THE SIMULATION OF RESISTIVE AND CAPACITIVE STRUCTURES

The purpose of the paper: Highlighting by means of mathematical (simulation) methods the real behavior of resistors and capacitors.

The paper has four sections:

- electrical stress of resistors
- resistors' frequency dependent behaviour
- capacitors' frequency dependent behaviour
- capacitors' electrical stress with respect to frequency

Work procedure:

I. RESISTORS' ELECTRICAL STRESS - SOLREZ.XMCD -

SOLREZ.XMCD is called.

1. Analysis of a resistor's stress for various values of the resistance

First, the diagram of the power dissipation with respect to ambient temperature is analyzed, for a carbon film resistor similar to the ones in the paper „Fixed Linear Resistors".

The following data is provided:

- Rn = 24 KΩ	rated resistance,
- Pn = 0.5 W	rated power
- Umax = 350 V	maximum voltage
- θn = 70°C	rated temperature
- θmax = 155°C	maximum temperature

The ambient temperatura varies between 1 and 200°C.

After stating the aforementioned parameters the program will plot the disipated power (P_d) with respect to the ambient temperature θ.

$$P_d(\theta) = \begin{cases} P_n, \text{for } \theta \le \theta_n \\ P_n \dfrac{\theta_{max} - \theta}{\theta_{max} - \theta_n}, \text{for } \theta > \theta_n \end{cases} \quad [1]$$

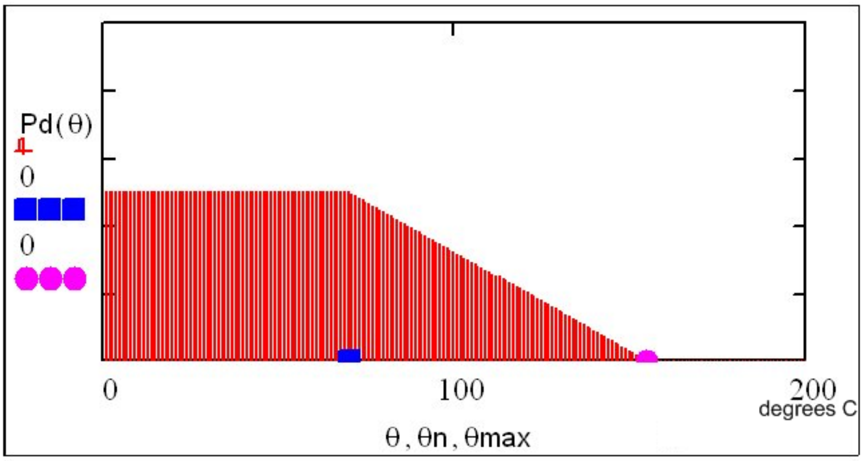


Fig. 1 Dissipation characteristic of a resistor

The maximum range for the voltage applied on a resistor is studied [Ua(θ)]. This range is

$$Ua(\theta) = \min\left(Umax, \sqrt{P_d(\theta) \cdot R_n} \right) \quad [2]$$

Plotted:

