Comparative study of the behaviour of sinusoidal alternating waves and rectangular alternating waves on living tissue and on artificial R and RC charge

Rodríguez Martín, JM

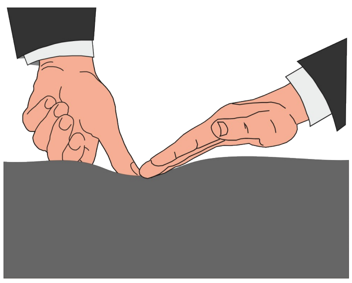
Spanish physiotherapist

Sumario

Translated into English with the help of Google Translate.

Original title in Spanish:

Estudio comparativo del comportamiento de ondas alternas sinusoidales y alternas rectangulares sobre los tejidos vivos y sobre carga artificial R y RC



Comparative study of the behaviour of sinusoidal alternating waves and rectangular alternating waves on living tissue and on artificial R and RC charge

Author

Rodríguez Martín, JM (Spanish physiotherapist)

abstract

Medium-frequency stimulators (with interferential and/or Kots current), some emit the carrier that forms the modulations with alternating sinusoidal waves (according to the classical description), but others output alternating quadrangular or rectangular waves. Situation that raises questions such as: Which way is the most correct? Is the same energy applied with both? How does reactive power influence the body?

To try to answer all or some of the above questions, some measurements will be developed experimentally with the two alternating modalities on circuits with artificial electrical charge and with charge of living tissues.

Key words

Medium frequency carrier. Sinusoidal alternating. Rectangular alternates. R charge and RC charge. Real power. Apparent power. Reactive power. Power factor. Phase difference between waves. Oscilloscope.

Introduction

When it comes to medium frequency, the classic concept states that it is formed by a carrier current between 2,000 and 10,000 Hz, with the option of modulating it at low frequency, whose new modulation frequency rarely exceeds 200 Hz. For example, the interferential ones are composed of the sinusoidal alternating carrier adjusted to an average of ±4,000 Hz modulated in different modalities to choose from.

It is common that electrotherapy equipment (usually moderately priced) instead of using alternating sinusoidal waves in the carrier, uses quadrangular alternating waves, altering the classic norm of alternating sinusoidal waves.

The reasons why designers apply this modality would be best to ask them. Perhaps it is due to the dominant trend of portable TENS and EMS based on rectangular pulses. Or is it intended to provide greater energy input? Is it about reducing costs?

At an industrial level it is easy to generate alternating sinusoidal waves because they come from rotating generators, implying that the waves generated are sinusoidal; But in low-power electronics based on computational circuits (such as electrotherapy stimulators) it is easier to generate rectangular or quadrangular waves than sine waves.

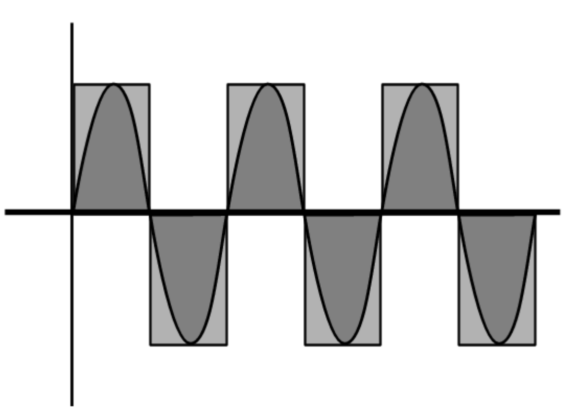


Figura 1: Differences in energy area between the quadrangular and the sinusoidal shape.

This change well deserves a comparative analysis between the two waveforms and the parametric consequences that would influence the patients' tissues, first on an artificial charge (which does not alter their resistance or impedance values) and then on real living tissues, which have the property that their behavior as a charge is not the same at the beginning as at the end of the test.

The concept of charge in a circuit refers to the element that receives the energy provided by the electric generator. In this case it refers to the body tissues and their treatment field between the electrodes, or failing that, artificial elements that replace living tissues.

Comparing the shapes and heights or amplitudes of both alternating waves, the energy area of the quadrangular is greater than the sinusoidal, being ±66% smaller than the rectangular Figure 1; Logically, this change in the energy area has to manifest itself in some way (as will be seen later).

With the objective of beginning the study that leads to conclusions, the RoMa practice box is prepared with its interposed resistance to capture the intensity wave, its charge resistance and a specific circuit that simulates tissue behavior with the greatest fidelity, in order to to represent a circuit of pure resistive charge [R] and another of more capacitive resistive charge [RC] just as soft body tissues would do in transcutaneous applications.

It is worth clarifying that the circuits considered RC can be composed in several ways:

- Parallel RC
- RC in series
- RC combined parallel and series
- Combined series and parallel RC.

In living tissues with transcutaneous applications (in alternating currents), the two electrodes, the skin barrier and the tissue interior will form the charge; so that the skin primarily behaves as a capacitor or capacitive part of it (although it also has resistance) and in the tissue interior the resistive component predominates (without neglecting its capacitive part), that is: in the face of alternating currents the charge of the fundamental circuit It will be CRC in series as shown in Figure 2.

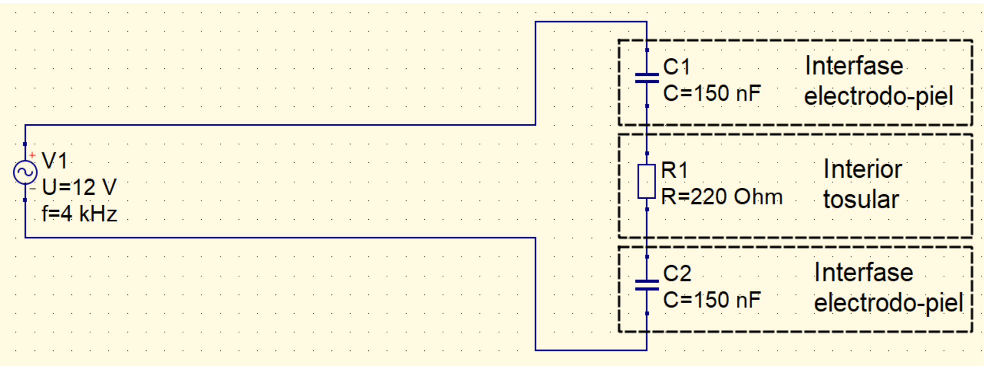


Figura 2: Scheme of tissue loading as a series CRC circuit.

In the face of the galvanic current, the three components will be R-R-R, because this current does not circulate through the capacitors, avoiding them, taking advantage of the resistive part of the skin and the tissue interior. However, in the case of pulsed and alternating single-phase, part of the energy circulates through the capacitors, and even in the alternating phase the capacitance greatly facilitates the passage.

