ENERGIZERS AND ENERGY

An Explanation of Electric Fence Concepts

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Contents

1 Introduction

Have you ever asked yourself the following questions ?

- how does an energizer work ?
- what is electrical current ?
- what is voltage ?
- what is resistance ?
- what are power and energy ?
- what is stored energy ?
- what is output energy ?
- what is an energizer energy-load curve ?
- what is shock energy ?
- what can peak voltage tell me ?
- what is an energizer voltage-load curve ?
- what does energizer efficiency mean ?
- what is a switched-output energizer ?
- what is an adaptive-control energizer ?

This booklet aims to answer those questions.

2 Energizers

Energizer Pulses

Electric fence energizers produce a short, high voltage pulse at a regular rate of about one pulse per second. Figure 1 shows a typical energizer pulse.

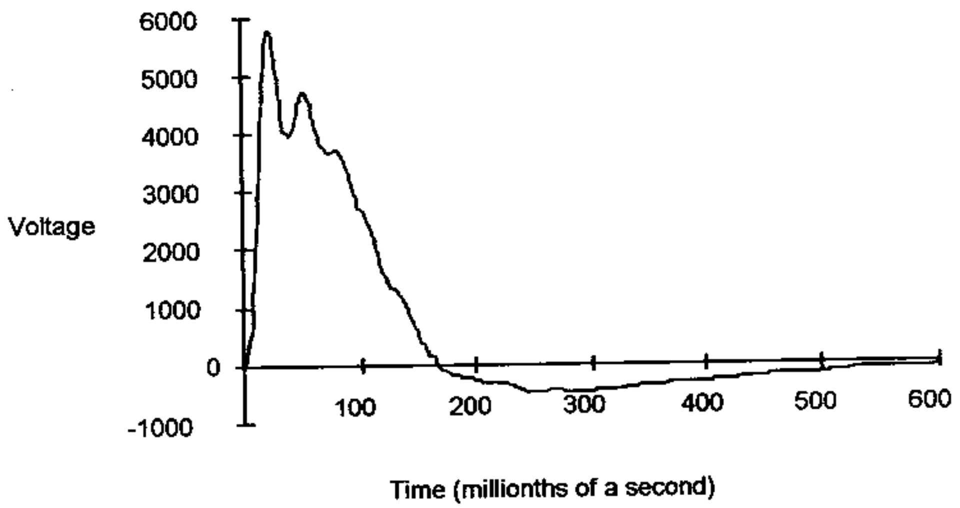

Figure 1. A Typical Energizer Pulse.

Note just how short the pulse really is - the whole event is over in less than one thousandth of a second (that's 0.001 seconds).

How Energizers Work

The energizer pulses may be very short but a lot of energy has to be transferred in that time. The way this is achieved is shown in Figure 2.

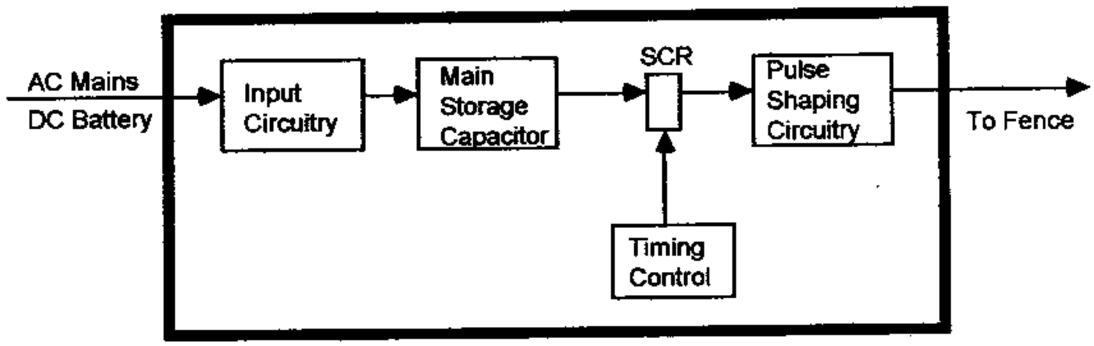

Figure 2. The Energizer.