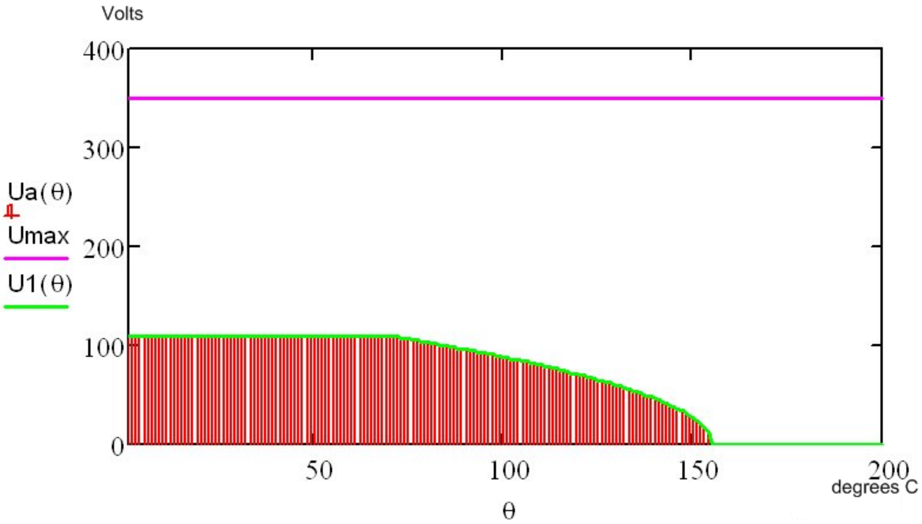


Fig.2 Plot of the admissble voltage

- Umax(θ)= 350 V constant (straight line),
- $U1(\theta) = \sqrt{P_d(\theta) \cdot R_n}$
- Ua(θ) = min (Umax,U1(θ))   (hashed area).

The maximum appliable voltage is plotted for different values of the ambient temperature:
Ua(1)   Ua at 1 °C,
Ua(θn)   Ua at the rated temperature,
Ua(θ1)   Ua for a temperature between the rated and maximum temperature,
Ua(θmax)   Ua at the maximum temperature.

Obs.:   Ua(θmax) = 0   (always)

The range for the applied voltages onto a resistor depends on its critical resistance:

$$Rcrt = Umax^2/Pn$$

It results Rcrt = 245 kΩ for the parameters given above.

- Three values of the rated resistance Rn have to be chosen, such that Rn ≈ Rcrt /10, Rn = Rcrt , Rn ≈ Rcrt ×10. For the three values, establish the correlation with the aspects mentioned in the previous sections, the range of applied voltages for each resistor. Plot the graphs and mention on the axis the corresponding values for the temperatures and voltages and comment upon the results.
- Discuss the three cases of the rated resistance for the values of the voltage Ua(θ) at 20 degrees, at the rated temperature and at θ1.

2. The analysis of the stress for a group of resistors:

2.1 Graphical resolution for the stress problem for a group of resistors

After passing item 1 determine the maximum voltage which can be applied at the terminals of a parallel grouping of resistors. The circuit is working in an unstable environment with respect to temperature. The temperature interval is θa (10..155) degrees C. The types and parameters of the resistors are:

a) A carbon film resistor TA670, manufacturer Multicomp

- Rn1 = 47 KΩ	rated resistance,
- Pn1 = 0.25 W	rated power
- Umax1 = 250 V	maximum voltage
- θn1 = 70°C	rated temperature
- θmax1 = 155°C	maximum temperature

b) A carbon composition resistor CBT50, manufacturer Tyco Electronics

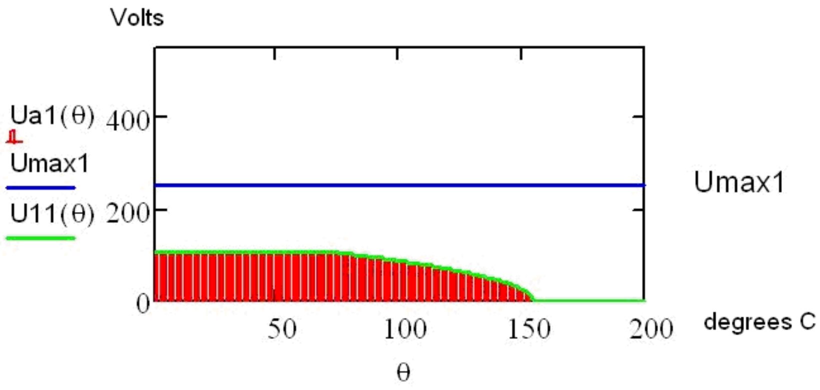
- Rn2 = 500000 Ω	rated resistance,
- Pn2 = 0.5 W	rated power
- Umax2 = 350 V	maximum voltage
- θn2 = 70°C	rated temperature
- θmax2 = 155°C	maximum temperature

c) A carbon film resistor TA670, manufacturer Multicomp

- Rn3 = 100000 Ω	rated resistance,
- Pn3 = 1 W	rated power
- Umax3 = 500 V	maximum voltage
- θn3 = 70°C	rated temperature
- θmax3 = 155°C	maximum temperature

After the computations the critical resistances result for each type of resistor Rcrt1, Rcrt2, Rcrt3.

