Photo Documentation

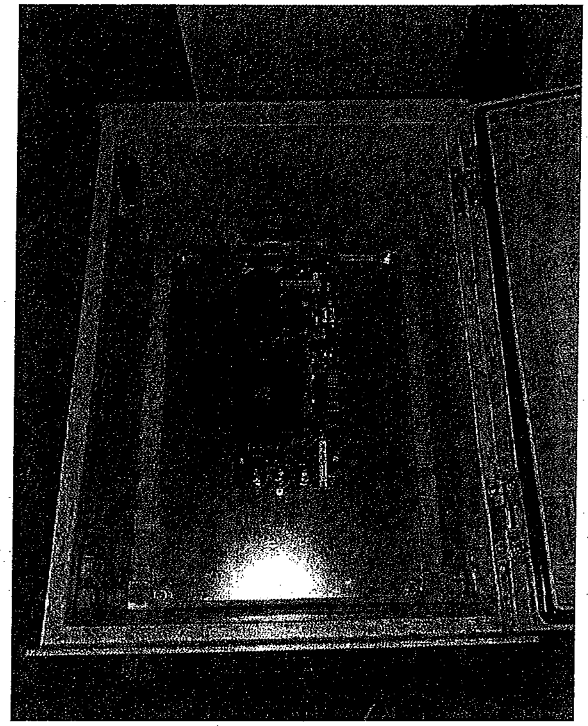

Figure : EF170

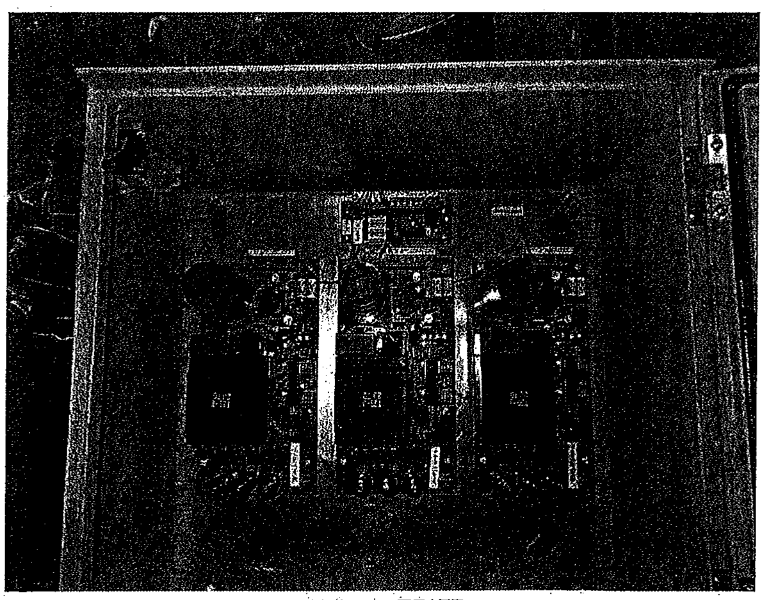

Figure : EF177

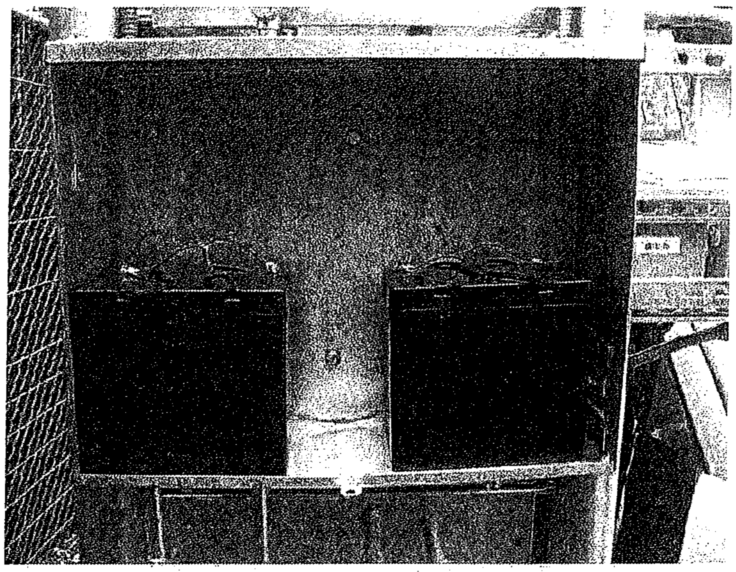

Figure 3: Battery Compartment

Figure 4: Solar Panel System

Figure 5: Fence Connections

Figure 6: Fence Warning and Physical Barrier

University of Wisconsin Test Data

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Testing the Safety of Advanced Perimeter Systems EF170, EF171, EF172, EF173 and EF174 Electrofence controllers using IEC 60335-2-76 standard

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Abstract

We tested five Advanced Perimeter Systems EF170, EF171, EF172, EF173 and EF174 Electrofence controllers (EFCs) to determine their current-versus-time waveforms. The EFCs EF170 and EF171 had one control unit each, while EF172, EF173 and EF174 had two control units each. We measured their safety characteristics using the existing IEC 60335-2-76 standard. We found that all the electric fence controllers passed the IEC 60335-2-76 standard.

1. Introduction

The vast majority of work on electric safety has been done using power line frequencies such as 60 Hz. Thus most standards for electric safety apply to continuous 60 Hz current applied hand to hand. A separate class of electric devices apply electric current as single or a train of short pulses, such as are found in electric fence controllers (EFCs). The standard that applies to EFCs is (IEC 60335-2-76, 2006). To estimate the ventricular fibrillation (VF) risk of EFCs, we use the excitation behavior of excitable cells. Geddes and Baker (1989) presented the cell membrane excitation model (Analytical Strength Duration Curve model) by a lumped parallel resistance capacitance (*RC*) circuit. This model determines the cell excitation thresholds for varying rectangular pulse durations by assigning the strength–duration rheobase currents, chronaxie, and time constants (Geddes and Baker, 1989). Though this model was originally developed based on the experimental results of rectangular pulses, the effectiveness of applying this model for other waveforms has been discussed (IEC 1987, Jones and Geddes 1977). The charge–duration curve, derived from the strength–duration curve, has been shown in sound agreement with various experimental results for irregular waveforms. This permits calculating the VF excitation threshold of EFCs with various nonrectangular waveforms.

2. Mathematical background and calculation procedures

Based on the cell membrane excitation model (Weiss–Lapique model), Geddes and Baker (1989) developed a lumped *RC* model (analytical strength–duration curve) to describe the membrane excitation behavior. This model has been widely used in various fields in electrophysiology to calculate the excitation threshold. Figure 1 shows the normalized strength–duration curve for current (I), charge (Q) and energy (U). The expression of charge is also known as the charge–duration curve which is important for short duration stimulations.