The value of the components to form the artificial C-R-C charge in series was achieved experimentally by testing different components until a combination was found that was approximate to that achieved in a tissue measurement, according to what was shown on the oscilloscope screen. With two 150 nF (nanofarad) capacitors and a 220 Ω resistor connected in series as in Figure 2, it was possible to imitate the results of the body readings. This C-R-C circuit or charge in Figure 2 or Figure 3 is not suitable for low frequency and/or currents with polarity, since the tissues behave in one way at low frequency and another at medium.

In the first series of tests, three types of measurements were experimented:

- About pure ohmic resistance of ±500 Ω (in the RoMa practice box)
- On body tissues (with new adhesive electrodes) and
- On an artificial charge that will simulate tissue behavior as much as possible, such as that in Figure 3, interposing the practice box.

The RoMa box is necessary to capture the data that the oscilloscope will process and display. Figure 4. The unmodulated 4,000 Hz sine wave and the unmodulated rectangular wave will also be applied at 4,000 Hz and with the same amplitudes. In the practice box, the voltage wave and the intensity wave are captured with their corresponding oscilloscope probes (channel A for the voltage wave and channel B for the intensity wave).

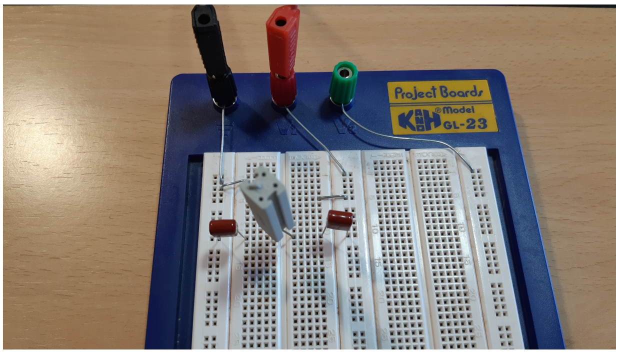


Figura 3: Assembly on test tablet with C-R-C components of 150 nF - 220 Ω - 150 nF.

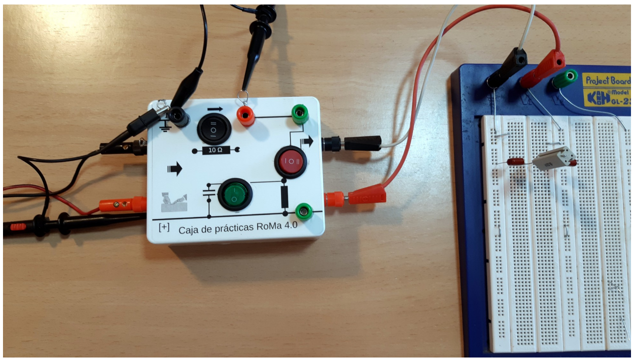


Figura 4: Set of the RoMa practice box with the strip for experimental setups.

Since the intensity wave is taken over a 10 Ω resistor, the value obtained will have to be divided by 10 for it to be real, a situation that is solved by setting the probe to ×10 (a maneuver that actually divides the value by 10 and solves the conversion). According to this, the volt figures of channel B are translated to mA directly.

The wave generator (Model FY6900) is adjusted to emit alternating sinusoidal waves with 12 V peak [Vp], which when converted to effective or RMS is about 8.5 V RMS (although it depends on the value of the charge). Application in VC or constant voltage mode. This will be the case in both sine and rectangular waves. This adjustment is made on the pure resistive charge of ±500 Ω

On the oscilloscope (PicoScope 2000 model and PicoScope 7 software) the voltage wave will be represented in channel A (blue), the intensity wave in channel B (pink) and the power wave (white and shaded Voltage by Intensity product). due to gaps and other circumstances). The oscilloscope also activates voltage, current, power factor, apparent power, real power and reactive power readings.

In the following oscilloscope figures it is important to locate the 0.0 horizontal line on the background bar and look at the vertical scales as well as their vertical range, in case you want to visually compare the waves.

Power Types

The applied energy is not measured in intensity [mA] or voltage [V], it is actually measured in power [W], which is the work generated in just 1 s and that comes from the product of V × I, but always in 1 s . However, there are several types of power, because one thing is the simple calculation of V × I, and another is applying conditions that influence and qualify the real power that is applied to the patient. Thus, depending on the behavior of the charge that receives the energy and its impedance, there are basically three types of power represented graphically in a right triangle similar to that in Figure 5:

- Apparent power (represented in the hypotenuse)
- Real power (represented on the adjacent leg)
- Reactive power (represented on the opposite leg)
- Power factor (depends on the angle Φ “phi”)

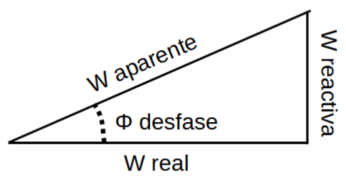


Figura 5: Right triangle of powers.

The apparent power is the product of V × I without further ado. The real power depends on the phase shift of the waves caused by the capacitive part of the charge and is the product of V × I × cos(Φ) or phi angle resulting from the phase shift between the voltage wave and the intensity wave. Reactive power is negative power or power that returns the charge to the power source; It is unused energy.

The power factor is a percentage or fraction of 1 that indicates the energy use that occurs in the circuit between the applied energy and the charge that receives it. The triangle in Figure 5 also indicates the behavior of the impedance presented by the charge (and allows it to be calculated).

Circuit with charge R

It begins with a classic measurement adapted to the theory Figure 6, coinciding with what is usually explained as a basic reference, applying alternating sinusoidal waves on a pure R charge and measuring in RMS or effective values, as shown in the image.

In this Figure 6, the voltage waveform measured by the oscilloscope is 10 V peak (6.99 V RMS). The intensity waveform on channel B indicates 14.59 mV (automatically translatable to 14.59 mA). The power wave [W] (above the 0.0 line) has twice the frequency of the original waves and is always positive because energy utilization approaches 100% (as indicated by the power factor at 0 .99 or 99%); utilization that is so high because the voltage and intensity waves circulate without phase shift, at the same time or practically superimposed. The working mode is VC or constant voltage.