- Plot Pd(θ) for each type of resistor
- Plot Ua(θ) for each type of resistor
- Define a maximum working temperature θfmax, for which the corresponding voltages will be computed. The initial value is θfmax=110 degrees.



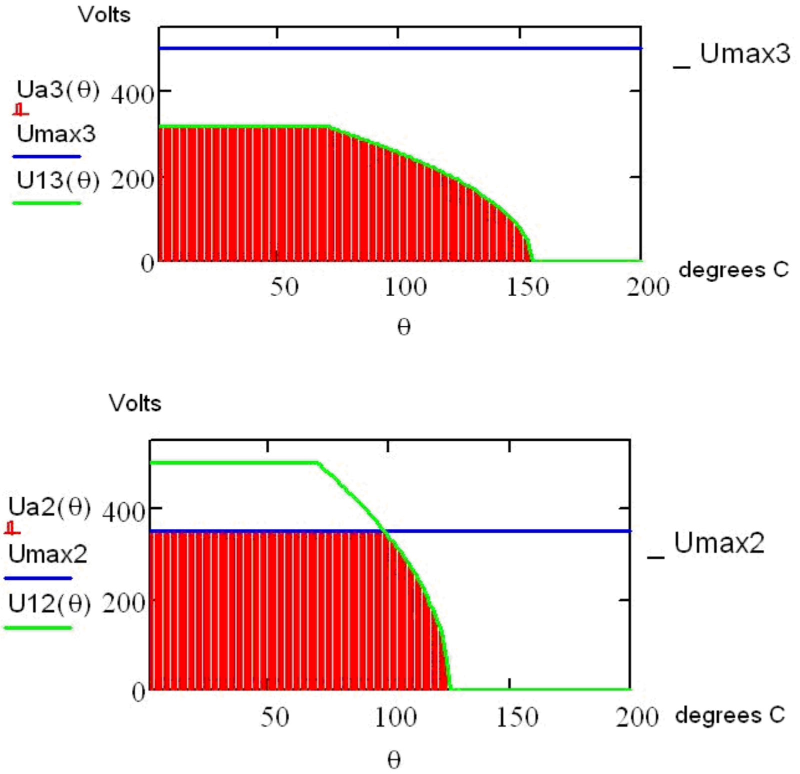


Fig. 3 The plots for the admissible voltage for the three resistors

The maximum admissible voltages result which can be applied for each type of resistor for an ambient temperature θ_{fmax}. The maximum admissible voltages will be mentioned for the following ambient temperatures θfmax: 20 degrees, 70 degrees, 100 degrees, 120 degrees by modifying the value in the program.

For the general case it will be used the plot that unites the individual stress for the three resistors Ua1(θ), Ua2(θ) and Ua3(θ). The admissible voltage results Uadm = min $(Ua1(\theta_{fmax}),Ua2(\theta_{fmax}),Ua3(\theta_{fmax}))$

The electrical stress of a group of resistors will be mathematically defined in the paper for ranges of temperature. In this sense the temperature at the intersection points on the plots need to be determined.

