# Practical Work

## Part 1: NON-LINEAR NETWORK:

**Definition:** a non-linear network is composed of a load which, connected to a sinusoidal voltage source, absorbs a non-sinusoidal current. A typical example is the motorization of a DC machine associated with a controlled rectifier. This is the case of the wind tunnel of Polytech.

Figure 1 shows the block diagram of the energy chain of the three-phase network to the DC motor. The current in a phase of the source (line current), written $i_{ph}$, is presented in figure 2. This is a real record from the oscilloscope. The average value of this current is zero, its RMS value is **27 A**. Figure 3 shows the amplitude spectrum of this signal.
We can note the presence of a first line at 50 Hz: this is the fundamental term. Its RMS value is written $\mathbf{I_1}$.
Other lines can be observed. They correspond to harmonics of rank 5, 7, 11, 13, 17, 29, 35, 41, 47. Their RMS values are written $\mathbf{I_h}$.
The following table gives the coefficients $a_h$:

$a_h = I_h / I_1$

| Rank h | 5 | 7 | 11 | 17 | 23 | 29 | 35 | 41 | 47 |
|---|---|---|---|---|---|---|---|---|---|
| $a_h$ | 0.36 | 0.04 | 0.1 | 0.07 | 0.04 | 0.034 | 0.034 | 0.034 | 0.034 |

**1** Give the expression of the total RMS value of the intensity, **I**, as a function of the RMS values of each term of the FOURIER series decomposition.
Deduce the expression of **I** as a function of $\mathbf{a_h}$.

**2** The total RMS value is 27 A. Deduce the RMS values at rank h

**3** The current distortion is characterized by two parameters:

- Total Harmonic Distortion $$THD = \frac{\sqrt{\sum_{2}^{\infty} I_h^2}}{I_1}$$

- Harmonic distortion coefficient $$D_F = \frac{\sqrt{\sum_{2}^{\infty} I_h^2}}{I}$$

Calculate these 2 parameters.

NB: Measuring devices provide directly these coefficients.

**4** Give the definition of the power factor **FP**.
Write and demonstrate its expression as a function of $I_1$, I, $\cos\varphi_1$ where $\varphi_1$ is the phase shift between the fundamental of the intensity and the line voltage of the phase of interest.

The measurement of the consumed power P provided the following value: 2910 W.

The phase voltage of the network U is 141 V. Calculate the power factor.
Deduce the value of $\cos\varphi_1$.
Calculate the reactive power.

**5** Define the apparent power of the network S, as well as the apparent power relative to the fundamental $\mathbf{S_1}$. Where does this one come from? What is its consequence?
From question 1, show the so-called distortion power written D.
Write the relation between the distortion power to $\mathbf{D_F}$ and **S**.

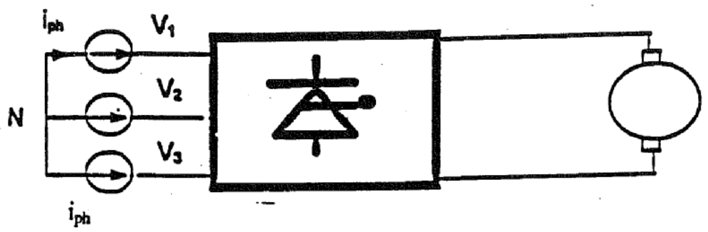


figure 1

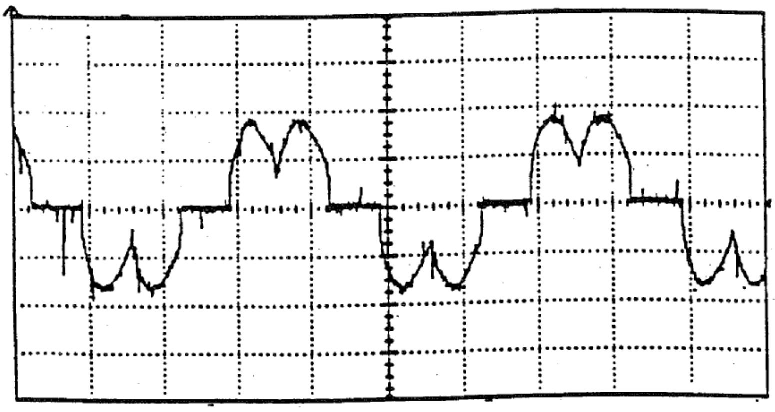

Figure 2

5ms/car

20 log $a_h$
10dB :