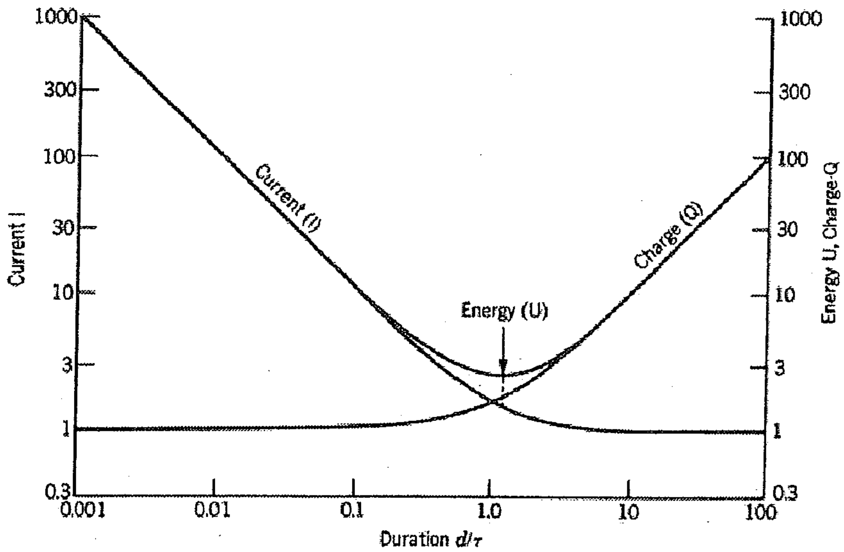

Figure 1. Normalized analytical strength–duration curve for current I, charge Q, and energy U. The x axis shows the normalized duration of d/τ. Note that for $d << \tau$, Q is constant and the most appropriate variable for estimating cell excitation. (from Geddes and Baker, 1989).

The equation for the strength–duration curve is (Geddes and Baker, 1989),

$$\Delta v = IR(1 - e^{-\frac{t}{\tau}}), \quad (1)$$

where I is a step current intensity, R is the shunt resistance, Δv is the depolarization potential threshold which is about 20 mV for myocardial cells, τ is the RC time constant, and t is the time I is applied.

If we let the stimulation duration go to infinity, the threshold current is defined as the rheobase current ($I = b$). If we substitute I in equation (1) by b and define the threshold current $I_d = \Delta v/R$ for the stimulation with duration d. Equation (1) becomes,

$$I_d = \frac{b}{1 - e^{-\frac{d}{\tau}}}. \quad (2)$$

We can calculate the threshold charge (Q_d) by integrating equation (2) and it becomes,

$$Q_d = I_d d = \frac{bd}{1 - e^{-\frac{d}{\tau}}}, \quad (3)$$

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For short duration stimulation ($d << \tau$) with duration shorter than 0.1 times the *RC* time constant, equation (3) can be approximated by equation (4) and it yields equation (5),

$$1-e^{-\frac{d}{\tau}} \approx \frac{d}{\tau}, \tag{4}$$

$$Q_d = b\tau \tag{5}$$

Equation (5) suggests that the charge excitation threshold for short duration stimulation is constant and equals the product of the *RC* time constant τ and the rheobase *b*. Geddes and Bourland (1985) showed that the charge–duration curve for single rectangular, trapezoidal, half sinusoid and critically damped waveforms had a good agreement for short duration stimulations. Therefore we used the same model to estimate thresholds for stimulation sources where *I* was not constant, under the same stimulation setting.

Cardiac cell excitation has been intensively studied at the 60 Hz power line frequency because most accidental electrocutions occur with 60 Hz current, which has a longer duration relative to the cardiac cell time constant of about 2 ms. However, EFCs operate with pulse durations much shorter than the time constant.

3. List of Equipment used and Validation of the Test Set-up

Figure 2 shows our experimental test set-up. The EFCs under test consist of Advanced Perimeter System Electro-Fence Controller: Model No. EF170-S0373-1 (EFC1), Model No. EF171-S0394-1 (EFC2), Model No. EF172-S0142-2 (EFC3), Model No. EF172-S0142-3 (EFC4), Model No. EF173-S0416-2 (EFC5), Model No. EF173-S0416-3 (EFC6), Model No. EF174-S0428-2 (EFC7) and Model No. EF174-S0428-3 (EFC8). A 12 V battery was used as a power source for the EFCs. The short duration electrical pulses from these ECFs passed through a series of five 100 Ω (NH050100R0FE02 50 W 100 Ω 1% Vishay Wirewound resistors – Chassis Mount) noninductive resistors which measure 497.4 Ω, which represents approximately the internal resistance of the human body. Pulses passed through five 50 Ω (NH05050R00FE02 50 W 50 Ω 1% Vishay Wirewound resistors – Chassis Mount) noninductive resistors connected in parallel which measure 10.07 Ω. The oscilloscope measured the output voltage across these sensing resistors. For these very short pulses it is important to use high voltage noninductive resistors because the same current flowing through a resistor that has substantial inductance will measure a larger current than a resistor that is noninductive. The data were collected in EXCEL format from a disk in the Agilent 54621 oscilloscope. Figure 3 was plotted using MATLAB.

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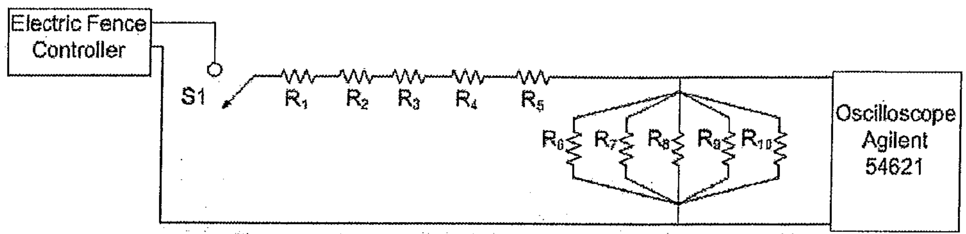

Figure 2. The switch S1 is closed to test the EFC according to IEC 60335-2-76 standard. The current flows through a string of 100 Ω resistors R_1 R_5 (total 497.4 Ω) which approximates the internal body resistance of 500 Ω. The resistors R_6–R_{10} in parallel (total 10.07 Ω) yields a low voltage that is measured by the oscilloscope.

EFCs are used for area security. We tested eight EFCs control units (EFC1–EFC8) of the five APS Electrofence controllers using the experimental set-up in Figure 2. In Figure 2 the switch S1 is closed to test the EFC according to the IEC 60335-2-76 standard.

We tested Advanced Perimeter Systems EF152 using the test set up shown in Figure 2. Figure 3 shows the shows the output current waveform for EF152. This waveform resembles the output current waveform for electric fence controller EF152 from previous testing, which confirms that our testing set up is connected correctly.