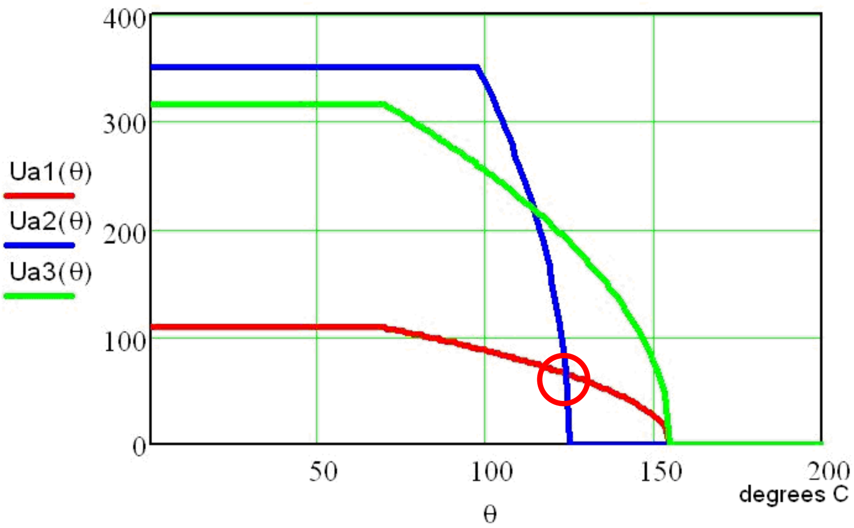


Fig 4. Plots for the power requirements of the three resistors

2.2 The same problem must be solved for other values of the rated resistance:

Carbon film resistor **TA670**	Carbon composition resistor **CBT50**	Carbon film resistor **TA672**
Rn1=360000 Ω	Rn2=390000 Ω	Rn3=75000 Ω

Homework (to be included in the paper): Solve the problem of electrical stress for a series of three resistors with the data given in section 2.1.

II. RESISTORS' FREQUENCY DEPENDENT BEHAVIOUR- COMPFREZ.XMCD -

COMPFREZ.XMCD is called**.**

Purpose: The study of the resistors' frequency dependent behaviour.

A cemented wire-wound resistor RBC 1003 is considered with the parameters:

R_n - 350 Ω rated resistance
tol - 10 % tolerance
P_n - 3 W rated power

The wire-wound resistor was made as follows:

l_b - 14 mm length of the wire-wounded part;
D_b - 3 mm wire-wound diameter;
N - 28 number of turns.

The parasitic inductance is computed:

$$L_p = \frac{\mu N^2 S}{l}$$

The parasitic capacity is harder to compute and it is experimentally deduced: C_p>>0.3 pF.

Given this data the resonance frequency can be computed (formula [1] in Mathcad).
The plot in figure 5 allows quick estimation of the capacitive or inductive behavior of the resistor.

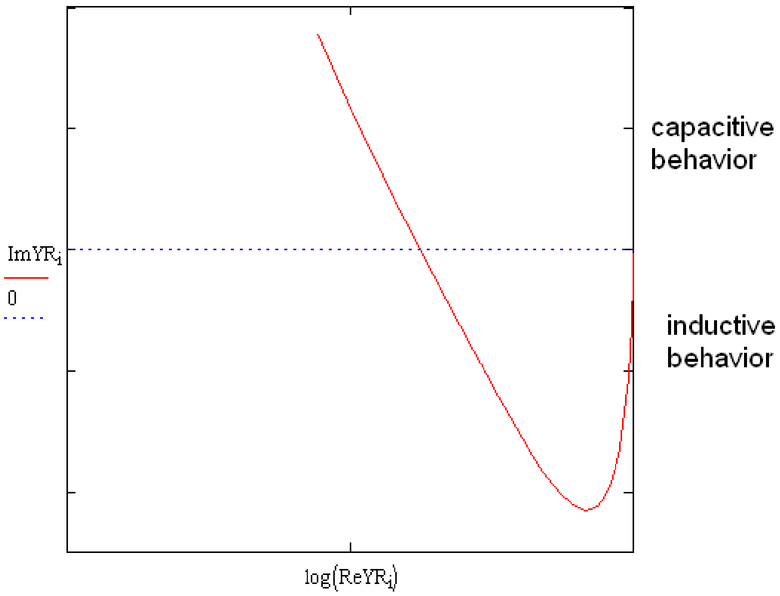


Fig. 5 Plotting the rezistive, inductive or capacitive frequency dependent behaviour

For: $\omega = 0$ - purely resistive behavior
$\omega \in (0, \omega_0)$ – inductive behavior
$\omega > \omega_0$ - capacitive behavior

For values of resistance exceeding R_c (problem 3 in the annex) the resistor has only capacitive behavior.