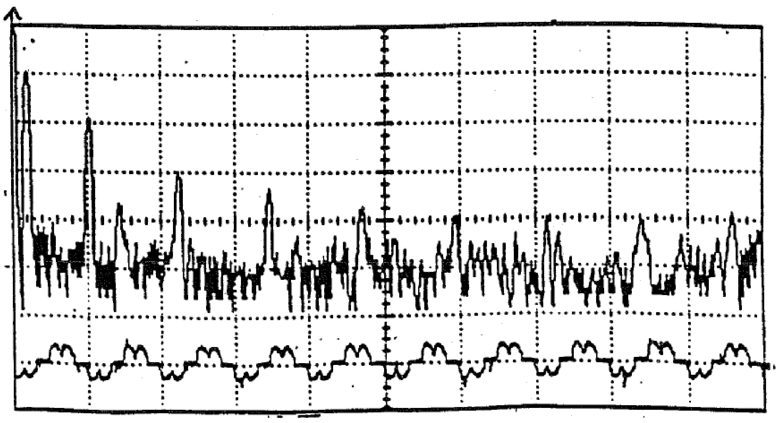

Figure 3

Frequency scale
250Hz/car

# Part 2: PASSIVE COMPENSATION OF HARMONICS ON A NONLINEAR NETWORK

**Introduction:**
This tutorial studies the influence of a nonlinear load on a line. We will perform the passive compensation of rank 5 together with the reactive energy compensation.

It uses the Pspice electronic simulation software. Six pre-edited files illustrate the different phases of the study.

**1/ Presentation of the non-linear load:**
In order to simplify, the study is carried out in single-phase and the load is modeled by 3 current sources comprising a fundamental component of 100A, a rank 5 component of 36A, a rank 7 component of 4A.
These currents are fully sinusoidal and therefore go through zero on the rising edge from the origin point.

| |
|---|
| Use the ME607-TD2.1 file to check the current source parameters and the transient simulation of the three currents. |

**2/ Effects of harmonic currents on the voltage of the user $u_c$:**
The harmonic currents have no effect on the quality of the voltage $u_c$ if the distribution lines are perfect. This is the case of the file ME607-TD2.1 for which $u_c$ is confused with $v_2$.
A single 1m cable has an inductance of 1µH. We consider here a line of 500 m with a series inductance of 0.5mH.
A conductor, even if it is made of copper, always has a resistance, for example 0.2Ω.

| |
|---|
| Use the file ME607-TD2.2 to visualize the voltage $u_c$ "at the terminals of the subscriber" and compare it to the voltage $v_2$ |

**3 Compensation of rank 5 by passive filtering:**
The principle of compensation by passive filtering consists of "trapping" the harmonics as close as possible to the source of currents to prevent them from going up the line and create an additional voltage drop in its constituting elements.
Trapping currents consists in giving them a path of weak or zero impedance by comparison to the path they follow before the correction and this, selectively in frequency. We must not act on the fundamental term.
Remember that you can short-circuit a power source without damage. Figure 1 illustrates the need for rank 5:

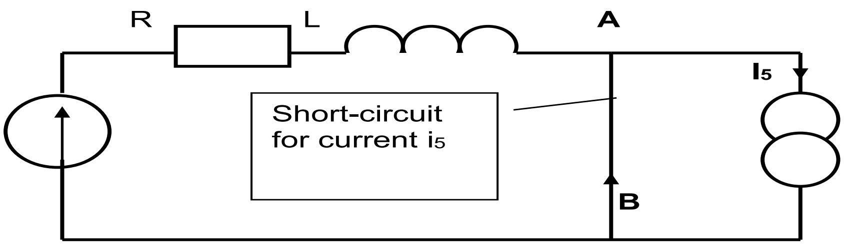


fig1

Show that the serial LC circuit is a good candidate for this function if one respects a condition on the value of the components L and C, by calculating its impedance **Z**.