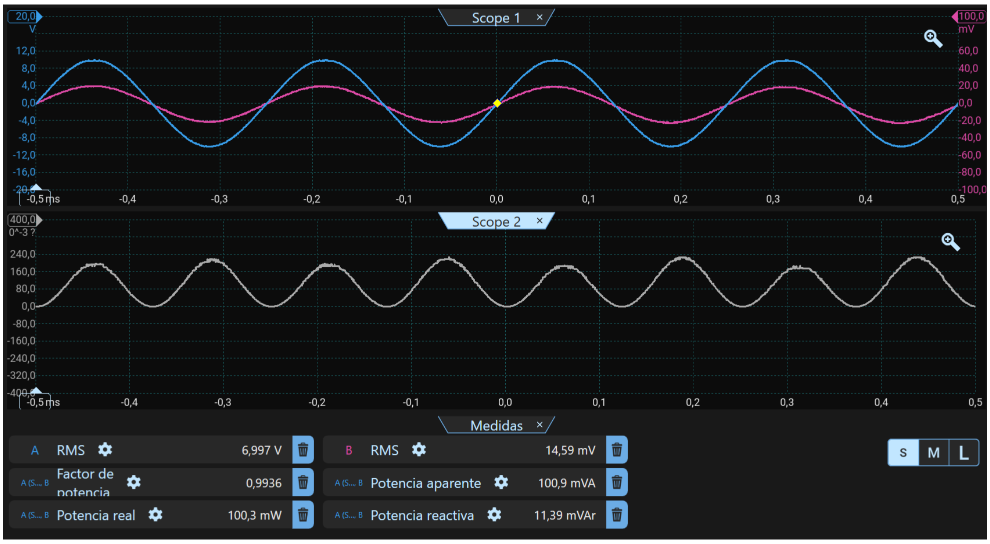


Figura 6: Voltage, intensity and power wave superimposed on pure resistance.

Regarding the power figures, the apparent and real power are very close, being respectively 100.9 and 100.3 mW RMS. The unusable power is on average 11.3 mVAr (which are not mW, as they are reactive millivolt-amperes).

It is essential to look at and memorize these figures to compare them with the following results in Figure 7, where the waves are now rectangular (with the same peak voltage as in the sinusoidal ones) but with totally different appearance results.

Analyzing Figure 7, since it is still applied to a pure resistive charge, the voltage wave is not deformed, neither is the intensity wave, and the power wave in theory should be a continuous line, but the practice of the circuit to be measured also alters somewhat. the theoretical result.

As for the figures, it stands out that now the RMS or effective value of the voltage is no longer 6.99 V RMS, it is now 10.51 V RMS. The intensity has risen from 14.59 in the sine wave to 21.90 mA in the quadrangular wave. The energy utilization factor remains above 99%. The apparent and real power are very close and well above those generated in the sine waves of 100.3 mW RMS versus 229.7 mW RMS (almost double). As for the phase difference between waves, it does not exist and as such is not represented.

The graph of results in Figure 8 shows that the energy use comparing the columns of [apparent W] and [real W] are very similar, since the reactive power is minimal. The power triangles indicate that the leg opposite the angle Φ is very short compared to the adjacent one (which represents the real power). This is an approximation to the ideal way to work and develop maximum energy efficiency between the stimulator and the charge. In theory, the ideal shape of the triangle is for the opposite leg to disappear, becoming a horizontal line characteristic of resistive charges and the total absence of capacitive or inductive charges.

The fact that the triangles still have a small opposite leg is due to the connections between pins and connectors, the internal interconnections of the box and those of the electronic test tablet.

Figura 7: Alternating quadrangular waves applied on pure resistance.

The power triangle of the quadrangular is much larger than that of the sinusoidal (as shown in the columns) indicating that the effectiveness of the rectangular shape is more than double that of the sinusoidal.

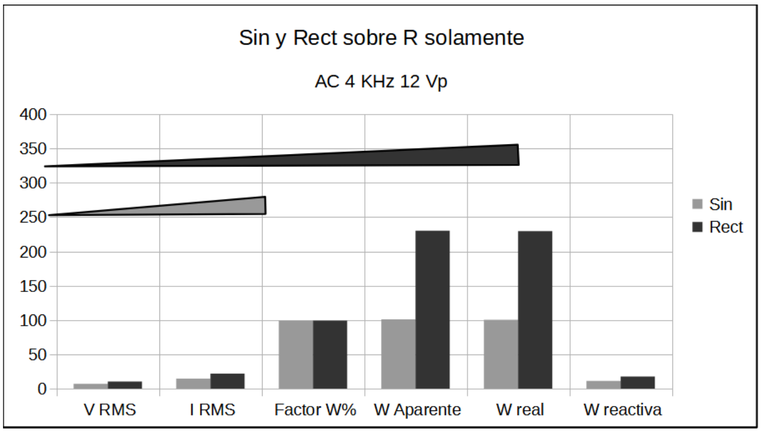


Figura 8: Evolution of the data applying 12 Vp of sinusoidal and rectangular alternating on pure ohmic resistance.

The most important provisional conclusion comparing sinusoidal and rectangular waves on pure resistive charge **is that with quadrangular waves, the energy contribution expressed in work in the unit of time, the quadrangular wave is more than twice as effective as the sinusoidal wave.**

Circuit where the charge is the body tissues

The next step is to measure tissue behavior, but with certain care: such as using new adhesive electrodes, placed contralaterally on the distal third of the thigh and avoiding the effect of tissue persistence when the current is applied, according to which, at the beginning of The measurement values are different from others taken after seconds or minutes of the measurement. Furthermore, the different measures will be spaced at least two or three minutes apart, in order to allow tissue bioelectrical re-adaptation. The settings on the generator are the same as those applied in the pure resistance measurement. The practice box is still used for data collection with the oscilloscope probes.

The result obtained with sine waves on living tissues is shown in Figure 9, where the voltage is 8.16 V RMS. The intensity of 16.84 mA RMS. The power factor is reduced to 56% due to the phase difference between the voltage wave and the intensity wave.

In the lower window, where the power wave is drawn, values above the 0.0 line can be used as real applied energy. Any value below the 0.0 line is energy that is not convertible into work to be done.

It is important to stop and compare Figure 6 with Figure 9 and pay attention to the upper window of the image, where the response on tissues draws a phase shift between the waves caused by the capacitive component presented by the body tissues.

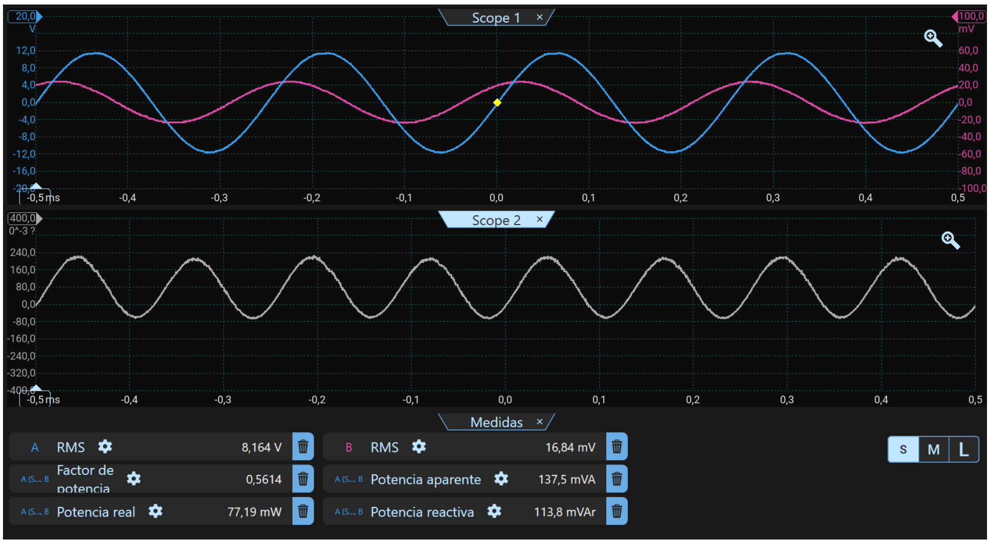


Figura 9: 4 KHz sinusoidal alternations on living tissues.