From the theoretical model presented at the course, formula [3] allows us to compute the impedance of the considered resistor.

In figure 6 the variation |Z|/R with respect to frequency is provided. The difference between f_o and f_r can be easily observed.

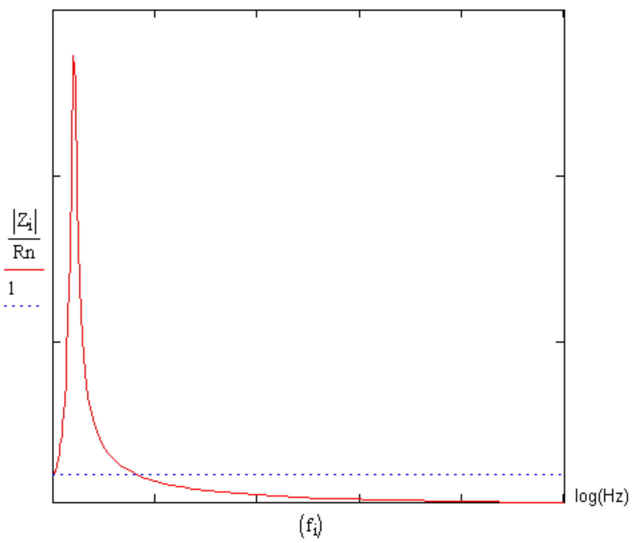


Fig. 6 The variation of the impedance's module within the frequency range

<u>Homework</u>: Solve problems [1 , 2, 3 şi 4] from Annex 5 = program COMPFREZ.XMCD.

III. CAPACITORS' FREQUENCY DEPENDENT BEHAVIOR COMPFCON.XMCD

COMPFCON.XMCD is called**.**

The program analyses the frequency dependent behavior of a capacitor, based on an equivalent circuit, through the study of the impedance **|Z(f)|,** and also the effect of connecting the capacitor in the circuit using two (inductive) traces.

The circuit used is given in the figure below:

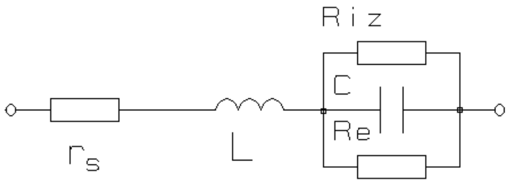


Fig. 7 The full series equivalent circuit of a capacitor.

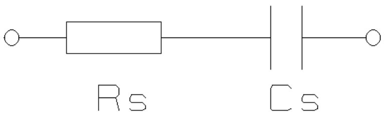


Fig.8 Equivalent circuit of a capacitor

Where:

- r_s the resistance of the plates and of the terminals;
- L inductance of the plates and of the terminals;
- Re dielectric loss resistance
- R_{iz} insulation resistance

The frequency dependence of **Cs** and **|Z(f)|** is given below:

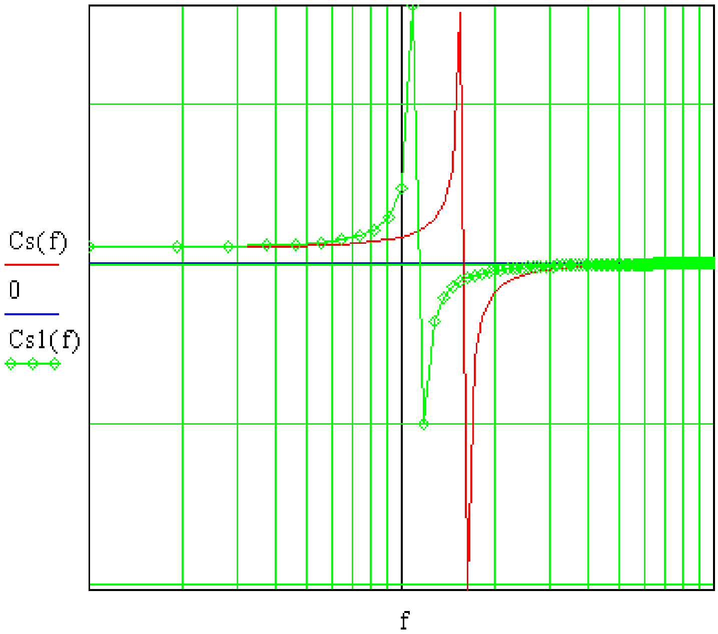


Fig. 9 The frequency dependence of **Cs,** the series equivalent capacity.

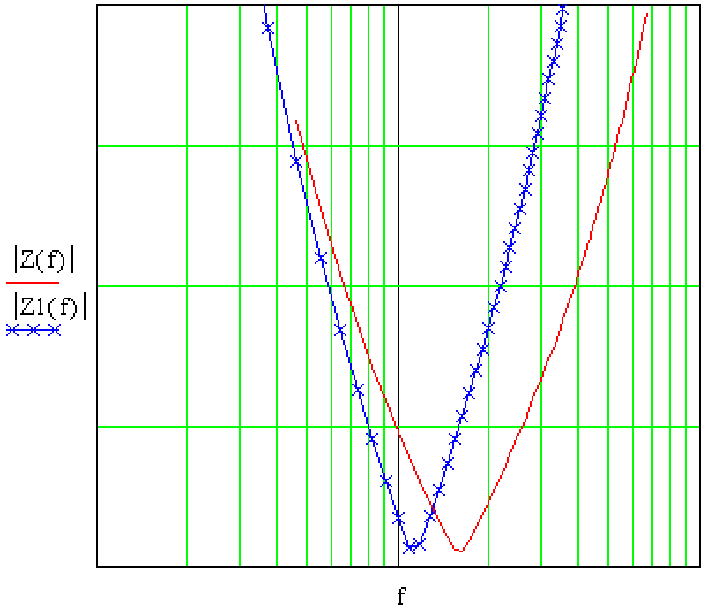


Fig 10 Impedance's modulus frequency dependence.

IV. THE ELECTRICAL STRESS OF THE CAPACITORS WITH FREQUENCY - SOLCON.XMCD-

SOLCON.XMCD is called.

SOLCON.XMCD shows how a capacitor is stressed with respect to frequency when a voltage is applied at its terminals. A short overview of the capacitors' parameters of interest to this paper is presented:

Rated capacitance, C – the capacitance inscribed on the body of the capacitor
Rated Voltage, Un – maximum voltage that can be applied on the capacitor for a normal long term working regime.
Loss tangent, tan δ - parameter which defines the active power losses in the capacitor, defined as the ratio between the active and reactive power ($\mathrm{tg}\,\delta = \frac{P_a}{P_r}$).
Rated power, Pn – maximum power that a capacitor can dissipate; power due to the dielectric losses.
Rated current, In – maximum current flowing through the capacitor. Its value is determined by the power losses between the capacitor's plates and terminals.

For a capacitor is provided the following data:

C= 68 nF,
Un= 160 V,
Pn= 0.05 W,
In= 0,1 A,
$\mathrm{tg}\,\delta = 8\cdot 10^{-3}$.

The frequency varies between (100¸ 100000) Hz with a 400 Hz step.

In accordance with the value of the maximum power dissipated by the capacitor $\mathbf{P_{dmax}}$ compared to the rated power there are the following cases:

a) Pn > Pdmax ,
b) Pn ≤ Pdmax

Correspondingly there are two different representations of the maximum voltage with respect to frequency (figures 11 and 12).

