Technical University of Cluj-Napoca
Faculty of Automation and Computer Science

Subject:

POWER ELECTRONICS IN AUTOMATIC CONTROL

Project:

DC STABILIZED SWITCHED MODE POWER SUPPLY

Student:_________________________

Group:_________

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DC STABILIZED SWITCHED MODE POWER SUPPLY

A.

The design of a DC uncontrolled power supply

Student Name:________________________

Group:________

A. THE DESIGN OF UNCONTROLLED DC POWER SUPPLY

A.1. Design and analysis of the line transformer
A.2. Design of the rectifier circuit
A.3. Design of the smoothing filter

A.1. Design and analysis of a line transformer

Initial data:

- Primary supply voltage (U_1=….)
- Secondary nominal voltages and currents
  - U_{2N}=……
  - I_{2N}=…….
- Data on the magnetic core: the use of laminated silicon steel sheets, coated with insulating layer; the shape of the sheets is (E+I)
- Winding data: enameled copper wire for coil with round section

A.1.1. Electric scheme of a line transformer

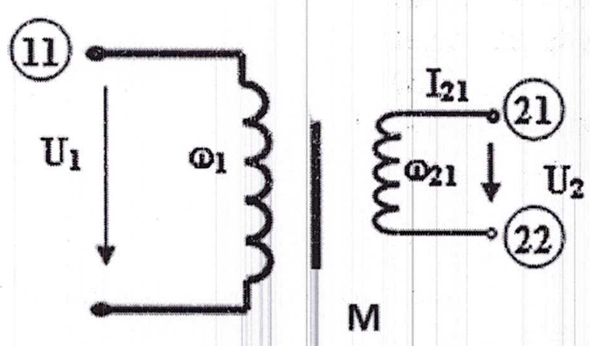

Fig. 1.

Where:

M = iron core,
w1 = primary winding,

w2 = secondary winding.

A.1.2. Line transformer design steps

A.1.2.1. Total power in the secondary winding (for $\cos\varphi = 1$)

$$P_2 = S_2 = U_2 \cdot I_2 = \dots\dots\dots \text{[W]}$$

A.1.2.2. Global power of the transformer

$$P_g = \frac{P_2}{2}\left(1 + \frac{1}{\eta_{tr}}\right) = \dots\dots\dots\dots \text{[W]}$$

where the estimated **efficiency** of the transformer (η_{tr}) of the transformer and the **permissible** current density J[A/mm2] are given in Table no.1.

Table no.1

P_2[W]	10	20	30	50	70	100	200	300	500	700	1000
η_{tr}	0,78	0,81	0,83	0,85	8,87	0,88	0,92	0,93	0,94	0,945	0,95
J [A/mm^2]	4	3,8	3,6	3,2		2,4	1,40	1,25	1		0,90

In order to determine the value of the efficiency (η_{tr}) corresponding to the computed secondary power (P_2), an interpolation may be necessary.

A.1.2.3. Approximation of the iron core section is given by the equation:

$$S_{Fe} = (1{,}1\dots1{,}5)\sqrt{P_g \frac{1+\eta_{tr}}{J \cdot \eta_{tr}}} = \dots\dots\dots\dots [cm^2]$$

A.1.2.4. Selection of the laminated sheets of the magnetic core

For the usual line transformer, the core is made of (E+I) silicon-steel laminated sheets with the rated value of induction B=1,1 [T]. In the specialized literature, these laminated sheets (toles) are classified in turn, depending on certain dimensional characteristics, there are nomenclatures that make it much easier to choose the desired type and to calculate the transformer. The main dimensions of the sheet are: the width of the sheet (1*) and the height of the window (h), resulting from this and the other dimensions. Obviously, it is assumed that the nature of the material from which the sheets are made is known, in our case iron-silicon sheet. Knowing the section is mandatory, because the maximum power that a transformer transfers (from primary to secondary) is dependent on the core section.

A 1.2.5 Computing of the primary winding current:

$$I_1 = P_g/U_1$$

$$I_1 = \ldots\ldots\ldots\ldots$$

A 1.2.6 Computing of nominal (secondary) load resistance:

$$R_{2N} = U_{2N}/ I_{2N}$$

$$R_{2N} = \ldots\ldots$$

A 1.2.7 Computing of secondary winding resistance:

$$R_2 = (0,5\ldots.1,5)\%* R_{2N}$$

$$R_2 = \ldots\ldots$$

A 1.2.8 Computing of primary winding resistance:

$$R_1 = (0,5\ldots0,7)\%*(U_1/I_1)$$

$$R_1 = \ldots\ldots$$

A1.2.9 Computing of reported secondary resistance (equivalent, total):

$$R_2^* = R_2 + R_1*(U_{2N}/U_1)^2$$

$$R_2^* = \ldots..$$

A.2. Design of the rectifier circuit

Electrical power generation and distribution is usually accomplished as alternating current due to simplicity and economical aspects. However, many types of electrical equipment operate with DC power supplies. The A.C. voltage must be, therefore, rectified and in most cases filtered to provide a desired D.C. output voltage at a required current or power level and quality.