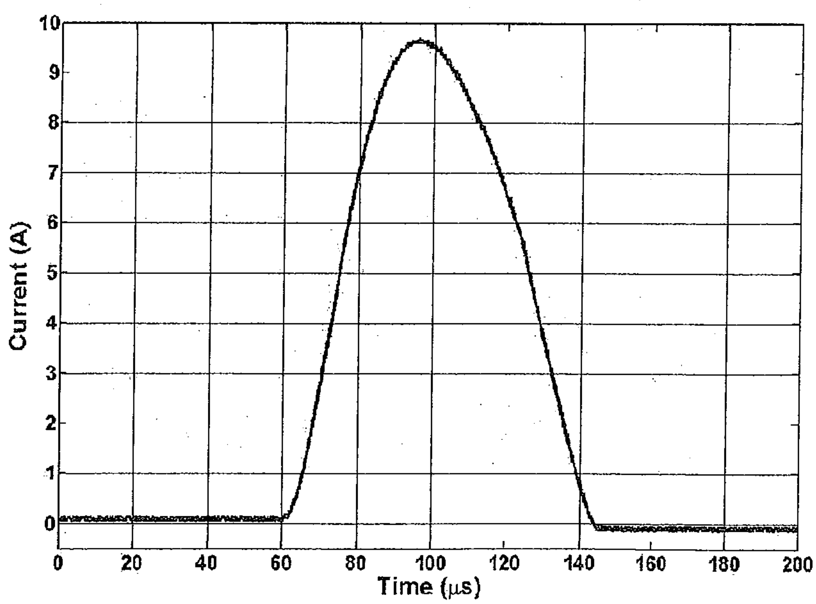

Figure 3. The output current waveform for electric fence controller EF152. This waveform resembles the output current waveform for electric fence controller EF152 from previous testing, which confirms that our testing set up is connected correctly.

4. Photos of the APS units tested

The figures below are the photographs of five Advanced Perimeter Systems EF170, EF171, EF172, EF173 and EF174 Electrofence controllers tested.

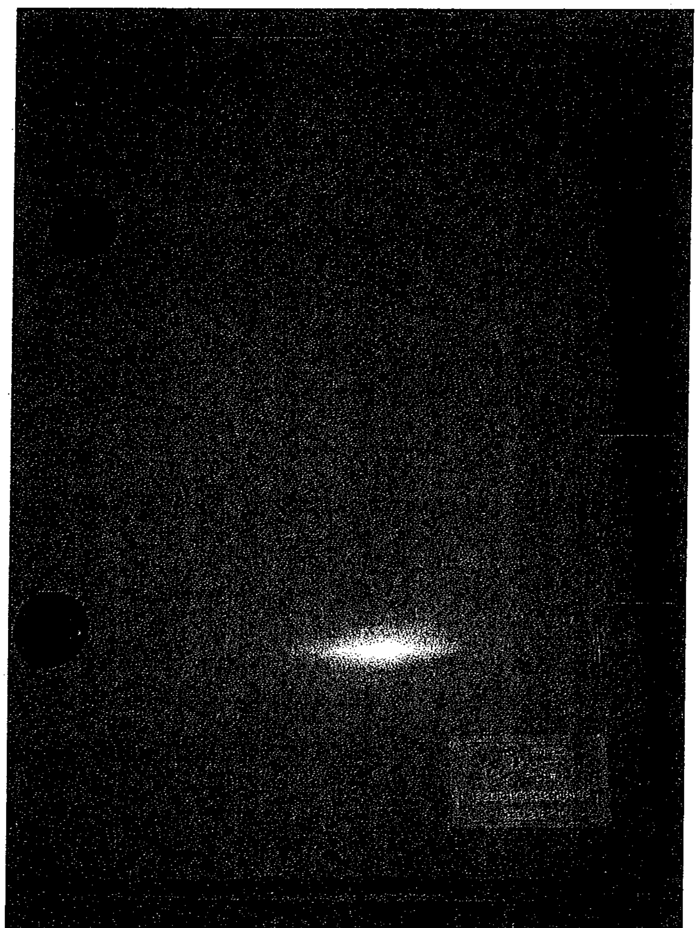

Figure 4. APS Electro-fence controller Model No. EF170.

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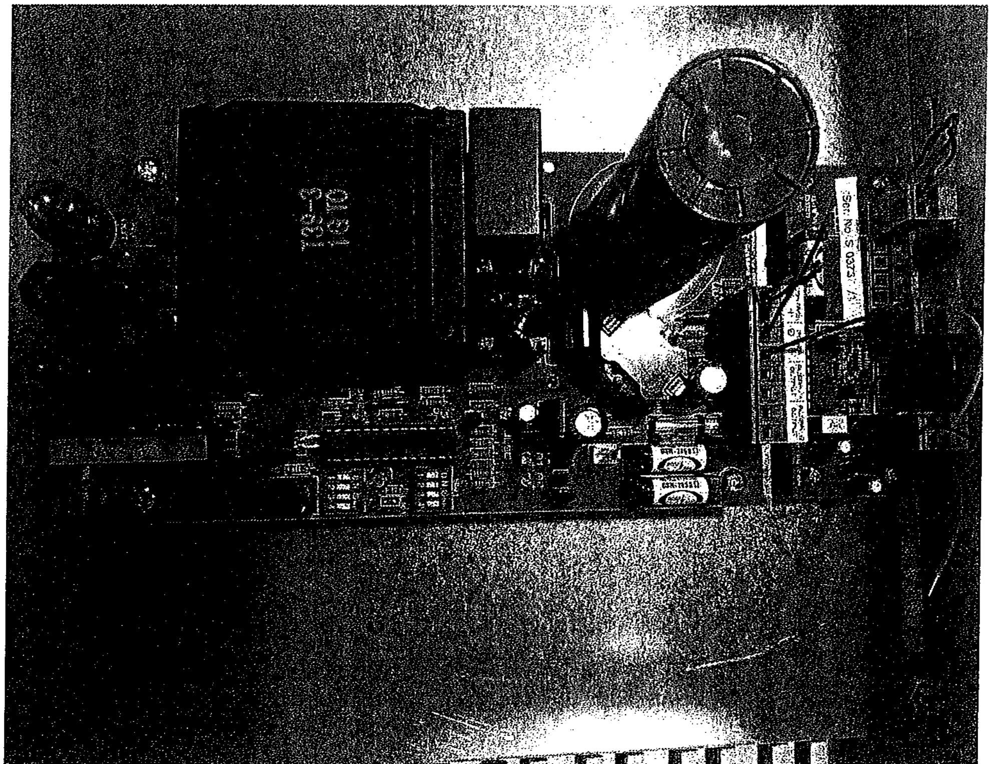

Figure 5. APS Electro-fence controller Model No. EF170, Ser No. S 0373. It has one control unit.