The *Input Circuitry* takes electrical energy from the supply (mains or battery) and makes it suitable for holding in the main storage capacitor.

The *Main Storage Capacitor* is a type of electrical "reservoir". The energy builds up in here.

The *Timing Control* sends a signal at regular intervals to the SCR. These signals are usually spaced 1-2 seconds apart.

The *SCR* is a type of electrical "gate". When it receives the message from the timing control it opens (or "fires"). The energy built up inside the main storage capacitor is then released.

The *Pulse Shaping Circuitry* shapes the energy as it rushes out onto the fence. This helps it to travel better down the fence. It normally consists of the output transformer and the output (or VDR) circuitry.

The capacitor is now empty (or "discharged"). Once again energy will build up, and the whole cycle will repeat itself.

The whole process is comparable with a domestic toilet. Water feeds slowly into a storage tank (the capacitor) and when the lever is pressed the stopper opens (the SCR fires) and all the water streams out in one big rush.

Figure 1. Location of the Rocky Mountain Arsenal in Colorado.

Pulse Shape

A wide variety of pulse shapes are possible depending on both the design of the energizer and the fence. Figure 3 demonstrates some of these pulse shapes.

Figure 3. Different Pulse Shapes.

The shape of the fence pulse is very important in determining how well it travels down the fence.

3 Basic Electrical Theory

What is Electrical Current ?

Electricity is the flow of electrons through a material. We can compare electrical current flowing in a wire with water flowing in a pipe.

Electricity flows easily through some materials, with difficulty in others and not at all in others. If electricity flows easily in a material (e.g. most metals) then we call it a conductor. If electricity won't flow in a material (e.g. plastic, rubber and glass) then we call it an insulator.

Electrical Current uses the symbol 'I' and is measured in amps (A). An amp is a measure of how many electrons flow past a point every second.

What is Voltage ?

Like most things electrons are lazy and do not form currents naturally. The force required to move the electrons is called voltage. If we compare electricity flowing in a wire with water flowing in a pipe then voltage is the electrical "pressure".

Voltage uses the symbol 'V' and is measured in volts (v).

How Are Voltage And Current Related ?

Voltage and current are generally related. This is called Ohms Law :-

$$I = \frac{V}{R}$$ Equation 1

where	V	=	voltage	(volts, V)
	I	=	current	(amps, A)
	R	=	resistance	(ohms, Ω)

All materials have a resistance (R) measured in ohms (Ω). In conductors the resistance is very low, while in insulators the resistance is very high. In general the resistance is fixed (i.e. it doesn't change), which means we always know the relationship between voltage and current for that component.

Note :- not all circuits obey Ohms Law. If the circuit includes capacitance or inductance (and not just resistance) then Ohms Law is no longer enough. More complicated equations can be used, but they are beyond the scope of this booklet. In general Ohms Law is sufficient for our needs.

What is Power ?

Power measures the strength of a system at any instant. For example the power rating of a light bulb indicates its brightness (e.g. a 100W bulb is brighter than a 40W bulb).

The power of an electrical system is given by the following formula :-

$$P = V \times I$$

Equation 2

where	P	=	power	(watts, W)
	V	=	voltage	(volts, V)
	I	=	current	(amps, A)

For example a 100W light bulb running from 240V has 0.42 amps of current flowing through it (100W = 240V x 0.42A).

Combining Equations 1 and 2 we obtain a new equation :-

$$P = \frac{V^2}{R}$$

Equation 3

where	P	=	power	(watts, W)
	V	=	voltage	(volts, V)
	R	=	resistance	(ohms, Ω)

What is Energy ?

Energy is a measure of the total amount of power that has flowed into a system. It is given by :-

$$E = P \times t$$

Equation 4

where	E	=	energy	(joules, J)
	P	=	power	(watts, W)
	t	=	time	(seconds, s)

In other words the amount of energy used by a light bulb depends on two factors :-

- how powerful the bulb is (i.e. the power rating of the bulb)
- how long the bulb is turned on (because the most powerful light in the world will not use any energy if it is turned off)

Another way of looking at the situation is to compare an electrical system to water flowing in a pipe. The power is like the amount of water flowing in the pipe at a single point in time. The energy is like the total amount of water that has gone through the pipe over a certain period of time.