Initial data:

- rectifier topology;
- secondary voltage and current supplied by the line transformer
- estimated values of smoothing capacitor

A.2.1. Rectifier topology

Full-wave rectification converts both polarities of the AC input waveform to DC (direct current), and yields a higher mean output voltage.

For the secondary winding (w_2) (terminals 21, 22) it is recommended a full-wave rectifier using four diodes in a bridge configuration, figure 6.

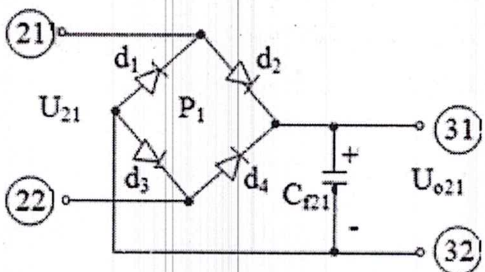

Fig.6

In order to choose the rectifier diodes or the rectifier bridges it is necessary to know the rectifiers electrical stress: the maximum voltage and the rectified currents (mean value). Based on these values, the necessary types and parameters of diodes or bridges can be chosen ,based on catalog data given in the table no 6.

Table no. 6

RECTIFIER BRIDGE

TYPE		I_d[A]	U_{inv} max[V]	$Ip^2\Delta t$ [A^2s]	Uef max [V]
1PM	0,5	1,2 A	50	4.5	35
	1		100		70
	2		200		140
	4		400		280
3 PM	0,5	3,2 A	50	24	35
	1		100		70
	2		200		140
	4		400		280
10 PM	0,5	10 A	50	162	35
	1		100		70
	2		200		140
	4		400		280

A.2.2. Rectifier design steps

A.2.2.1 Factor of safety:

A safety factor is imposed: $\sigma \cong 1{,}5$.

A.2.2.2. Voltage stress of the rectifiers

The maxim value of the voltages arising in the rectifier circuits depends on the secondary voltages and on the rectifier version.

The maxim value of the voltage applied on the reverse biased rectifier for a high value of the smoothing capacitor is approximated by the usual formulas:

$$U_{max21} = \sqrt{2} \cdot U_{21} = \text{............}[V]$$

For the rectifiers selection, taking into account the factor of safety ($\sigma \approx 1.5$), the maximum voltage accepted by the reversed biased rectifiers is given by the equations:

$$U^{*}_{max21} = 1{,}5 \cdot \sqrt{2} \cdot U_{21} = 2{,}12 \cdot U_{21} = \text{............}[V]$$

for the rectifier bridge.

A.2.2.2. The current stress of the rectifiers:

In direct bias

$$\bar{I}_{2i} \cong 0{,}7 \cdot \tilde{I}_{2i}(A)$$

In order to choose the appropriate type of rectifier, the following equations are considered:

$$\bar{I}_2^* = 1{,}5 \cdot 0{,}7 \cdot \tilde{I}_2 = 1{,}05 \cdot \tilde{I}_2(A),$$

$$\bar{I}_2^* = \ldots\ldots\ldots (A)$$

The following rectifier is chosen from catalog:

-
- bridge rectifier of type .... with

.... $[V] > U^*_{max\,21}\,[V]$

$I_d =$ .... $> \bar{I}_2^*[A]$

$I_p^2 \cdot \Delta t =$ .... $(A^2.sec$– from the datasheet

A.2.2.3. Testing the rectifier considering the starting current

The „starting" current, is the current delivered right after the power source is powered-on and the smoothing capacitors is uncharged.

In table no. 7 are presented the estimated values (*mF*) (usual values for laboratory power supplies) of the smoothing capacitors for different values of the rectified voltage and current, $(\bar{U}_0, \bar{I}_0)$.