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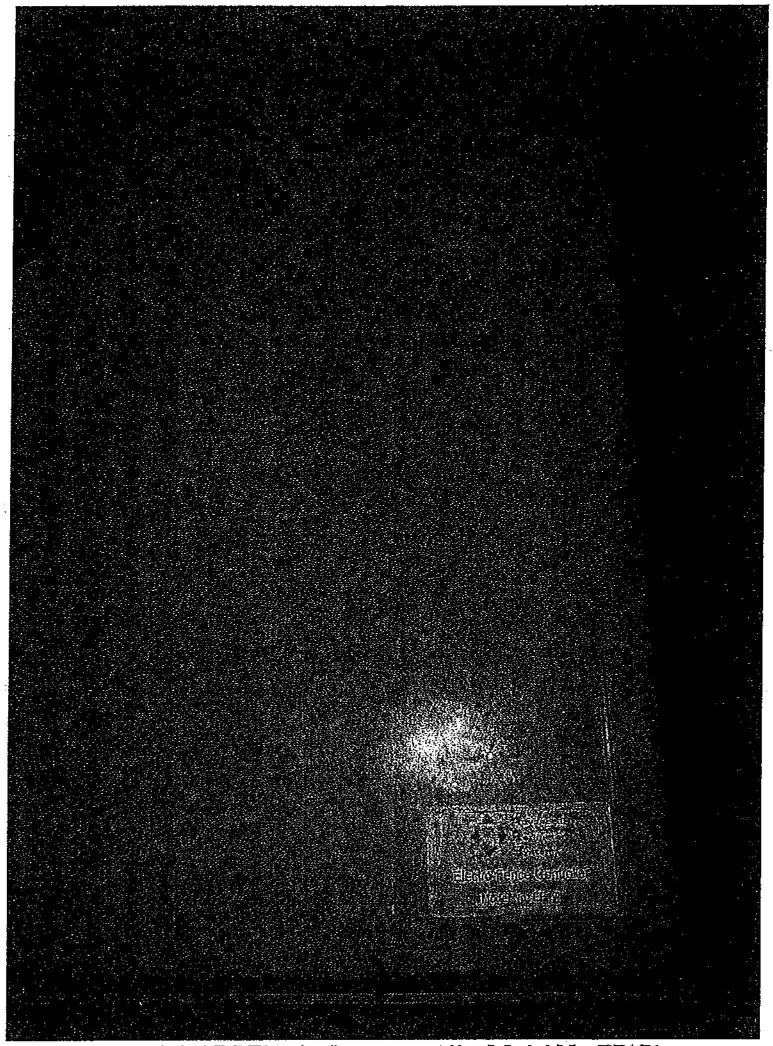

Figure 6. APS Electro-fence controller Model No. EF171.

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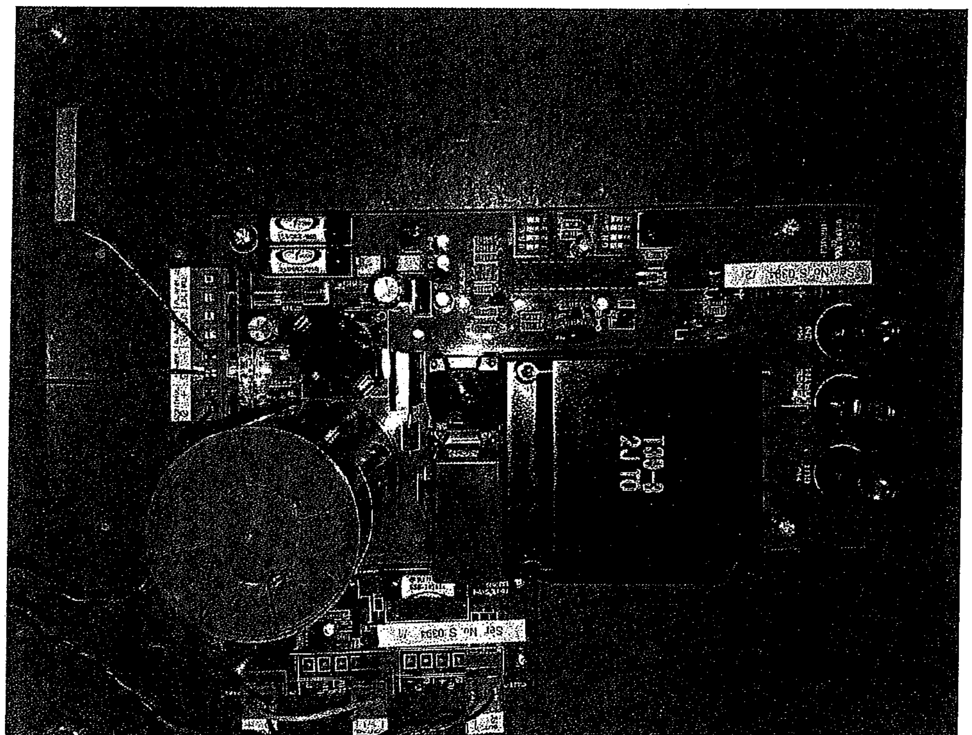

Figure 7. APS Electro-fence controller Model No. EF171, Ser No. S 0394. It has one control unit.

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Figure 8. APS Electro-fence controller Model No. EF172.

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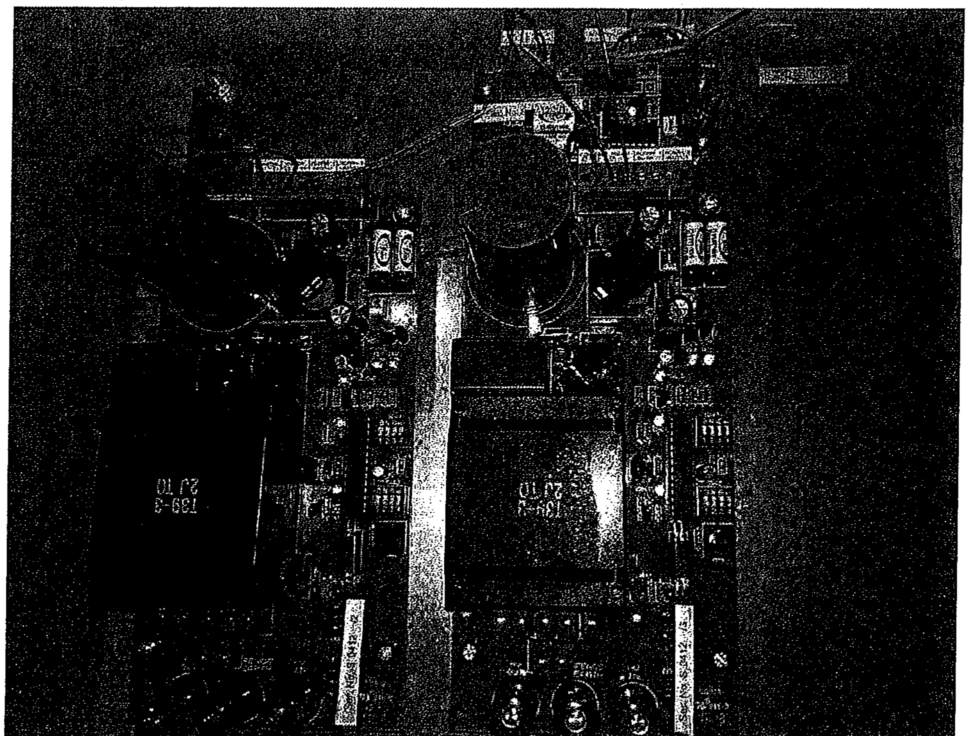

Figure 9. APS Electro-fence controller Model No. EF172, Ser No. S 0412. It has two control units.