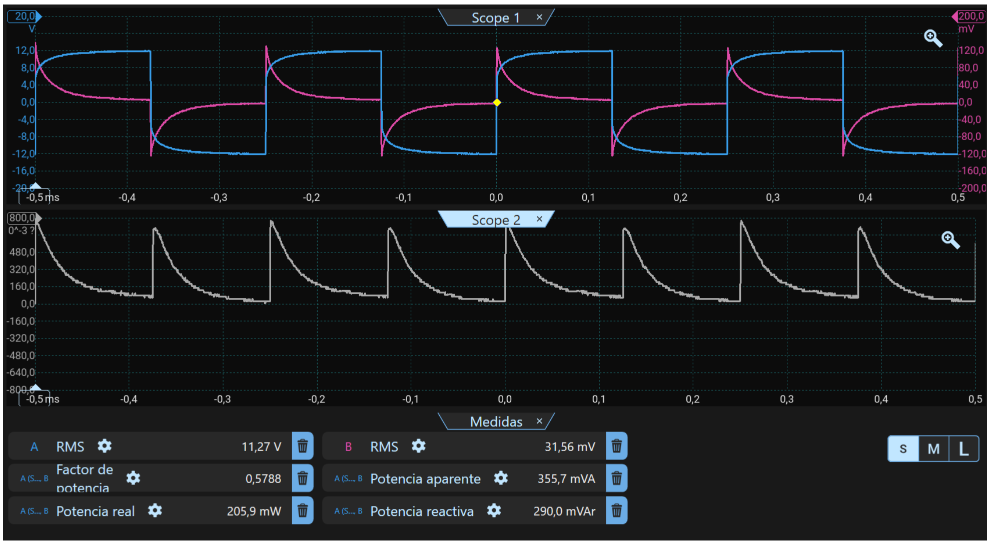


Figura 10: Alterna cuadrangular sobre tejidos corporales de 12 Vp y 4 KHz de frecuencia.

As for the real power applied, it is 77.19 mW RMS, far from the apparent one, with a value of 137.5 mVA (being figures higher than those obtained from the pure ohmic resistance of about 500 Ω); which means that the impedance is now less than that presented by the resistance. The reactive power is already considerable.

After two or three minutes of the sinusoidal measurement, the rectangular alternator is applied in the same place and the appearance of Figure 10 is obtained, where it is essential to study the shape of the voltage waves (which slightly lose their shape). Likewise, the intensity waves are drawn with important peaks coinciding with the changes in polarity (but no phase shift is drawn).

The power wave (in the lower window) traces important peaks coinciding with the polarity changes of both the voltage wave and the intensity wave. It is essential to understand tissue bioelectric behavior to record these power peaks in memory, because depending on the composition of the charge, these power waves can be different visually.

The data capture in Figure 10 shows values such as that the voltage is 11.27 V RMS (very close to the value of 12 Vp). Intensity of 31.56 mA RMS. The power factor is 57% of usable energy. The actual power applied is 205.9 mW RMS. The apparent power is excessively high, reaching 355.7 mVA, but all of them are not usable. The reactive power is also very high.

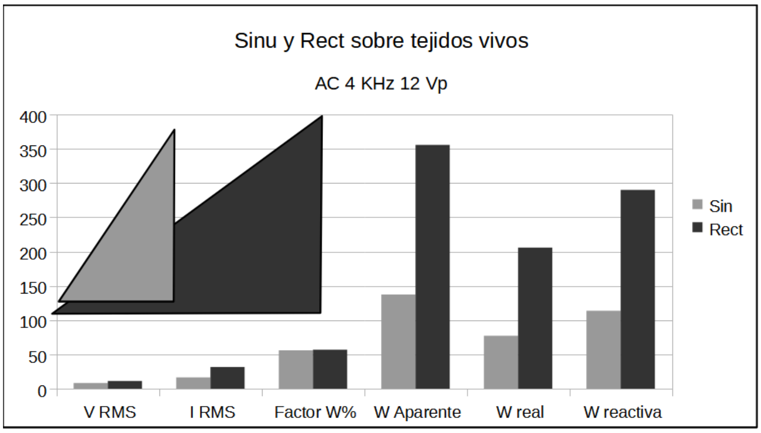


Figura 11: Evolution of the data applying 12 Vp of sinusoidal and rectangular alternating on living tissues.

The analysis of Figure 11 once again highlights that the results in rectangular waves are superior to sine waves although the real power does not exceed that achieved on pure ohmic resistance. Remember that the base of these drawn triangles represents the real power applied.

The power triangles superimposed on the graph trace hypotenuses with a great inclination (exactly 55.8º for the sinusoidal and 36.3º for the rectangular) which indicates the great influence of the capacitive component on the charge (more in the sinusoidal than in the quadrangular).). The real power used is more than double in the rectangular one than in the sinusoidal one. The rectangular one is closer to resistive behavior than the sinusoidal one, which is closer to capacitive (inclination less than 45º and inclination greater than 45º respectively).

The patient's sensory and motor perception is much more intense with the quadrangular than with the sinusoidal. The positive power peaks in Figure 10 in each polarity change (double frequency than the carrier) compared to the waves of smooth change in power in Figure 9, are responsible for the best depolarization of the nervous membrane, both sensory and motorboat.

Circuit with C-R-C charge in series

With the aim of searching and understanding tissue behavior in the face of sinusoidal and quadrangular alternations, different experiments were carried out by forming an artificial charge using capacitors and resistors (not coils) in parallel, in series, combined, etc.; until an image very similar to the tissue response appeared on the screen (at least similar to that of the explored model). See Figure 3.

The solution was found in the combination that can be read in Figure 2, indicating that the skin-electrode interface (adhesive gel electrodes) behave as capacitors and the tissue interior as a resistance of about 220 Ω. In the tests, with 180 Ω it was possible to match the tissue results, but the adjustable potentiometer that achieved this was replaced by a fixed resistance of 220 Ω (as the closest value available).

