The Determination of the Most Effective Current Type for Electrical Damage of Plants

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Abstract

Objectives: The electric treatment of plants is used to stimulate their growth, development and productivity increase to achieve a lethal damage - to accelerate ripening, eliminate weeds, the weeding of crops between rows. Methods: The plant material is treated to expedite its drying, increase juice production, etc. The impact could be performed using the electric and magnetic fields, various types and stages of electrical discharges, different electrical currents: DC, pulsed, alternating sinusoidal and non-sinusoidal one, etc. The greatest interest from the energy and technological points of view is presented by the need for the most effective current determination influencing on these plants. Finding: After the study on the electronic processing of sunflower, tobacco, and various weed species occurring and after the study of the processes carried out at that the effectiveness of different types of currents used during processing compared. The theoretical comparison of energy equal alternating currents at the frequency of 50 and 400 Hz and the pulse current at its exposure on the plant tissues of tobacco and sunflower to achieve lethal (irreversible) damage allowed to state that the electrical processing of plant species with discharge voltage pulses is more effective than the impact by energy equal sinusoidal voltage. It estimated quantitatively that the released energy in the plant tissue at its processing by energetically equal pulsed current and the current with the frequency of 50 Hz is accompanied by the release of energy in the tissues 5.6 times higher in the case of pulse exposure and 5.7 times higher at the pulse current and 400 Hz current comparison. Conclusion: This type of plant tissue processing is not only technologically efficient due to a severe, profound damage to an intracellular structure, but will be accompanied by lower energy costs.

Keywords: Degree of Damage, Electric Current Type, Equivalent, Half of the Period, Lethal Damage, Power, Pulse, Sinusoidal

1. Introduction

The electrical effects on plants may be carried out to stimulate their growth, development, productivity increase and to achieve lethal damage for ripening, drying, juice production increase, elimination of weeds, etc. 1-7. At that this action may be carried out by various kinds of electric and magnetic fields, various types and stages of electrical discharges, and different electric currents: DC pulsed, alternating sinusoidal, non-sinusoidal AC using an electric spark discharge and without it, etc. From the energy and technological points of view, it is critical to identify the most useful of these currents, and this is the aim of the article study. Let's consider the solution to this problem using the example of an electrical treatment to obtain a lethal tissue damage of sunflower and tobacco plants.
to increase ripening and drying of achiness, leaves and weeds to destroy them.

2. Methodology and Results

Since the interaction of any damaging factor with a vegetable object, is energetic one, the amount of energy produced in a plant tissue is accepted as the criterion for the assessment of current type effectiveness. All variants of the impact of different types of current must be equal to energy. This means that the same patterns of plant stems should be fed with the same amount of energy by various sorts of currents and at that, the energies released in tissues shall be compared; the efficiency of current type depends on the amount of energy. To perform a comparison let’s use a known equivalent electrical circuit of substitution and the conductive properties and parameters of a plant tissue. Due to the presence of plant tissue change of an electrical capacity and because of the possible polarization of the working electrodes constant current will be less efficient than the AC and pulse currents, particularly at the beginning of processing, when the capacitive properties of the cell membranes are not broken yet. Therefore we compare further only two kinds of currents: pulse and alternating one. Alternating non-sinusoidal current because of the similarity with the sinusoidal one, the variety of possible options and the relative complexity of their production is not considered. The voltage pulse was taken as a calculated one, which may be obtained from a pilot device, and which may be used then for the experimental verification of theoretical conclusions. The comparison is conducted according to two basic options. 1) voltage pulse and a sinusoidal voltage equivalent to it during a half of a period equal to the pulse duration Figure 1 sinusoidal voltage during half a period with the frequencies of 50 and 400 Hz, and its equivalents of several voltages pulse Figure 2. The equality of actual voltage values of these current types is taken for the criterion of energy equal voltage impulse, and sinusoidal voltage is made for half a period. Thus, for the comparison of the first option Figure 1 the operating values at the same duration of 4,5×10⁻⁶s will be the following ones

\[ U_u = \sqrt{\frac{\sum u_i^2 \cdot \Delta t_i}{t_u}}; \quad U_c = \frac{U_m}{\sqrt{2}}. \]