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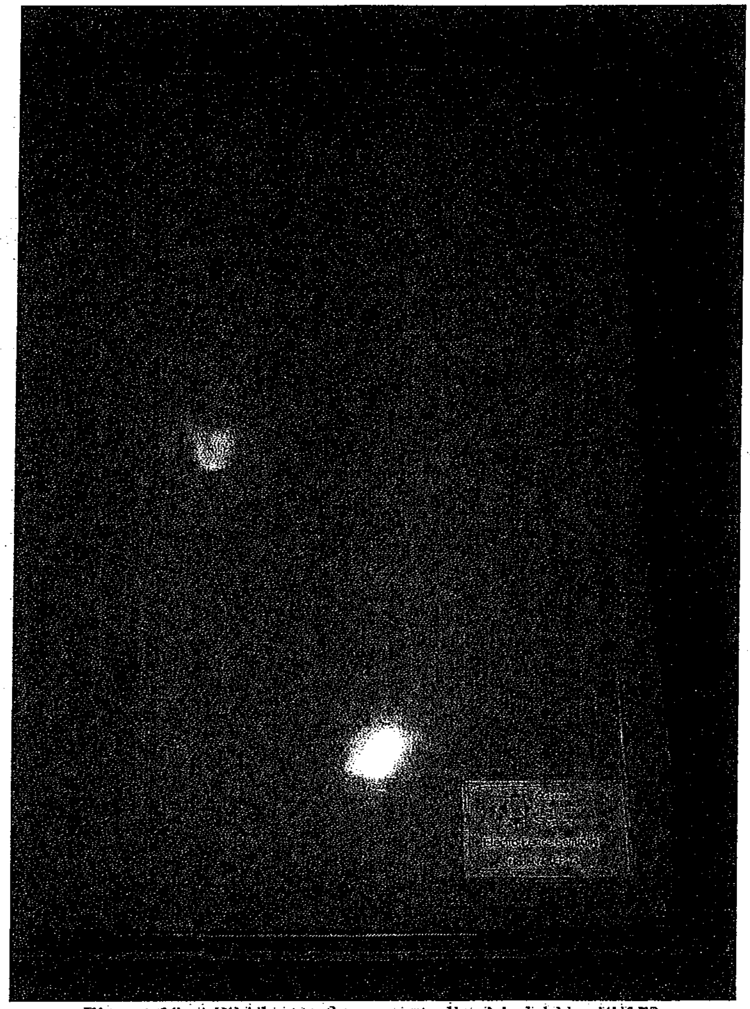

Figure 10. APS Electro-fence controller Model No. EF173.

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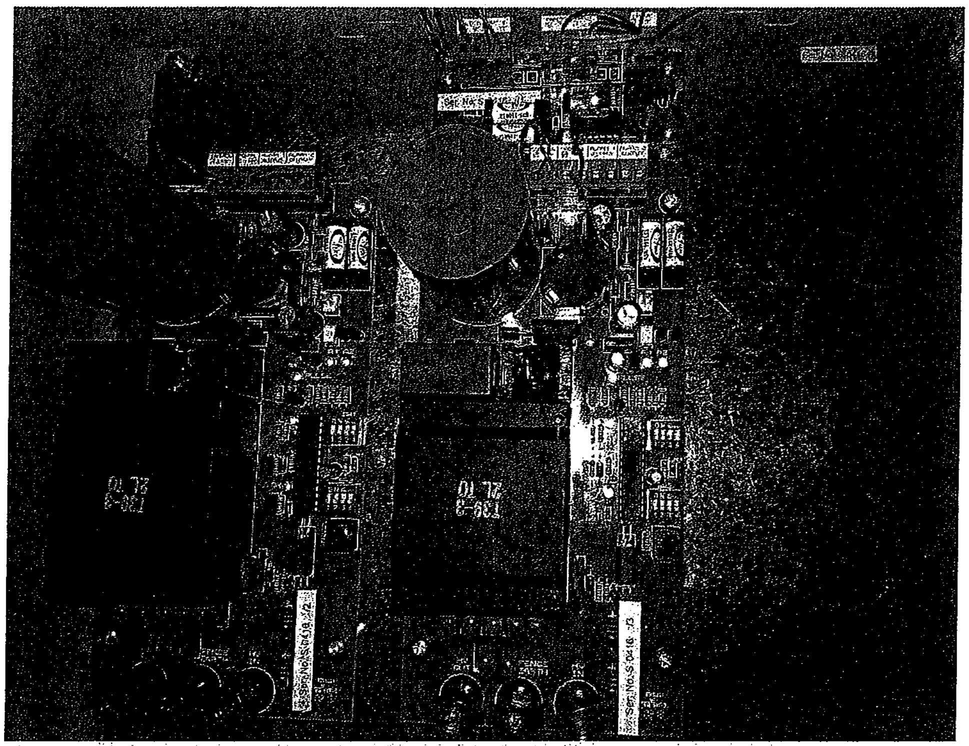

Figure 11. APS Electro-fence controller Model No. EF173, Ser No. S 0416. It has two control units.

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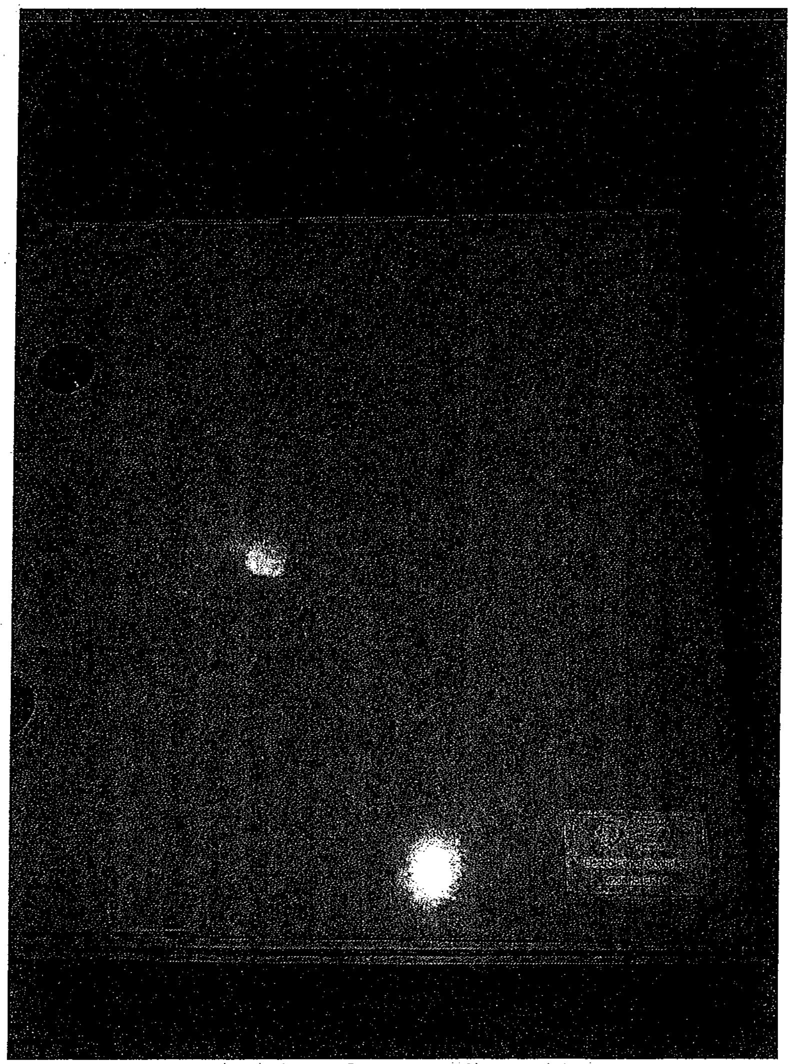