Worked Example One

Our first worked example is a 10 volt power supply connected across a resistor.

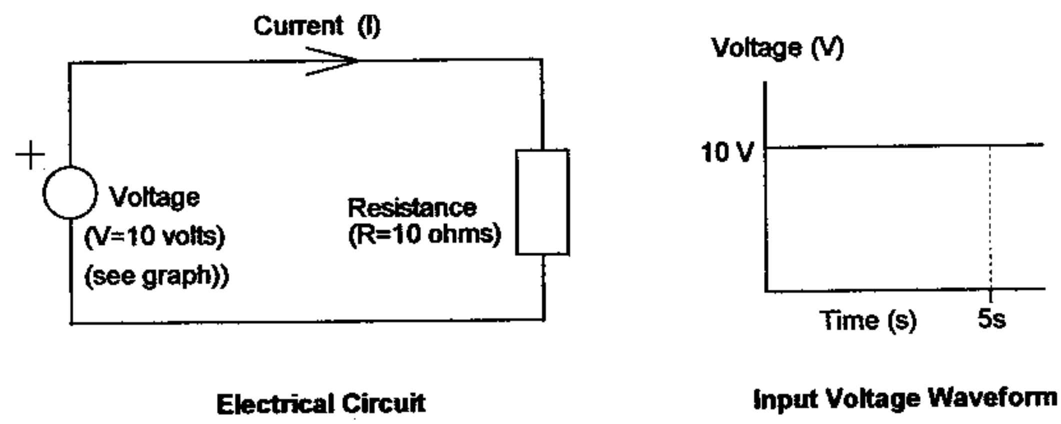

Figure 4 - Worked Example 1

The power flowing in the circuit can be calculated using Equation 3.

$$P = \frac{V^2}{R} = \frac{10^2}{10} = \frac{100}{10} = 10\text{W}$$

The total energy transferred in the five seconds can be calculated using Equation 4

$$\begin{aligned} E &= P \times t \\ &= 10 \times 5 \\ &= 50J \end{aligned}$$

Worked Example Two

Our second example is more complicated. In this example the voltage input has different values at different times. This can be compared to a water pipe with the tap being turned on by different amounts at different times.

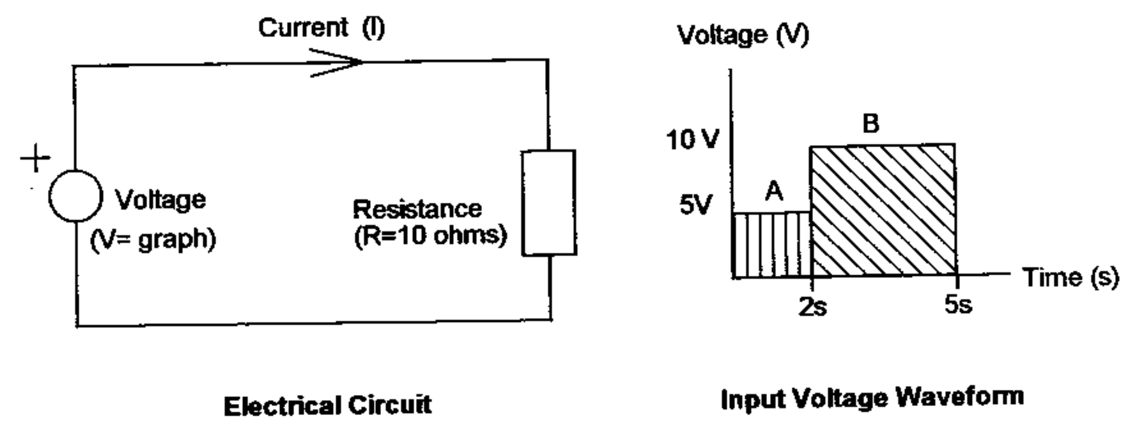

Figure 5 - Worked Example 2

In this case the power and energy are worked out separately for the two waveform sections (Section A and Section B).