Give this condition linking LC and $5\omega_0$ if $\omega_0$ is the pulsation of the network.
Verify that the following values satisfy this condition: 20.5 µH, 19.5 mF.

**3.1**

> Use the file ME607-TD2.3 to observe $u_c$ and $v_2$ by using two different values for R 0,2Ω then 0,1Ω

In fact, everything goes as if the impedance seen between the points AB increases, then contributing to the increase of $u_c$.

To verify this, we will simulate a frequency study to get the ZAB impedance. It is given by the following definition:

$\underline{Z}_{AB}=\frac{\underline{U}_c}{\underline{I}_{AB}}$ **where $\underline{I}_{AB}$** is the overall current that enters in A and leaves in B, the side of the voltage source. The plot in logarithmic coordinates provides better visibility:

$$20\log\left|\frac{\underline{U}_{AB}}{\underline{I}_{AB}}\right|$$

**3.2**

> The ME607-TD2.3 includes the frequency study using the AC procedure. Plot the ZAB impedance as a function of to the frequency after eliminating the line resistance

The complete calculation of the impedance $\underline{Z}_{AB}$ leads to:

$$\underline{Z}_{AB}=\frac{\left(1-L_2C_1\omega^2\right)\left(R_2+jL_1\omega\right)}{1-\omega^2\left(L_1+L_2\right)C_1+jR_2C_1\omega}\approx\frac{\left(1-L_2C_1\omega^2\right)jL_1\omega}{1-\omega^2\left(L_1+L_2\right)C_1}$$ for $R_2$ becoming very weak

This expression shows a zero at the denominator that provides a maximum on the module and a zero on the numerator that provides a minimum.
Calculate the values of the frequencies obtained for the extrema and compare them to the singular values of the impedance **$\underline{Z}_{AB}$.**

In fact, since the resistance $R_2$ is not always known, there is a risk of an overvoltage. The values of both $L_2$, $C_1$ are decisive but are not known, only their product is provided by the condition 3.1: $\sqrt{L_2C_1}=\frac{1}{\omega_0}$

Another criterion can be used to determine the value of $C_1$ and then obtain $L_2$ by the condition.

**4 Case of the load consuming reactive energy:**

**4.1**

The ME607-TD2.4 file presents a load that consumes reactive power. From the file parameters (current and voltage,) calculate the reactive energy consumed by the load.

**4.2**As seen previously in tutorial 1, it is possible to compensate this reactive power written Q (to be justified), by placing a capacitor in parallel on the load.
Express C and calculate its value

The ME607-TD2.4 file is used to introduce this capacitor. Check by plotting $V_2$ and $i_{R1}$ that the compensation is successful.
Give the RMS value of the voltage $u_C$.

**5 Non-linear load consuming reactive power:**

**5.1**The compensation of harmonic 5 has given criterion 3.1 which sets the value of the product $L_2C_1$.
The need to compensate the reactive power gives the value of $C_1$.
Conclude with the calculation of $L_2$. Thus, the $L_2C_1$ cell (**$\underline{Z_{AB}}$**) ensures both constraints.

Calculate the value of $L_2$.

The file ME607-TD2.5 makes it possible to draw the synthesis by observing the voltage $u_c$ and the current in the line
1 / How do you know that the compensation of the reactive power is achieved?
2 / Calculate the value of the inductance in the filter.
3 / What is the value of the ratio between the RMS values of the line current and the fundamental term of the load?
4 / Considering that the active power is maintained, give the theoretical value of the ratio defined in question 3 /

**5.2** The quality of the compensation of the 5th harmonic can be analyzed by observing the Fourier amplitude spectrum.

Thanks to the FFT function, the ME607-TD2.5 file allows observation of the amplitude spectrum of the Fourier series decomposition.

The main defect of this compensation is that it concerns only one harmonic rank. Here, the amplitude of the rank 7 is sufficiently weak to be neglected but, if it were not the case, it would be necessary to add a complementary cell with the risks of possible interactions as seen in **3.2**.