Based on their equality, the peak value of sinusoidal voltage may be calculated according to the following formula

\[ U_{mc} = \frac{1}{2} \sqrt{\frac{\sum u_i^2 \cdot \Delta t_i}{t_u}} = 2 \sqrt{\frac{1}{2} \frac{\sum u_i^2 \cdot \Delta t_i}{T}}. \] (1)

The energies absorbed by plant tissue will be determined by the expressions for the impulse excitation

\[ W_u = \frac{\sum u_i^2 \cdot \Delta t}{R_u}. \] (2)

And for the impact by sinusoidal voltage during half a period
\[ W_C = \frac{1}{R_C} \int_{0}^{T/2} U^2_{m_c} \cdot \sin^2 \omega t \, dt = \frac{U^2_{m_c}}{4R_C} \cdot T. \]  

(3)

Here the resistances \( R_i \) and \( R_c \) are the equivalent resistances of the fabric during the operation time, respectively, the voltage pulse and sinusoidal voltage. The value \( R_i \) is calculated according to the experimental oscillograms of current and voltage on the fabrics and is equal to 190 ohms. From the oscillograms (1) we find that \( U_{mc}=7.81 \) kW. According to the experimental current-voltage characteristic of sunflower plant tissue, for the average diameter of a sunflower stem in the 15 mm place of processing, we find the equivalent resistance of the stem \( R_c=280 \) Ohms. The calculations according to (2) and (3) provide the values of \( W_i=0.8 \) J and \( W_c=0.47 \) J. These values indicate that the impulse effect on the plant tissue is 1.7 times more useful than the impact by a sinusoidal voltage. The practical interest is presented by the comparison of these currents initial impact on living plant tissue the capacitive properties of its cell membranes are not violated. In this case, the tissue resistance may be determined by the input impedance of its equivalent substitution circuit. And using the same expressions (2) and (3) we obtain \( W_i=0.02 \) J and \( W_c=0.0177 \) J, i.e. and at the beginning of processing the pulse impact is more efficient than sinusoidal one by 13%. For the second variant of comparison Figure 2, let’s take the duration of exposure to the tissue equal to the half period of the sinusoidal voltage at some low standard frequency \( f \), such as 50 Hz or 400 Hz. Such rates should be considered because of the relative ease of the method practical implementation using standard power equipment as small power generators and transformers with such frequencies frequency are produced by industry. During the half of the received frequency period, the impact \( m \) will be provided for the tissue as in the first variant of pulses.

\[ m = \frac{T}{2} \cdot \frac{t_{ciab}}{t_{diab} + t_{diab}}. \]  

(4)

For these pulses the actual voltage will be the following one

\[ U_u = \sqrt{\frac{2 \sum_{i=1}^{k} u_i^2 \cdot \Delta t_i}{t_{ciab} + t_{diab}}}. \]  

(5)

For the equivalent sinusoid Figure 2 the current value should be the same, and its amplitude will be the following one,

\[ U_{m_c} = \sqrt{\sum_{i=1}^{k} u_i^2 \cdot \Delta t_i}. \]  

(6)

Based on the capacity of the discharge circuit experimental values and the energy of a single pulse, the duration of the discharge, the spark channel deionization rate, the duration of the charge capacitors the highest frequency of discharges in the circuit will be the following one, 5.6x10^4 Hz and \( T_c = t_{ciab} + t_{diab} = 180 \times 10^{-6} \) s. At the standard frequency of compared sinusoid \( f = 50 \) Hz during the half the number of chargers will make \( m = 55 \ldots 56 \) according to (4). The amplitude of the sinusoidal voltage will be 1310 W according to (5) and (6). The average tension on a plant stem will be the following one:

\[ E = \frac{U_{m_c}}{d_{cm}} = \frac{1310}{15} \approx 87 \text{ W/mm}. \]