Section A :

$$P = \frac{V^2}{R} = \frac{5^2}{10} = \frac{25}{10} = 2.5W$$

$$E = P \times t = 2.5 \times 2 = 5J$$

Section B :

$$P = \frac{V^2}{R} = \frac{10^2}{10} = \frac{100}{10} = 10W$$

$$E = P \times t = 10 \times 3 = 30J$$

Notice that the power has increased in section B from 2.5W to 10W.

The total energy transferred over the 7 seconds is simply obtained by adding the energy transferred in section A (5J) and the energy transferred in section B (30J). This total is 35 J.

Worked Example Three

In many real situations the voltage constantly changes with time. For example, the voltage waveform below shows a typical energizer pulse.

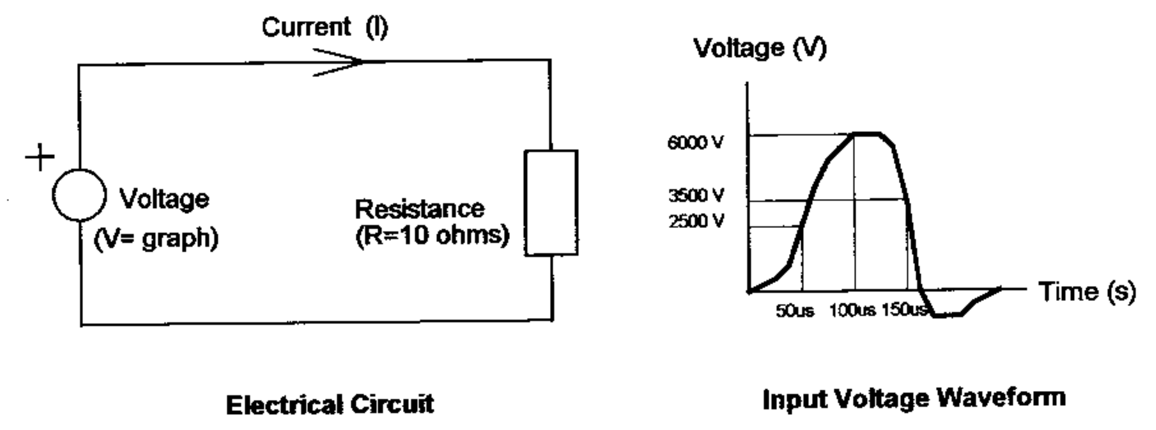

Figure 6 - Worked Example 3

The power is relatively easy to calculate because power is only relevant for a particular instant in time. For example :-

At 50 μs, $P = \frac{V^2}{R} = \frac{2500^2}{10} = 625{,}000\text{W} = 625\text{kW}$

At 100 μs, $P = \frac{6000^2}{10} = 3600\text{kW}$

At 150 μs, $P = \frac{3500^2}{10} = 1225\text{kW}$

An energy calculation is more difficult than power. We cannot simply multiply the power by the length of time as we did before because the power does not stay constant. We do not know which value of power to multiply with which time.

What we must do is to divide the waveform up into a number of very small intervals, - that way we can assume the power is almost constant during each interval. We then work out the energy for each interval, and add them up to obtain the total energy. (This is basically what we did in Worked Example 2, except now we have to use many more intervals.)

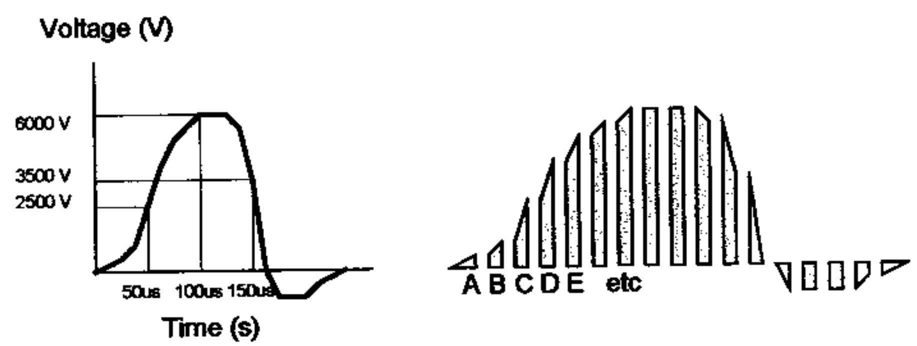

Figure 7 - Splitting up an Energy Calculation

This method becomes more accurate as the number of 'time slices' increases and the width of each interval gets smaller.