The application of 4 KHz sinusoidal alternating current on the artificial C-R-C circuit (represented in Figure 2) generated in the oscilloscope the data contained in Figure 12, which shows the phase difference between the voltage wave and the intensity wave, and also how As expected, the lower apparent power wave, part of its trajectory is below the 0.0 horizontal line.

The voltage read in Figure 12 is 8.21 V RMS. The intensity indicates 17 mA RMS. The power factor is reduced to 43.6%. The apparent power is 140 mVA. The actual power indicates 61 mW RMS. The reactive power is 126 mVAr.

These results are not too far from those obtained from measurements on living tissues, among other reasons because it is about approaching them with elements that form an artificial charge.

Figure 13 shows the result on the same artificial C-R-C charge of [150 nF – 220 Ω – 150 nF], using the rectangular shape, with the following results: Voltage 11.28 V RMS. Intensity 28.83 mA RMS. Power factor 52.8%. Apparent power 325.1 VA. Real power 171.9 mW RMS. Reactive power 275.9 mVAr.

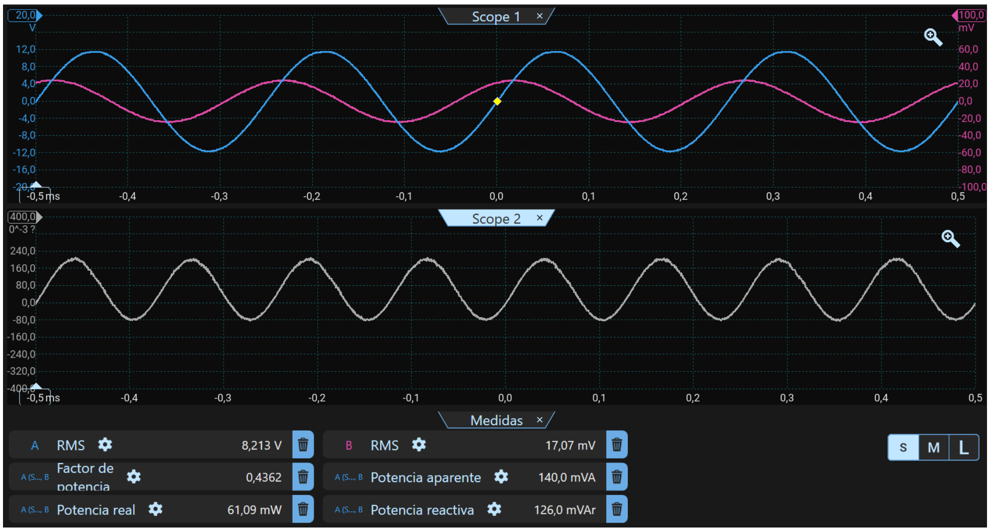


Figura 12: Sinusoidal alternation of 4 KHz and 12 Vp applied on a C-R-C circuit in series.

It is important to stop and compare Figure 13 with Figure 10 and dedicate time to the comparative observation of the shapes, and it is also advisable to stop and read the values in the measurements.

Figura 13: Quadrangular alternator of 4 KHz and 12 Vp applied on a C-R-C circuit in series.

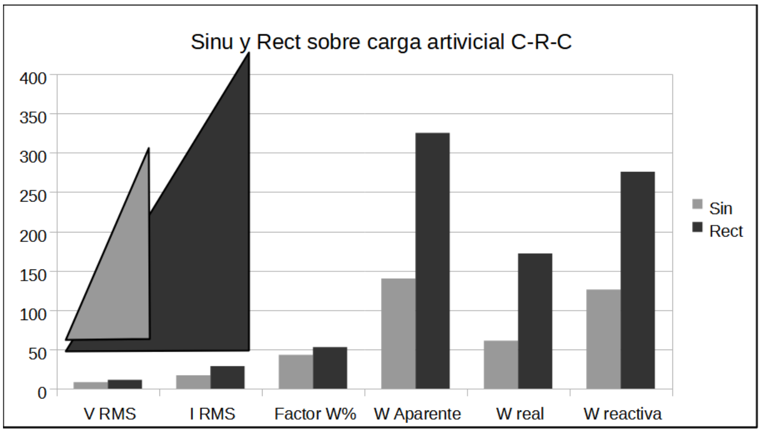


Figura 14: Evolution of the data applying 12 Vp of sinusoidal and rectangular alternating on C-R-C artificial charge.

It once again becomes clear that the real power used is greater with rectangular waves. The power triangles also draw the angular path of the hypotenuse clearly exceeding 45º and approaching 90º, pointing out the strong capacitive component of the charge (greater in sinusoidal than in quadrangular as occurred in the application on tissues).

As is being demonstrated, one approach is theory and another is the reality of body tissues, which do not behave as a pure resistive charge (except when faced with galvanic current), since when faced with alternating currents they act as a partly resistive charge. and partly capacitive, that is, an RC charge, specifically C-R-C (C for one electrode plus the skin, R for the tissue interior and C for the other electrode and the skin).

On artificial RC charge in series and parallel

By carrying out repeated tests in order to find the electronic components that would form an artificial charge, and how to connect them to simulate the tissue response, a multitude of different shapes have appeared on the screen in the quadrangular ones, since in the sinusoidal ones they are always the same except that the values be modified or outdated to a greater or lesser extent. As for the quadrangulars, important changes are shown, fundamentally in the pattern that forms the power wave, as in Figure 15 or Figure 16, in which negative power peaks appear with a large amount of reactive power and low real or effective power.

Figura 15: Application of rectangular alternators on artificial RC charge in parallel.

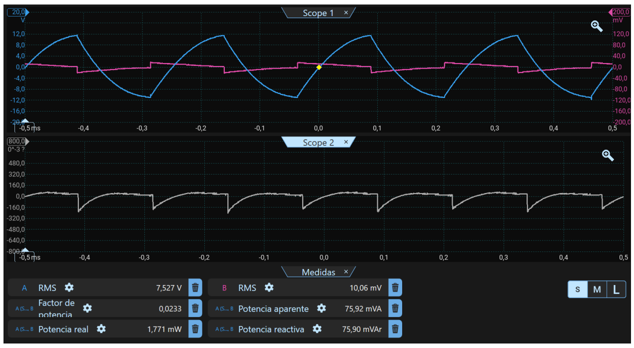


Figura 16: Application of rectangular alternators on artificial harge C or a capacitor only.

These power waves (with the negative peak) have nothing to do with the positive peak of the previous figures, including those of tissue response, where the RC circuit is in series. Now the circuit is in parallel and the response is similar to what is seen in Figure 15. This typical pattern of the RC charge in parallel is perfectly distinguished from the RC pattern in series. Compare Figure 15 with Figure 13.

In Figure 16, the energy is applied directly to a capacitor (without resistance) in which very weak negative peaks continue to appear in the power wave, the very weak intensity wave and the exaggeratedly deformed voltage wave. This causes the energy actually applied to be minimal. The Deep Osillation ® technique is based on this phenomenon.