Figure 12. APS Electro-fence controller Model No. EF174.

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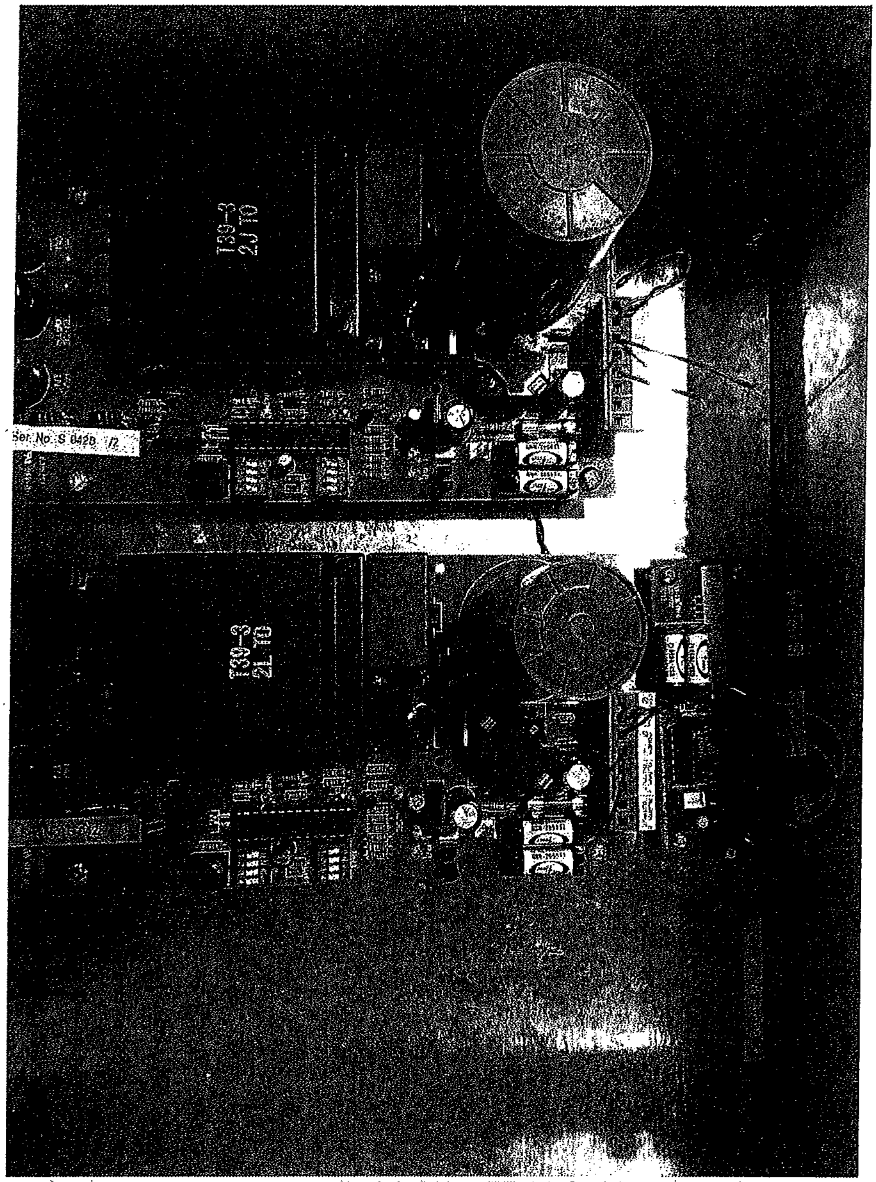

Figure 13. APS Electro-fence controller Model No. EF174, Ser No S 0428. It has two control units.

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References

Geddes L A, and Baker L E 1989 *Principles of applied biomedical instrumentation* (New York: John Wiley & Sons) pp 458–61

Geddes L A and Bourland J D 1985 The strength-duration curve. *IEEE. Trans. Biomed. Eng.* **32(6)** 458–9

IEC 1987 *International Electrotechnical Commission IEC Report: Effects of current passing through the human body* (IEC 60479-2) pp 47

IEC 2006 *Household and similar electrical appliances – Safety – Part 2-76: Particular requirements for electric fence energizers.* (IEC 60335-2-76, Edition 2.1)

Jones M and Geddes L A 1977 Strength duration curves for cardiac pacemaking and ventricular fibrillation *Cardiovasc. Res. Center Bull.* **15** 101–12

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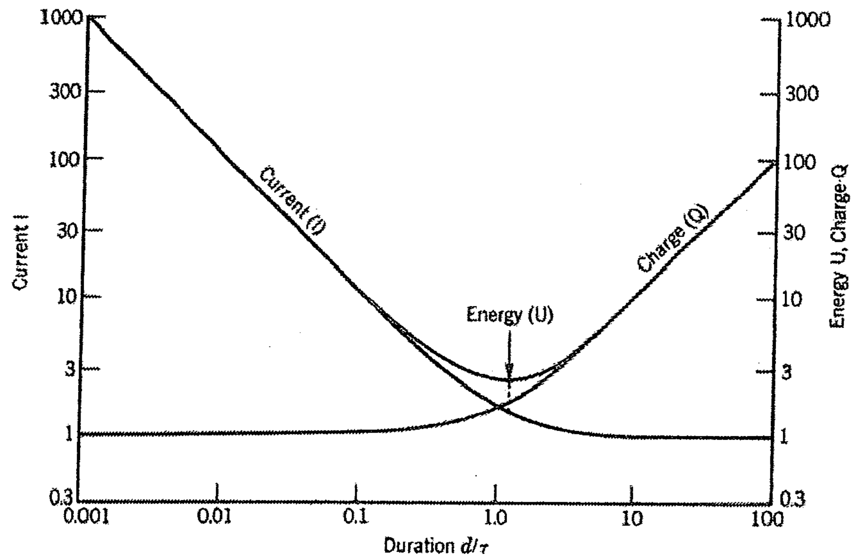