Table no. 7

$\bar{I}_0$ [A] / $\bar{U}_0$ [V]	0.2	0.4	0.6	0.8	1.0	1.2	1.4	1.6	1.8	2	2.2	2.4	2.6	2.8	3
10	0.75	1.5	2.25	3	3.75	4.5	5.25	6	6.75	7.5	8.25	9	9.75	10.5	11.25
20	0.4	0.8	1.2	1.6	2	2.4	2.8	3.2	3.6	4	4.4	4.8	5.2	5.6	6

30	0.25	0.50	0.75	1	1.25	1.5	1.75	2	2.25	2.5	2.75	3	3.25	3.5	3.75
40	0.2	0.4	0.6	0.8	1	1.2	1.4	1.6	1.8	2	2.2	2.4	2.6	2.8	3
50	0.15	0.3	0.45	0.6	0.75	0.9	1.05	1.2	1.35	1.5	1.65	1.8	1.95	2.1	2.25
60	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1	1.1	1.2	1.3	1.4	1.5

The „starting" current is approximated using:

$$I_p \cong I_{Dp} \cong \frac{\sqrt{2} \cdot \tilde{U}_2}{R_2^* + k \cdot r_d}$$

$$I_p = \ldots\ldots [A]$$

where (r_d) is the „equivalent" resistance of the diode and (k) is the number of diodes working simultaneously in the circuit:

- k=2 for figure 6. (bridge rectifier)

The estimated values for the rectifiers, equivalent dynamic resistances for low voltages ($U_{inv_{datasheet}} < 100 - 150V$) are given in table no.8.

Table no.8

I_D [A]	0.3	0.7	1	3	5	10
r_d [Ω]	4	1.7	1.2-3.75	0.4	0.24	0.12

The "initial" charging time of capacitors can be determined based of the following relation:

$$\Delta t^* \cong (R_2^* + k \cdot r_d) \cdot C_f,$$

for which:

$$\Delta t^* = \ldots\ldots [sec];$$

The "thermal capacity" of the rectifier at the initial charging is:

$$I_p^2 \cdot \Delta t^* = \frac{2(\tilde{U}_2)^2}{(R_2^* + k \cdot r_d)} \cdot C_f,$$

This value must be smaller than the datasheet values for the "thermal capacity" ($I_D^2 \cdot \Delta t$) for the chosen rectifier bridge

A.3. Design of the smoothing filter

A.3.1. Design of the filter capacitor

The design steps are used to determine the necessary values of the capacitive filter (C_{f21}), The filter quality is estimated using the *ripple factor (p)* and the *filtering coefficient (q)*.

If we consider the voltage obtained after rectifying an AC voltage, we will observe a DC component ($\overline{U}$), equal to the mean value of the rectified voltage, over which overlaps the alternating component ($\Delta\tilde{U}$). Due to the fact that the alternating component („ripple") presents a complex form, difficult to describe analytically, it is approximated to the first harmonic ($\tilde{U}_1$) , whose amplitude is close to the amplitude of the alternating component. The input ripple factor (p) is defined by:

$$p_i = \frac{\Delta\tilde{U}}{\overline{U}} \cong \frac{\tilde{U}_1}{\overline{U}}$$

In the case of full wave rectifier (ideal), without capacitor

$$p \equiv p_i = \frac{2}{3} \cong 67\%.$$

If an effectiv voltage (U_{ef}) is rectified and if the rectifier voltage drop is neglected, the mean value of the output voltage (without filter) is:

$$\overline{U} = \frac{2\sqrt{2}}{\Pi} \cdot \tilde{U}_{ef} \cong 0{,}9 \cdot \tilde{U}_{ef}$$

If (ΔU_D) is the rectifier voltage drop (considered $\Delta U_D = 0{,}75V$), for the bridge rectifier presented in figure 6.

$$\overline{U}_2 \cong 0{,}9 \cdot e_2^* - 2\Delta U_D$$

The filter capacitor will reduce the alternating component and will increase the mean value, depending on the value of the filter capacitor and also of the load resistance:

$$\overline{U}_2 \cong (0{,}9 \div 1{,}41) \cdot e_2^* - k \cdot \Delta U_D;\ ;\ k = 2.$$

For high values of load resistance and filter capacitor, we will choose the value (1,41), while for small values of load resistance and filter capacitor, (0,9) will be chosen (that is , without capacitor).