Figure 17 graphs the values read in Figure 15 and Figure 16, observing that the apparent and reactive power over RC in parallel are exaggerated, but the real W applied falls apart (purple column). Above C the readings are very low, and the real power does not reach 2 mW RMS. It is striking that the apparent and reactive power are practically the same, which generates the very tall but very narrow triangles (which maintain the measured proportions) in Figure 18, where the small, barely visible triangle is a vertical line with the hypotenuse practically at 90º, as corresponds to capacitors.

All these variations will depend on the values of the resistance in Ω and the capacitance in nF, in addition to their connection. Living tissues are actually a network of resistors and capacitors in series and parallel that add up to a global value with a predominance of one type in some tissues, while others offer another tendency.

It seems like it would be good to start including the power waveform in oscilloscope displays, in addition to the voltage and intensity waves. Knowing the behavior and pattern that shapes the power wave provides very relevant information that has not been contemplated until now in the field of physiotherapy.

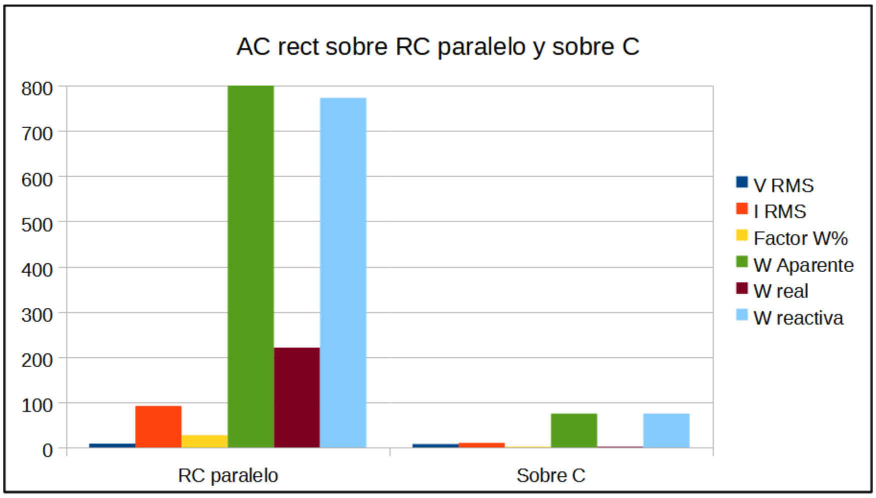


Figura 17: Parameter graphs on parallel RC and on capacitor only. The actual power applied to the capacitor is minimal.

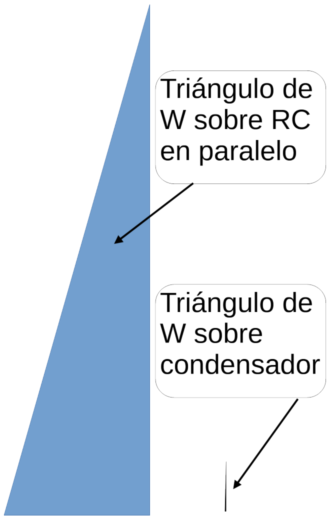


Figura 18: Triangles of W on RC in parallel and on C.

When abundant treatments with medium-frequency currents such as interferential currents and their variants have been applied, it can be empirically observed that they generate a slight increase in temperature in the treatment field; And the question arises: Will this heat generated be due to reactive power?

Influence of different types of electrodes

The medium frequency is applied to body tissues:

- using adhesive gel electrodes,
- with conductive rubber electrodes wrapped in soaked chamois,
- using metal plates separated from the skin by moistened sponges (such as suction cups),
- by means of metallic point electrodes covered by moistened chamois and
- other occurrences.

This raises the following question: Do all electrode variants produce the same tissue behavior?

The application with adhesive gel electrodes has already been shown in Figure 9 and Figure 10, therefore, in the same area and person, two other tests are repeated with sine and quadrangular waves using: first two metal electrodes covered by chamois moistened with tap water and then two silicone electrodes covered by moistened chamois (these with very little use to guarantee good conductivity). The size of the electrodes in these two tests are very similar to the surface of the adhesive electrodes that were used in the previous measurement. Suction cups are not used to avoid the tissue suction effect. The current parameters are the same as in the previous tests.

The response of the metal electrodes with chamois can be seen in Figure 19 and Figure 20 using sinusoidal and quadrangular alternating respectively.

The sine waves do not suffer important alterations, except the values and the phase shift; but the quadrangular ones (focusing attention on the power waves) maintain the positive peaks very similar to those obtained with adhesive electrodes on living tissues.

If Figure 20 is compared with Figure 22, the peaks of the power wave maintain the same appearance in terms of shape, the response in terms of figures is different.

Graphing the figures of the three modalities with which it was applied to living tissues, in Figure 23 the real power did not exceed 100 mW RMS, and much less with the variant of metal electrodes. Comparing this last image with Figure 24, it continues to stand out that the powers applied with quadrangular ones are much higher than the sinusoidal ones. The metallic option is again below.

Figura 19: Application on body tissues with alternating sinusoidal 4 KHz 12 Vp. Metal electrodes covered with moistened suede.

Figura 20: Application on body tissues with rectangular alternating 4 KHz 12 Vp. Metal electrodes covered with moistened suede.

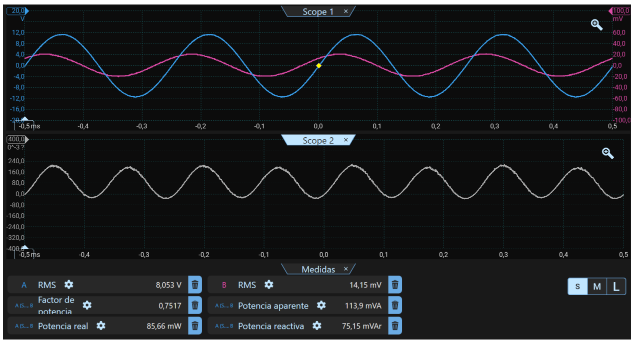


Figura 21: Application on body tissues with alternating sinusoidal 4 KHz 12 Vp. Rubber electrodes with damp cloth.

Figura 22: Application on body tissues with alternating quadrangular 4 KHz 12 Vp. Rubber electrodes with damp cloth.

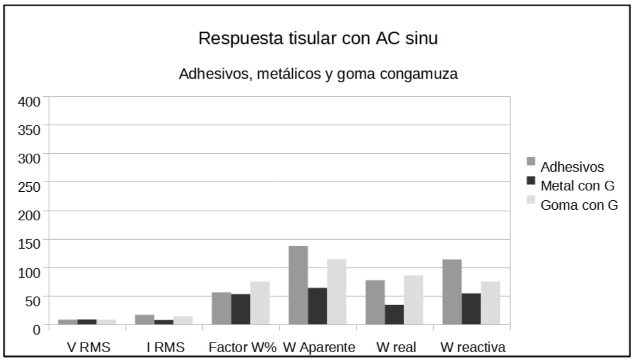


Figura 23: Tissue response with sinusoidal AC applied with adhesive electrodes, with metal electrodes wrapped in moistened chamois and with conductive rubber wrapped in moistened chamois.

