KT315G

Table 7. Parameters of the transistor KT315G.

Type	H_{21e},	$U_{BE.\ sat.}$, V
KT315G	350	1
$U_{CE.sat.}$, V	U_{kemax}, V	I_{kemax}, A
0.4	1	0.1

Select the VT2 transistor – KP302A

Table 8. Parameters of the transistor KP302A.

Type	$U_{GD\ max}$, V	$U_{GS\ max}$, V
KP302A	20	10
$U_{DS\ max}$, V	I_{max}, µA	
20	24	

The base current:

$$I_B = \frac{I_{ps}}{h_{21max}} = \frac{1 \cdot 10^{-3}}{350} = 2.85\ \mu A$$

Base resistance:

$$R_B = \frac{E - U_{BE\ sat}}{I_B} = \frac{15 - 1}{2.85 \cdot 10^{-6}} = 4.9\ MOhm$$

Is selected by row e24: $R_B = 5.6\ MOhm$.

4 Results

As a result, the circuit was simulated and substantially improved in the Multisim program using a separate power source for the control device, which allows controlling the processes occurring both in the network and in the load, regardless of the state of the power unit (RL = 0 or RL = ∞) [11], which simplifies the task of building a reliable control device.

Using the obtained calculations, it is planned to make a test model of the device. The results of this testing will be described in a future article.

5 Discussion

In this section, I want to discuss the merits of a switching voltage regulator relative to a linear regulator. Firstly, it has less energy loss for heating the regulating element, which increases the efficiency of the stabilizer and allows the use of a regulating element of lower power, and a radiator of smaller sizes and weights. You can also note a high efficiency, especially when working in a wide range of input voltages [12, 137]; small dimensions and mass (high specific power); fundamental possibility of galvanic isolation of input and output circuits.

6 Conclusion

Today, the scope of application of such devices has decreased in connection with reduction of power supply sources with transformerless input. Nevertheless, the use of switching regulators in a number of cases, it is economically more profitable than any other DC-DC Converter [13, 202].

In this paper we discuss the main provisions for the design of power supplies and electronic equipment. When developing a supply of funds was received for construction of circuits of power. Required the estimated coefficient characterizing their performance [14, 47]. On the technical task [15, 97] was calculated switching voltage regulator, developed in the software Multisim that will be done in further studies.

References

[1] V.P. Shuvalov, *Telecommunication systems* (M.: Radio and communication, 236, 2000)

[2] A.Kh. Shogenov, D.S. Strebkov, Ya.Kh. Shogenov; Ed. Analog, digital and power electronics: textbook (M.: FIZMATLIT, 215, 2017)

[3] E.M. Romash, *High-Frequency transistor converters* (M.: Radio Communications, 174, 1988).

[4] I. Hamidah, D.F. Ramadhan, The Performance Comparison Between Commercial Automatic Voltage Stabilizer And Programmable Automatic Voltage Stabilizer, Article (2020). ISBN: 1823-4690

[5] P. Bogomolov, I. Borzdyko, AC Voltage Stabilizer, Article. DOI: 10.30987/conference article_5c19e5e6ca1ba2.66670915 (2018)

[6] E.I. Brezhnev, *Effect Transistor apparatus of wide application: reference book* (M.: Radio and communication, 278, 1981)

[7] V.V. Durkin, *Circuitry of analog electronic devices, Basic concepts, feedbacks, the operation of the amplifying element in the circuit: study guide* (Novosibirsk: NSTU Publishing House, 165, 2017)

[8] A.V. Mitrofanov, *Pulsed sources of secondary power in consumer audio* (M.: Radio Communication, 204, 1987)

[9] R. Maharjan, S. Kamalasadan, Voltage Stability Index for Online Voltage Stability Assessment, Article. DOI: 10.1109/NAPS.2015.7335245 (2020)

[10] M.S. Rawat, S. Vadhera, Voltage Stability Assessment Techniques for Modern Power Systems, Article (2020). ISBN: 9781522585534

[11] V.K. Bityukov, D.S. Simachkov, *Sources of secondary power: textbook* (M.: Infra-Engineering, 2017)

[12] G. Sysoeva, *Power supply devices and systems of telecommunications: textbook* (VSL, 255, 2002)

[13] A.A. Bass, *Secondary power supply Sources with transformerless input* (M.: Radio Communication, 368, 1987)

[14] N.V. Sukhanova, Fundamentals of Electronics and Digital Circuitry: textbook (Voronezh: VGUIT, 247, 2017)

[15] E.T. Romancewe. *The Development and preparation of design documentation of electronic equipment*: a handbook (2nd ed. and additional, M.: Radio and communication, 114, 1989)