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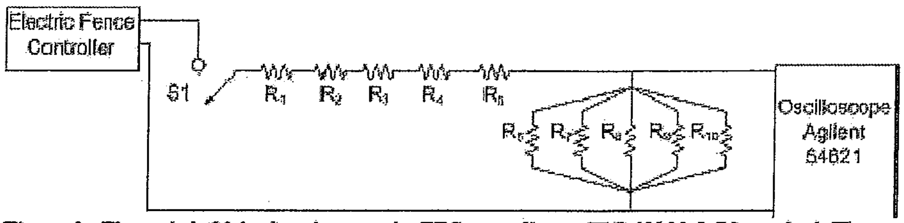

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EFCs are used for area security. We tested eight EFCs (EFC1–EFC8) using the experimental set-up in Figure 2 and obtained the output currents shown in Figures 3 – 11. In Figure 2 the switch S1 is closed to test the EFC according to the IEC 60335-2-76 standard. We tested Advanced Perimeter Systems EF152 using the test set up shown in Figure 2. Figure 3 shows the shows the output current waveform for EF152. This waveform resembles the output current waveform for electric fence controller EF152 from previous testing, which confirms that our testing set up is connected correctly.

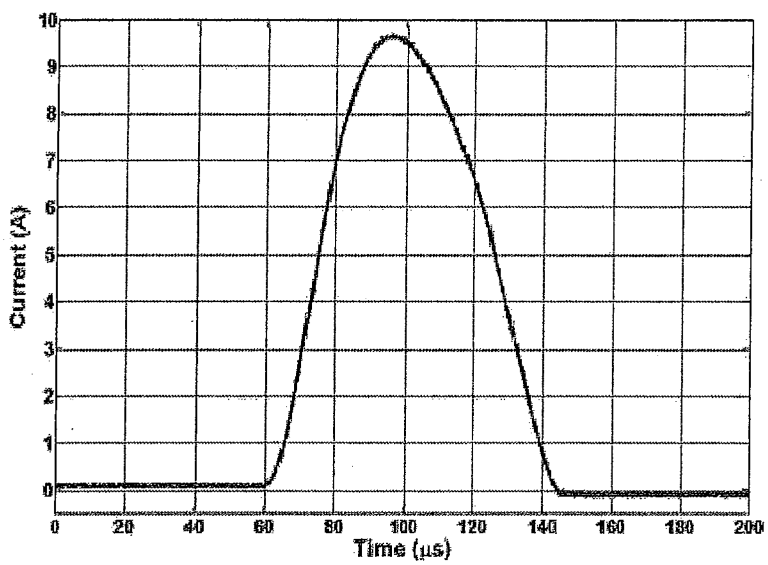

Figure 3. The output current waveform for electric fence controller EF152. This waveform resembles the output current waveform for electric fence controller EF152 from previous testing, which confirms that our testing set up is connected correctly.

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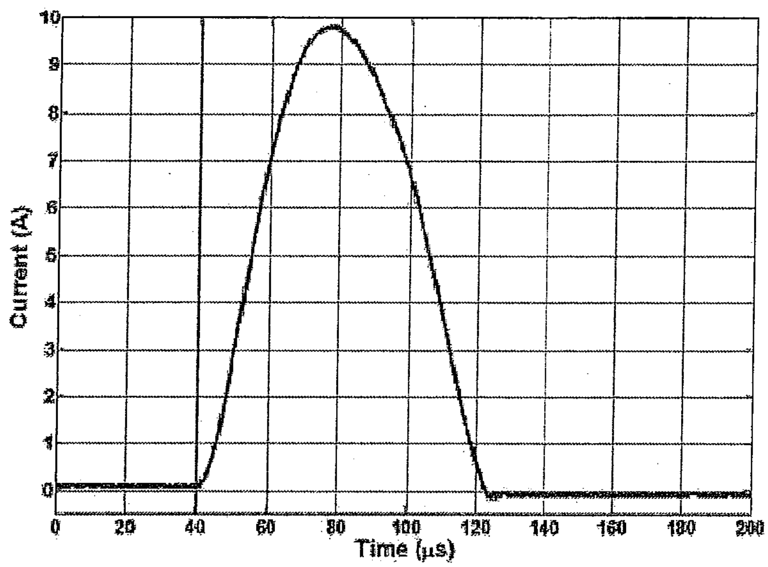

Figure 4. The output current waveform for electric fence controller EFC1 (EF170-S0373-1). The I_{rms} according to IEC 60335-2-76 standard for EFC1 is 8.22 A.

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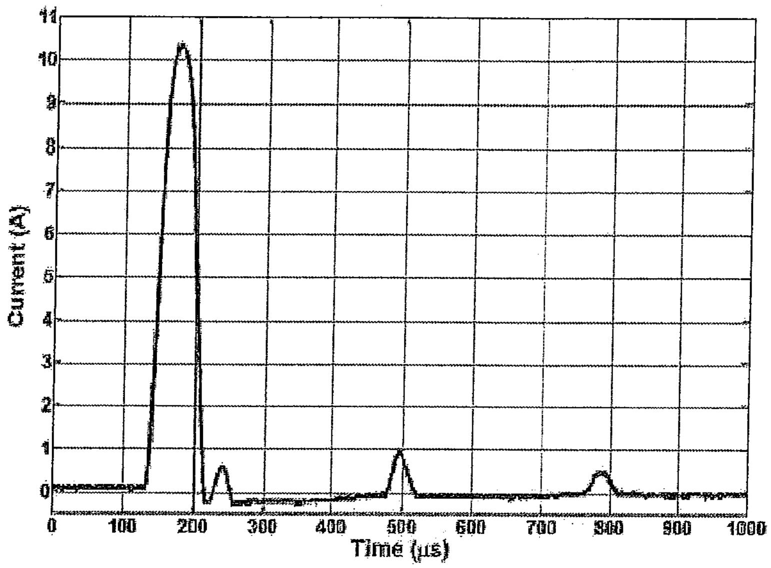

Figure 9. The output current waveform for electric fence controller EFC6 (EF173-S0416-3). The I_{mi} according to IEC 60335-2-76 standard for EFC6 is 8.83 A.