By the extrapolation of plant tissue v.a.h. according to obtained tension, we will obtain the current \( I \) 810 -3 A. And then we get the resistance \( R_c = 1074 \) ohms equivalent to discharge. The energy released in tissues from the sinusoidal voltage during 0.01 s will be 7.87 J according to (3). The total energy of 55 pulses for the same period will make 44.4 J, i.e., 5.6 times more. If we compare the effects by a pulsed voltage and a sinusoidal voltage with the frequency of 400 Hz, we get the following values: \( U_{m_c} = 0.00125 \) s. \( m = 7 \) discharges; \( 7W_u = 5.6 \) J; \( W_c = 0.98 \) J. I.e. during the impact by the sinusoidal voltage of 400 Hz 5.7 times less energy is released in the plant tissue is released than at the plant tissue processing by pulse voltage. It should be noted that in fact, the greatest value of released energy \( W_i \) and \( W_c \) ratio will be less than the calculated one as the average resistances are accepted as equivalent resistances of an object to simplify the calculations. In fact, the resistance is the function of the energy released in the tissues. Furthermore, the change in the amplitude of the sinusoidal voltage will likely lead to the changes in the intensity of damaging plant tissue factor that is not taken into account in the above-mentioned considerations. Thus, the abovementioned theoretical analysis shows that the electrical processing of plant objects by discharge voltage pulses is more effective than the impact.
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by the sinusoidal voltage of equal energy. Experimental verification of this conclusion was carried out by comparing the degrees of same sunflower stem damage from the effects of sinusoidal voltage with the amplitude of 1310 V during half of the period at the frequency of 50 Hz and 55 voltage pulses at the magnitude of 9.16 kV and the duration of 4.5x10^-6 s. This technique is based on experimentally tested assumption that the extent of the plant tissue damage is proportional to the amount of absorbed energy. The degree of plant tissue damage \( S_{пк} \) refers to the quantity the numerical value of which is equal to the ratio of tissue impedance active component after the treatment resistance at a fixed frequency of the measuring current, in this case at the frequency of \( f = 10 \) kHz. The plant stem was fixed between the electrodes at the direct contact with them. Half of the sinusoidal voltage period is applied to the stem using a specially designed circuit in which the role of the core, closing the circuit with a plasma object was performed by a controlled ball spark gap. The duration of the discharge in this interval was 0.01 s. The treatments of stems with discharge pulses of voltage delivered from a high voltage pulse generator (VPG) with adjustable amplitude and pulse energy. The technique was described in, where the method of plant tissue damage degree measuring is described. The results are shown in Table 1 (as an example) and on Figure 3. Table 1 demonstrates the main parameters of single energy equal effects on tobacco stalks in the transverse direction and at sinusoidal and pulses voltages. Figure 3 shows the dependences of pulsed and sinusoidal elements at the current frequency of 50 Hz from the number \( m_{ск} \) of individual energy equal effects on the same plants. Since the processing energies of plants are proportional to the number of effects, the both dependencies on the extent of tissue damage \( S_{пк} \) of plant objects, have S-shaped form. However, for a sinusoidal form of the active voltage, the affecting degree of damage \( S_{пк} \) is significantly shifted to a larger number area (about two times) of single exposures. Approximately the same number of influences after \( S_{пк} \) will reach its maximum value in comparison with \( S_{пк} \) (outside the right part of the figure). Therefore, it is evident that the ratio of the damage degree \( S_{пк} \) to \( S_{пк} \) at the beginning and the end of processing is numerically equal to one, and in the middle part of dependence on \( m_{ск} \) it has a pronounced maximum: when damage is not present, then \( S_{пк} = S_{пк} = 1 \) and at the end of limit processing for both types of current the damages have the same maximum degree, and their ratio is equal to one. The biggest difference between the degrees of damage \( S_{пк} \) and \( S_{пк} \) and the greatest value of their relationship depend on the physiological development and the state of plant stems, on their geometric dimensions, etc. That is, all numerical values in all three dependencies will vary from plant to plant, but their characters will be the same with Figure 3. The presented material shows that the electrical processing of sunflower and tobacco plants, to achieve their lethal damage by discharge voltage pulses is more efficient than the processing by varying sinusoidal current, it enables to use the potential of power supply better. Similar studies were carried out for weeds. Separate fragments of city Mari weeds and thrown back amaranth were taken as the objects of processing. At the determination of damage degree numerical values of cultivated weed tissues, the stipulation was also set that the amount of energy delivered to the tissue in comparable cases should be the same, or very close by value. To conduct the experiments, the scheme was developed that allows to cut one, two and four periods of the current sinusoidal voltage of industrial frequency and supply it to the input of a step-up transformer, providing the impact on the studied plant tissue. VPG was used with the regulated parameters of a discharge contour to perform the pulse processing of plants. The amount of absorbed energy by the tissue under study was evaluated by the following expressions:

- for sinusoidal impact:

\[
W_{МС} = \int_0^t u(t) \cdot i(t) dt = \int_0^t U_{MC} \cdot I_{MC} \cdot \sin^2 \omega t \cdot dt , \tag{7}
\]

Where \( U_{MC} \cdot I_{MC} \) is the peak value of sinusoidal form voltage and current, kV and A; \( t \) - time during which the absorption of energy is considered, c; \( \omega \) - current angular frequency, rad/s.

- for high voltage pulse impact:

\[
W_{\phi} = 0,5 \cdot k_p \cdot m \cdot C_k \cdot U_0^2 , \tag{8}
\]

Where \( k_p \) is the degree of discharge capacity (by voltage), taken at 0.9 ... 0.95; \( U_0 \) - initial voltage of discharge circuit applied to the area of plant tissue with the length \( l_{pm} \) and the diameter \( d_{pm} \), kV; \( C_k \) - discharge contour capacity, F.

He experimental studies performed in vitro with the fragments of weed stems allowed to obtain the following results Table 2. The Table shows that an electric pulse treatment of plants is more effective technologically than the treatment with high-sinusoidal voltage. Therefore, it
is necessary to develop appropriate pulse schematic solutions for the technical implementation of electric weeding.

Table 1. Experimental effectiveness of current types

| Current type       | Impact period                      | Voltage amplitude, kW | Active voltage, kW | Repeatability | Damage degree, g.u. | Damage degree relation |
|--------------------|------------------------------------|-----------------------|-------------------|---------------|---------------------|------------------------|
| Pulse              | 55 imp. according to $4,5 \times 10^6$ s | 9,16                  | 0,928             | 6             | $S_e=1,5$           | $\frac{S_f e}{S_f n}=1,3$ |
| Sinusoidal, $f=50$ Hz | 0,01 s                            | 1,308                 | 0,928             | 6             | $S_e=1,15$           |                        |

Table 2. Comparative indicators of weed stem tissue damage at sinusoidal and pulsed high-voltage exposure

| Weed type                      | High voltage ($U_{max}=2$ kV) sinusoidal impact of: | High voltage impulse impact ($U_0=2$ kV) with the pulse number m, at $C_k=1000$ pF: | | | | |
|--------------------------------|------------------------------------------------------|-----------------------------------------------------------------------------------|---|---|---|---|
|                                | One period t=0,02 c | Two periods t=0,04 c | Four periods t=0,08 c | m= 200 | m=400 | m=800 |
| Thrown back amaranth           | Affecting energy, J: | Affecting energy, J: | Plant tissue damage level, r.u. | Plant tissue damage level, r.u. |
|                                | 0,485 | 0,970 | 1,865 | 0,380 | 0,760 | 1,520 |
|                                | 1,47 | 2,03 | 2,46 | 3,72 | 4,13 | 4,75 |
| City pigweed                   | Affecting energy, J: | Affecting energy, J: | Plant tissue damage level, r.u. | Plant tissue damage level, r.u. |
|                                | 0,394 | 0,857 | 1,701 | 0,380 | 0,760 | 1,520 |
|                                | 1,43 | 1,80 | 2,29 | 4,10 | 6,10 | 6,90 |

Figure 3. The Dependences of Plant Tissue Damage Degrees at the Exposure to Pulsed and Sinusoidal Voltages and their Relation from the Number m of Single Energy Equal Effects.

3. Conclusions

The electrical treatment of sunflower, tobacco, and weeds to achieve technologically necessary lethal damage demands the use of the most effective electric current type. This statement is developed by the theoretical premises and experimental study data to assess the extent of different plant tissue damage treated with the energy equivalent sinusoidal and pulsed currents.

4. Summary

Thus, the presented materials of general estimate and the experimental study results suggest the possibility of an influencing factor use - a pulse mode of electrical processing of plants and plant raw materials in the processes of crop production and the processing of raw materials from it with the best technological performances and minimal energy consumption.
5. Conflict of Interest

The authors acknowledge that the presented data do not contain any conflict of interest.

6. References

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