For case a) there are two characteristic frequencies for the capacitor $\mathbf{f}_{\alpha}$ and $\mathbf{f}_{\beta}$ delimiting the stress ranges. For case b) there is only one characteristic frequency: **fc**. The program chooses by taking into account $\mathbf{P}_{dmax}$ the corresponding proper case.

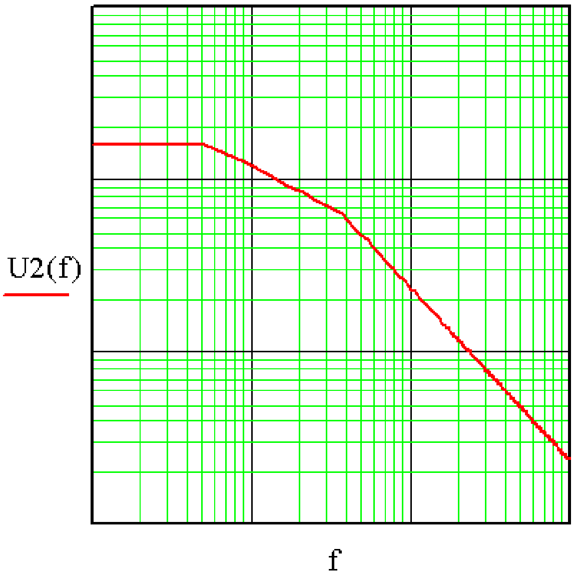


Fig. 11 Maximum voltage applied at the capacitor's terminals in the case Pdmax > Pn.

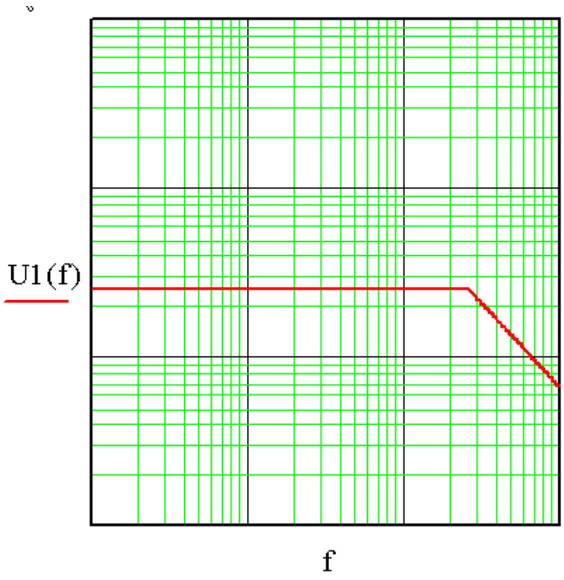


Fig. 12 Maximum voltage applied at the capacitor's terminals in the case Pdmax < Pn.

In case a), until the frequency $\mathbf{f}_{\alpha}$ is reached the voltage must not be exceeded, hence the voltage **Un** can be applied. At frequency $\mathbf{f}_{\alpha}$, due to the power dissipated in the dielectric, the rated power is reached and, from this frequency on, the voltage must correspondingly be decreased. At frequency $\mathbf{f}_{\beta}$ the rated current, **In**, is reached and, for even higher frequencies, the voltage must be further decreased.

The voltage formulas are:

for $f < f\alpha$ $\quad U(f)=Un$

for $f_\alpha < f < f_\beta$ $\quad U(f) = \sqrt{\dfrac{P_n}{2 \cdot \pi \cdot f \cdot C \cdot tg\delta}}$

for $f > f_\beta$ $\quad U(f) = \dfrac{I_n}{2 \cdot \pi \cdot f \cdot C}$

In case b) Pdmax ≤ Pn, there is no power limitation because the value **Pn** is never reached, not even in the worst case scenario. When the frequency increases the rated current is reached at some point, value which must not be exceeded. The voltage is:

for $f < fc$ $\quad U(f) = Un$

for $f > fc$ $\quad U(f) = \dfrac{I_n}{2 \cdot \pi \cdot f \cdot C}$