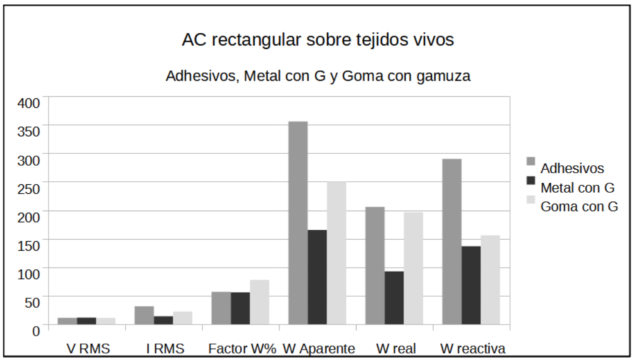


Figura 24: Tissue response with quadrangular AC applied with adhesive electrodes, with metal electrodes wrapped in moistened chamois and with conductive rubber wrapped in moistened chamois.

The most efficient method turned out to be the application with adhesive electrodes, followed by conductive silicone electrodes wrapped in moistened chamois, and the least effective was the application of metal electrodes covered by moistened chamois. It is true that it also depends on the state of the adhesives and the humidity of the chamois; but it was an attempt to make applications with the usual methodology.

Do all body tissues exhibit the same behavior?

Not all tissues have the same bioelectric behavior, but on this occasion a young 13-year-old model is chosen to apply to the distal third of the thigh (contralateral between the external and internal faces) and a 73-year-old model to compare the same. area under the same conditions.

Figura 25: Response in a 13-year-old model to 12 Vp rectangular alternators.

Figura 26: Response in a 73-year-old model to 12 Vp rectangular alternators.

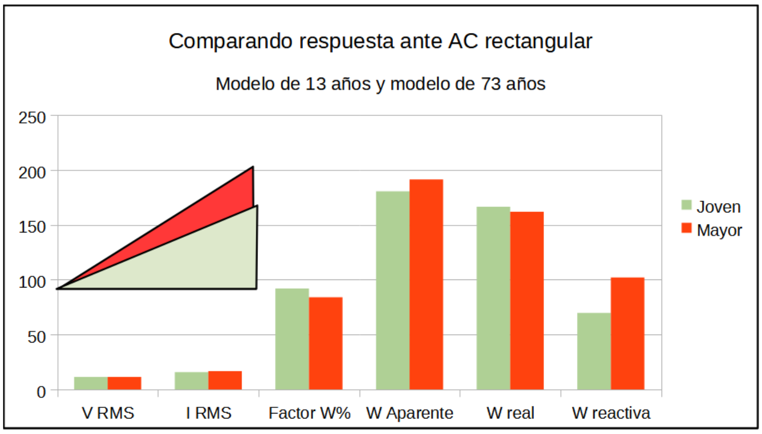


Figura 27: Results graphed between a young model of 13 years old and an older model of 73 years old.

With carbon-doped rubber electrodes covered by moistened chamois, a rectangular alternating pattern is applied with the same parameters that have been used in all measurements.

In both Figure 25 and Figure 26 the power waves are very similar in shape and pattern, which implies that the charge in both cases is of the C-R-C type, as in the previous measurements. The inclination of the hypotenuse in the power triangle seems important in both cases, although it does not reach 45º (specifically 32º in the largest of the triangles).

As can be analyzed in Figure 27, the triangle of the young model has less capacitive component than the older model, this being the characteristic that most differentiates the behavior, because the real power is very similar. Reactive power is the most unequal data.

Tissue behavior in CC and VC

At medium frequency, the stimulator can be adjusted either in constant current [CC] mode or in constant voltage [VC] mode. In the beginning of interference it was common to work with the VC mode, but currently both can be used, or perhaps by default, for safety and out of habit transferred from low frequency use, recently the CC mode is used more.

It is important to check if the waves are altered or undergo changes, fundamentally the power wave, since this is the one that will generate greater or lesser tissue response. In practice, from the sensory or motor point of view, in the CC mode the perception was more intense, although the intensity was the same.

To observe the results, alternating quadrangular waves are applied to body tissues using conductive rubber electrodes covered by moistened chamois. The stimulator is first adjusted to work in VC mode as in Figure 28, and subsequently it is applied in CC mode as in Figure 29, so that in both cases the intensity knob is turned until the OSCILLOSCOPE reads ± 10mA.

In the VC (constant voltage) mode, the electronic system of the device tries to keep the voltage stabilized and unalterable and adapted to what is regulated with the potentiometer, therefore, in Figure 28 it can be seen that the voltage wave (blue) is to remain as rectangular as possible, while the intensity (pink) has to adapt to the behavior of the circuit and its charge according to Ohm's law. It is very important to pay attention to the power wave (white) on the lower screen to compare it with the other modality.

In CC mode (Constant Current or Intensity) the stimulator fights to maintain the wave and the intensity parameter as a stabilized element depending on the intensity control, so it will be the voltage wave that will adapt to the conditions of the circuit and of the charge. This is why in Figure 29, the intensity wave (pink) remains quadrangular and the voltage wave is deformed by the capacitive component of the charge. All of this causes the power wave to be different in terms of shape, in terms of the real power applied and in terms of perception on the patient (always applying 10 mA RMS read by the oscilloscope).

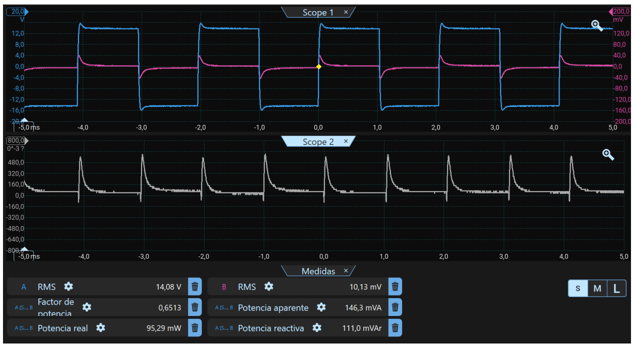


Figura 28: Stimulator working in VC mode on body tissues.