The proper method of doing this calculation is a mathematical technique called "integration". Our energy calculations would then be written this way :-

$$E = \int_0^T V(t) \,.\, I^2(t) \,.\, dt$$

Equation 5

where				
	E	=	energy	(joules, J)
	V (t)	=	voltage	(volts, V)
	I (t)	=	current	(amps, A)
	T	=	pulse duration	(seconds, s)

Obviously such a calculation is not simple.

The Energy of a Pulse

Another way of looking at the energy calculation of a pulse is to picture the pulse as a box. The height, depth and width of the "box" are the voltage, current and time of the pulse. The volume of the "box" is the energy. Admittedly this "box" has a rather strange shape (see Figure 8).

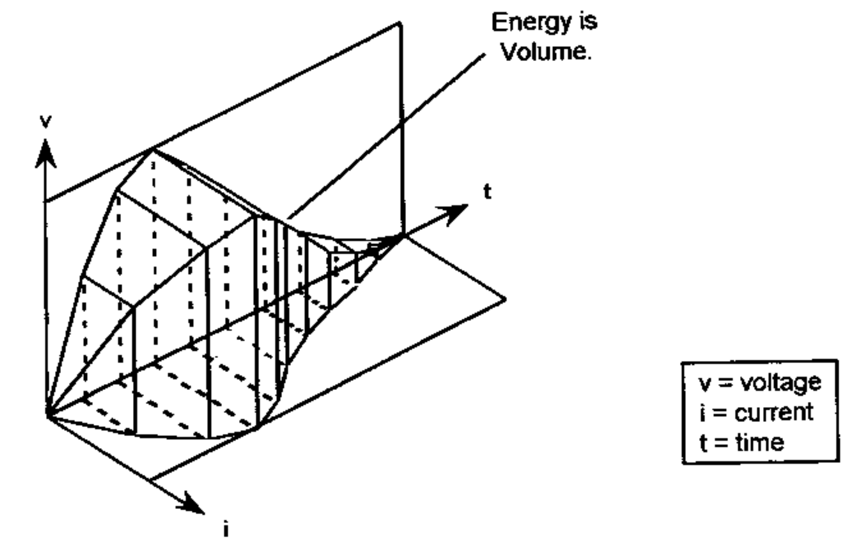

Figure 8. What is Energy ?.

Basically the more voltage, and the more current, and the longer they both exist, then the greater the energy.

4 Energy and Electric Fencing

So what does all this electrical theory mean to electric fencing ? Let's try and move away from the mathematics, and talk about something more real.

Stored Energy

The amount of energy stored in the main storage capacitor gives you the "size" of the energizer. It's a bit like the cc rating of an engine - it's the best starting point to compare two energizers as it's straightforward and does not depend on running conditions.

The Output Energy of an Energizer

One of the most important aspects of the pulse coming from an energizer is how much energy it has. This determines how much fence can be energised, and how big a shock can be delivered to animals touching the fence. (Contrary to widespread belief it is not voltage that gives the size of the shock.)

A very important question is how much stored energy (in the energizer) is transferred into output energy (in the fence pulses). This depends on the design of the energizer and the conditions in which it is operating. Some energy will always be lost no matter what.

Fences differ widely in the way they behave. As fences get longer or more overgrown they represent a heavier load and absorb more of the pulse's energy. If the energizer is well designed then this heavier fence load will draw greater energy out of the energizer.

Eventually however a point is reached when the energizer cannot provide more, and the output energy starts to fall away. The energizer then becomes over-extended.

This behaviour is demonstrated in the *Energy-Load Curve* of Figure 9.