It is assumed that the ripple coefficient must be reduced from p_i=67% to

$$p_o = (8 - 10)\%$$

for nominal load resistances ($R_{SN} = \frac{U_2}{I_2}$)

A.3.2. Design steps for filter capacity value

A.3.2.1. The filtering coefficient is computed as

$$q = \frac{p_i}{p_o} = \ldots\ldots\ldots (>>1)$$

A.3.2.2. Equivalent resistances

Based on the nominal load resistances (R_{SN}), and the rectifier overall resistances

$$R_{rt} = R_2^* + k \cdot r_d;$$

k=2 (bridge rectifiers),

$$R_{rt} = \ldots\ldots\ldots\ldots\ldots\ldots$$

the necessary value of the filter capacitor can be computed.

A.3.2.3. Smoothing capacitor values

$$C_f^* = \frac{1600 \cdot q(R_{rt} + R_{SN})}{R_{rt} \cdot R_{SN}} \quad [\mu F]$$

so that

$$C_f^* = \frac{1600 \cdot q(R_{rt} + R_{SN})}{R_{rt} \cdot R_{SN}} = \ldots\ldots\ldots\ldots \quad [\mu F]$$

The computed value can be compared with the estimated values from table no.7, (C_f).

A.3.2.4. Behavior analysis of the rectifier with smoothing filter

In order to determine the **exact** value of the rectified mean voltage **considering a load** and a filter capacitor, a complex calculus is necessary. In order to avoid complex calculus, the diagrams presented in figure 9 can be used, where:

$$\begin{cases} R_r = R_{rti} = R_2^* + k \cdot r_d \\ R_o = R_{SiN} = \dfrac{U_{2i}}{I_{2i}}, \\ \omega = 314(rad/sec)\,;\, C_o = C_{fi}^*, \text{ (table no 7)} \\ E_{oi} = 1{,}41 \cdot e_{2i}^* \quad k \cdot \Delta U_D, k = 1 \, or \, k = 2 \end{cases}$$

$$\begin{cases} R_r = R_{rt} = R_2^* + k \cdot r_d = \ldots\ldots\ldots\ldots \\ R_o = R_{SN} = \dfrac{U_2}{I_2} = \ldots\ldots\ldots\ldots \\ \omega = 314(rad/sec)\,;\, C_o = C_f^* = \ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{ (table no 7)} \\ E_o = 1{,}41 \cdot e_2^* \quad k \cdot \Delta U_D = \ldots\ldots\ldots\, k = 2 \end{cases}$$

The previously presented relations are applied for secondary winding and the voltage coefficient is obtained:

$k_u = \frac{U_o}{E_o}$ based on $(\omega C_o R_o)$ and on $k_r = \frac{R_r}{R_o}$

so that, with load, (for $\bar{I}_{0i} = \bar{I}_{2i}$), the smoothing capacitor voltage is described by:

$$\bar{U}_{oiN}^* - k_{ui}^* \cdot \bar{E}_{oi};$$

$$\bar{U}_{oN}^* - k_u^* \cdot \bar{E}_o - \ldots\ldots\ldots\ldots\ldots\ldots$$

The linearized load characteristics are described in figure 7

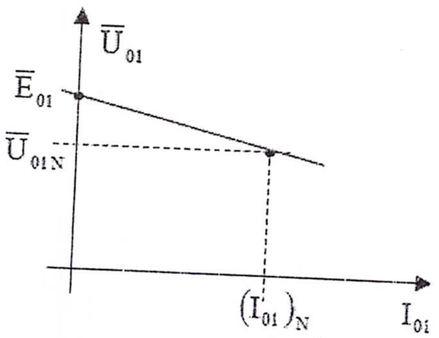

Fig 7. Linearized transformer load characteristic

A.3.2.5. Design of the filter capacity value (C_f^{**}), using diagrams

Starting from the imposed value of the ripple factor (p_o), and based on the values of the equivalent resistances

$$R_o = R_{SiN} \text{ and } R_r = R_{rti} = R_{2i}^* + k \cdot r_d$$

and using the diagram presented in figure 10, the value of the product ($\omega C_o R_o$) can be determined so that

$$C_{oi} = C_{fi}^{**} = \left(\frac{\omega C_o R_o}{\omega R_o}\right)_i \ [F],$$

$$C_o = C_f^{**} = \left(\frac{\omega C_o R_o}{\omega R_o}\right) = \text{..............} \ [F]$$

A.3.2.6. The final value of the filter capacitor is determined as the mean value of

$$\bar{C}_f = \frac{C_f^* + C_f^{**}}{2} \ [F],$$

15

$$\bar{C}_{f1} = \frac{C_{f1}^{*} + C_{f1}^{**}}{2} = \ldots\ldots\ldots\ldots [F]$$

The working voltage of the capacitors will be equal to the datasheet value for the maxim value of the voltage applied on the reverse biased rectifier.