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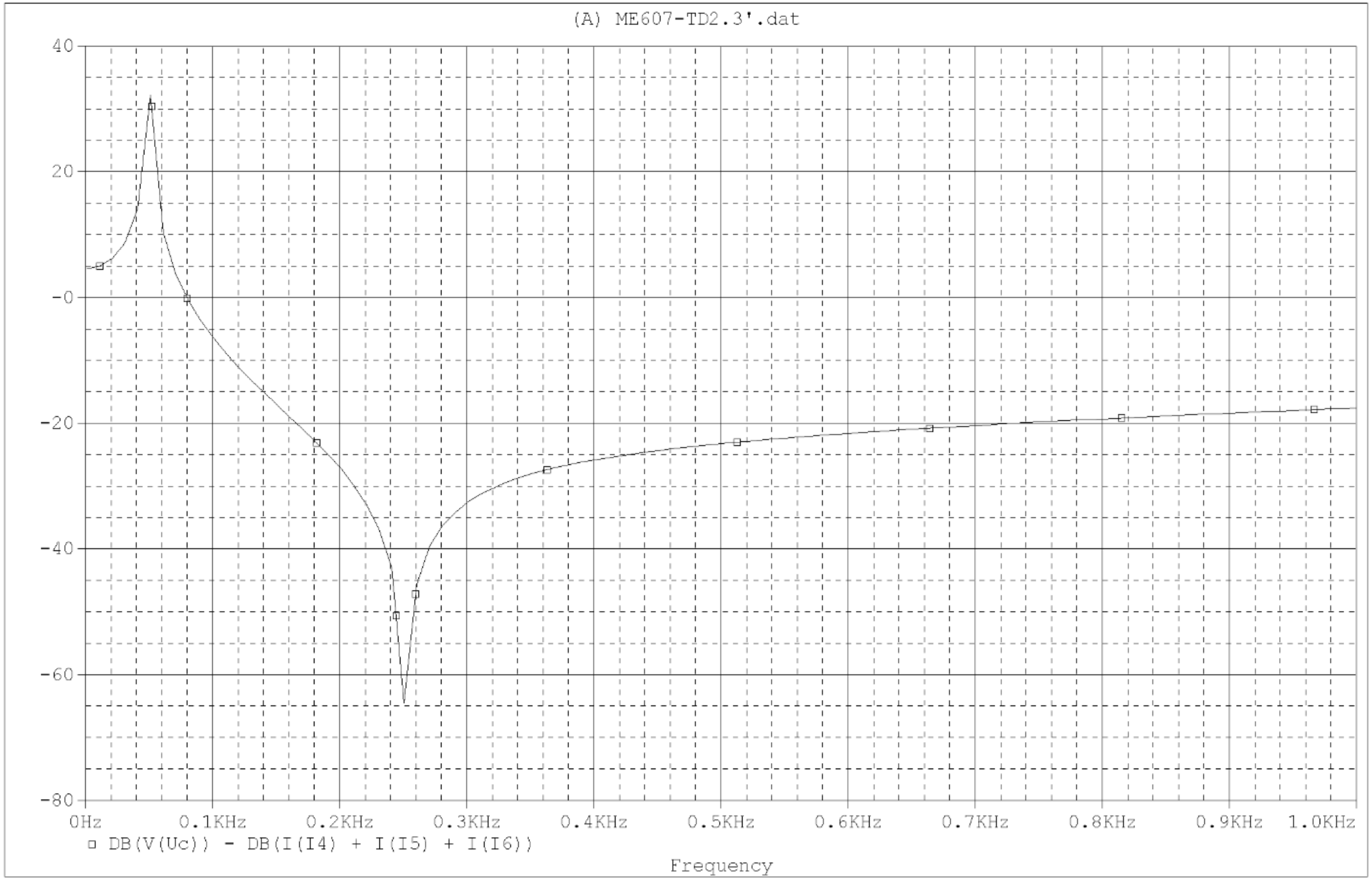


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