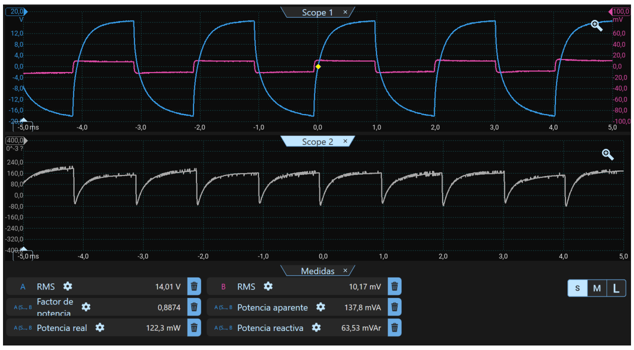


Figura 29: Stimulator working in CC mode on living tissues.

On the other hand, another fundamental difference appears that was already seen in the section referring to the response on artificial charges RC in parallel and C, since the pattern that generates the power wave is different in Figure 28 than that of Figure 29, with positive or negative peaks in polarity changes. When the voltage wave undergoes changes from the first moments of the rise or fall, that is when the negative peak appears. However, if the voltage wave rises or falls straight in the first moments, the peak in the power wave will logically be positive.

Paying attention to the figures of the real power used, in VC mode 95.29 mW RMS is applied, while in CC mode it is 123.3 mW RMS; which makes sense that the model showed greater sensory stimulation with the CC mode. (purple columns in Figure 30).

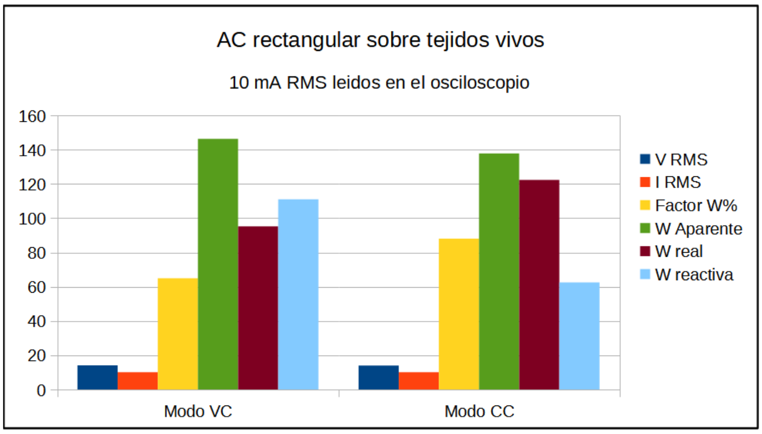


Figura 30: Response graph on electrical parameters in VC and CC mode.

The graphing of parameters in Figure 30 allows us to focus attention on the last three columns of each group, in which it can be perfectly understood that the behavior of the power is not the same in VC as in CC. The reactive W is strikingly lower in CC than in VC, which will generate a power triangle with the opposite leg short and the hypotenuse at an angle below 45º (predominantly resistive behavior) as can be seen in the second triangle in Figure 31. .

In the same Figure 31, comparing the two triangles, the inclination of the hypotenuse in the first is (±45º) indicating that in the VC mode the capacitive component has more prominence than in CC mode; Furthermore, the actual applied power is lower in the VC mode triangle.

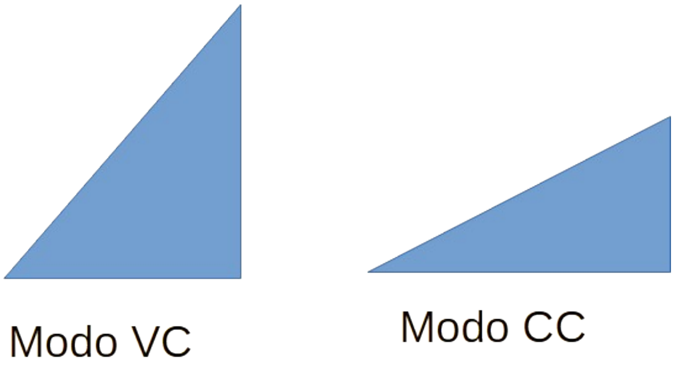


Figura 31: Triángulos de potencia de los modos VC y CC respectivamente.

Conclusions

From this series of observations some conclusions can be drawn, including the review of widely held concepts (including those of this author) on the quality of sinusoidal ones and considering rectangular ones as substitutes for the former. Apart from this comment, notes can be summarized such as:

- Living tissues are actually a network of resistors and capacitors in series and parallel that add up to a global value as RC charge.
- The correct parameter to assess the applied energy is the power, specifically the real power or mW RMS.
- Sine waves are not deformed, they only shift out of phase between the voltage wave and the intensity wave. The power wave they generate is also sinusoidal with more or less efficiency.
- Quadrangular waves suffer deformations due to the capacitive component of the charge.
- The deformations of quadrangular waves are different when CC mode or VC mode is set.
- The sinusoidal shape, given the same charge, generates a greater capacitive component than the quadrangular one.
- The quadrangular shape provides much more energy than the sinusoidal one.
- Sensory and motor perception is greater in the quadrangular than in the sinusoidal.
- Power triangles tend to be more resistive when the current is rectangular, and more capacitive in sinusoidal alternating current.
- The pattern that shapes the power wave (with rectangular alternating) allows us to understand the RC configuration of the charge that receives the applied current.
- The electrodes with the best results are the adhesive gel ones and the conductive rubber ones wrapped in moistened chamois.
- In DC mode with rectangular alternators, sensory and motor perception is greater than with sinusoidal alternating.
- The positive onset peak power pattern predominantly reflects a series RC charge. The power wave pattern with negative starting peak marks a parallel RC charge.
- Stimulators with the carrier based on the rectangular alternating current require less energy to achieve the same tissue effect.

In the summary of this work, three questions were raised, which we will try to answer according to what has been observed so far.

Which way is the most correct?

Well, it depends on the therapist's objective, since the least affected by differences in load is the sine wave, but the most effective is the rectangular wave.

Is the same energy applied with both?

Well, it has been seen that it is not, since the quadrangular wave provides more energy as was easy to intuit, due to its greater energy area demonstrated by successive measurements.

How does reactive power influence the body?

Reactive power is that which goes and returns through the circuit without generating work and a large part of it is used to charge and discharge tissue "capacitors" repeatedly, without knowing what biological effects are usable in that sense, since the biological consequences They have always been based on the resistive tissue part. Question pending investigation.

Since the Deep Oscillation ® technique is based on applying electrical charges in two electric fields separated by a non-conductive membrane (patient field versus head field); Although there is no energy flow, the electrical masses accumulated alternately between the two electric fields cause mechanical attractions and repulsions coinciding with the changes in polarity in the waves, evident if the head moves through the treatment area. In this circumstance there is no real power applied, but there is apparent and reactive power.

This technique is low frequency and may not be transferable from the point of view of its mechanical effects at medium frequency, but the electrical influence on changes in tissue capacitance remains to be determined, although it is all a matter of measuring the values before and after apply the technique to clear up doubts.