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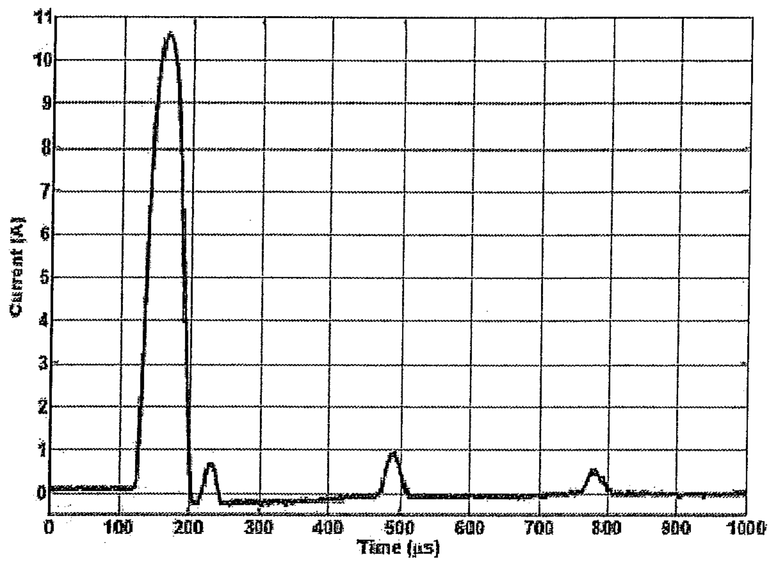

Figure 10. The output current waveform for electric fence controller EFC7 (EF174-S0428-2). The I_{rms} according to IEC 60335-2-76 standard for EFC7 is 9.00 A.

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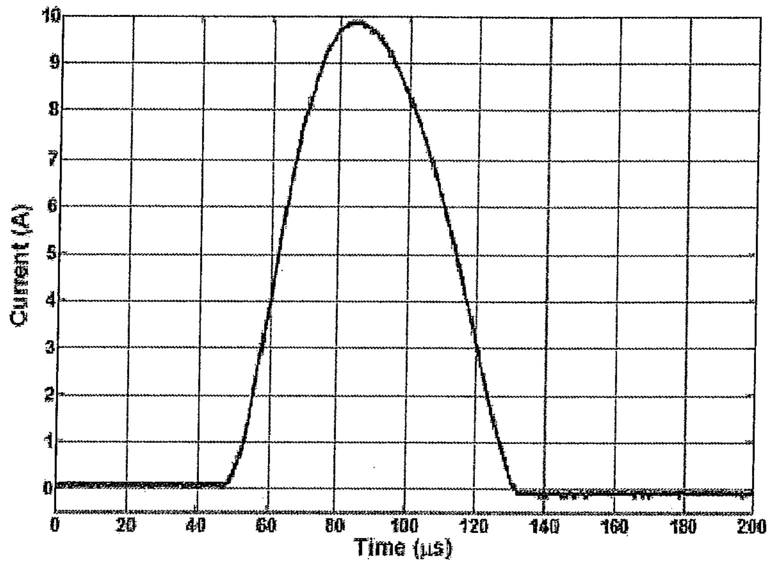

Figure 11. The output current waveform for electric fence controller EFC8 (EF174-S0428-3). The I_{rms} according to IEC 60335-2-76 standard for EFC8 is 8.24 A.

4. Results

Table 1 shows the approximate results for the rms current, power, duration, impulse repetition rate and energy/impulse for all the EFCs.

Table 1 Approximate results for all EFCs.

EFCs		EFC1	EFC2	EFC3	EFC4	EFC5	EFC6	EFC7	EFC8
Parameters	Units								
Total Energy	A^2ms	3.74	4.73	3.75	3.72	4.54	4.47	4.55	3.81
95% Energy Duration	μs	53	53	53	53	55	54	53	53
I_{rms}	A	8.22	8.17	8.20	8.18	8.86	8.83	9.00	8.24
IEC Standard I_{rms}	A	15.7	15.7	15.7	15.7	15.7	15.7	15.7	15.7
Impulse repetition rate (*IRR*)	Hz	0.82	0.82	0.82	0.82	0.81	0.81	0.82	0.82
IEC Standard *IRR*	Hz	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Energy/Impulse	J	1.90	2.40	1.90	1.89	2.30	2.27	2.31	1.93
IEC Standard Energy/Impulse	J	5	5	5	5	5	5	5	5
Pass IEC Standard	Yes/No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

IEC (2006) defines in 3.116 "impulse duration: duration of that part of the impulse that contains 95% of the overall energy and is the shortest interval of integration of $I^2(t)$ that gives 95% of the integration of $I^2(t)$ over the total impulse. $I(t)$ is the impulse current as a function of

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time." In 3.117 it defines "output current: r.m.s. value of the output current per impulse calculated over the impulse duration." In 3.118 it defines "standard load: load consisting of a non-inductive resistor of 500 Ω ± 2.5 Ω and a variable resistor that is adjusted so as to maximize the energy per impulse or output current in the 500 Ω resistor, as applicable." In 22.108, "Energizer output characteristics shall be such that – the impulse repetition rate shall not exceed 1 Hz; – the impulse duration of the impulse in the 500 Ω component of the standard load shall not exceed 10 ms; – for energy limited energizers the energy/impulse in the 500 Ω component of the standard load shall not exceed 5 J; The energy/impulse is the energy measured in the impulse over the impulse duration. – for current limited energizers the output current in the 500 Ω component of the standard load shall not exceed for an impulse duration of greater than 0.1 ms, the value specified by the characteristic limit line detailed in Figure 102; an impulse duration of not greater than 0.1 ms, 15 700 mA. The equation of the line relating impulse duration (ms) to output current (mA) for 1 000 mA < output current < 15 700 mA, is given by impulse duration = $41.885 \times 10^3 \times (\text{output current})^{-1.34}$." We used these definitions and calculated the total energy, the shortest duration where 95% of the total energy occurs, the rms current for that duration from Figures 4–11 for the EFCs (EFC1–EFC8). Table 1 lists the results. Table 1 shows that all the EFCs pass the IEC 60335-2-76 standard. For all EFCs, the impulse repetition rate is about 0.82 Hz and less than the recommended maximum 1 Hz repetition rate; the impulse duration of the impulse in the 500 Ω component of the standard load is about 0.055 ms and less than the recommended maximum 10 ms duration and the energy/impulse in the 500 Ω component of the standard load is about 2 J and less than the recommended maximum value of 5 J. Example calculation of energy/impulse for EFC7 is shown below:

Energy/impulse = $\int I^2(t)\, R\, dt = 4.55\ A^2{\cdot}ms \times 507.47\ \Omega = 2.31\ J$.

5. Discussion

IEC (2006) integrates $I^2(t)$, which is roughly equal to $I(t)$. Their Figure 102 roughly follows charge. The 500 Ω resistor closely approximates the resistance of the body and determines the current that flows through the body. We found the Advanced Perimeter Systems EF170, EF171, EF172, EF173 and EF174 Electrofence controllers passed the IEC 60335-2-76 standard.

References

Geddes L A, and Baker L E 1989 *Principles of applied biomedical instrumentation* (New York: John Wiley & Sons) pp 458–61

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Conclusion

The products covered by this Report have been found to be operational and the construction complies with the applicable requirements outlined in referenced Standard(s). The equipment was field labeled. Final approval of the equipment shall be determined by the authority having jurisdiction.