Low Impedance energiser

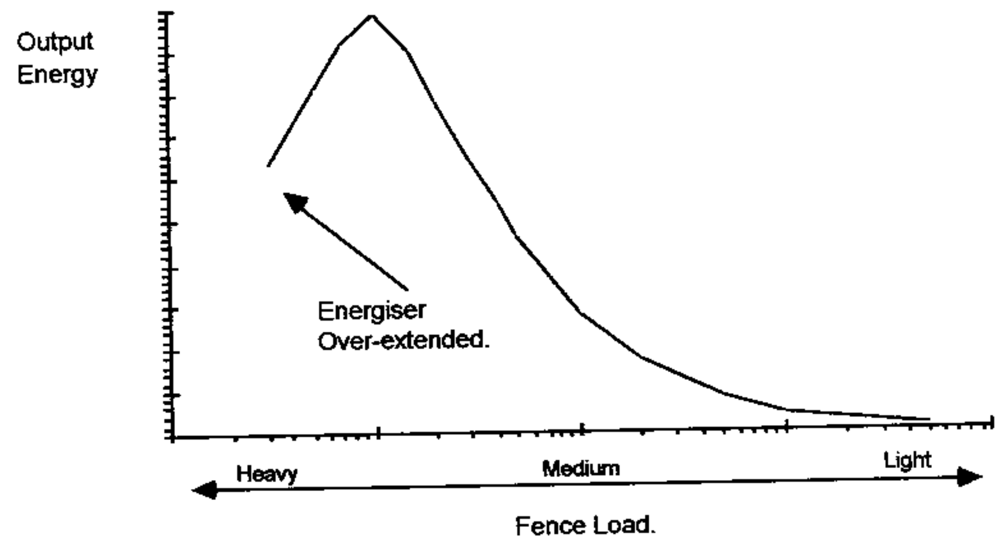

Figure 9. Output Energy versus Load.

"Shockability"

What really counts of course is the energy which an animal (or human) feels when touching the fence i.e. what is the fence's "shockability". Any farmer will tell you that as a fence becomes longer or much overgrown it gives less of a shock. The reason is simple, the fence and vegetation absorb more energy, and there is less remaining to shock the animal. See Figure 10.

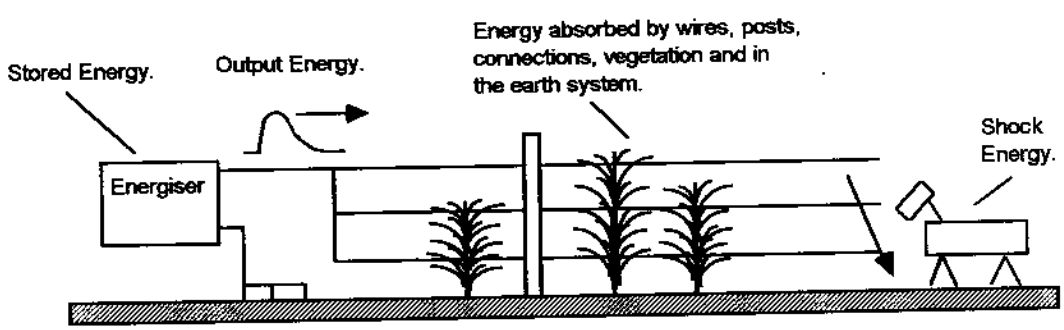

Figure 10. Where the Energy goes.

Now it may appear looking at the graph in Figure 9 that if a heavier fence load can lead to greater output energy then it may also lead to greater shock energy. This is not the case. If the fence is a heavier load (e.g. more overgrown) then most of the extra energy which the energizer delivers will be absorbed by the heavier fence load - meaning there will still be less remaining for the animal. What it does mean is that the shock energy will not fall as much as it would have if the energizer output were constant.

This ability to maintain "shockability" under imperfect fence conditions is what distinguishes the modern low-impedance energizer from its predecessors. The proper way to actually increase the shock energy of course is to improve the fence or use a better energizer.

5 Voltage and Electric Fencing

Peak Voltage

So if energy is so important then why is peak voltage so widely used?

Well, firstly it's much easier to measure. Hand-held meters which measure voltage have been available for some time and give a quick, accurate and reliable reading. In comparison energy is much more difficult to measure (as we have seen with our worked examples in Section 3).

Secondly (and more importantly) peak voltage readings are all that most people need to check the quality of a fence. The fence voltage drops as the fence load increases (as shown in the *Voltage-Load Curve* of Figure 11), and this behaviour can be used to determine if the fence is overextended.

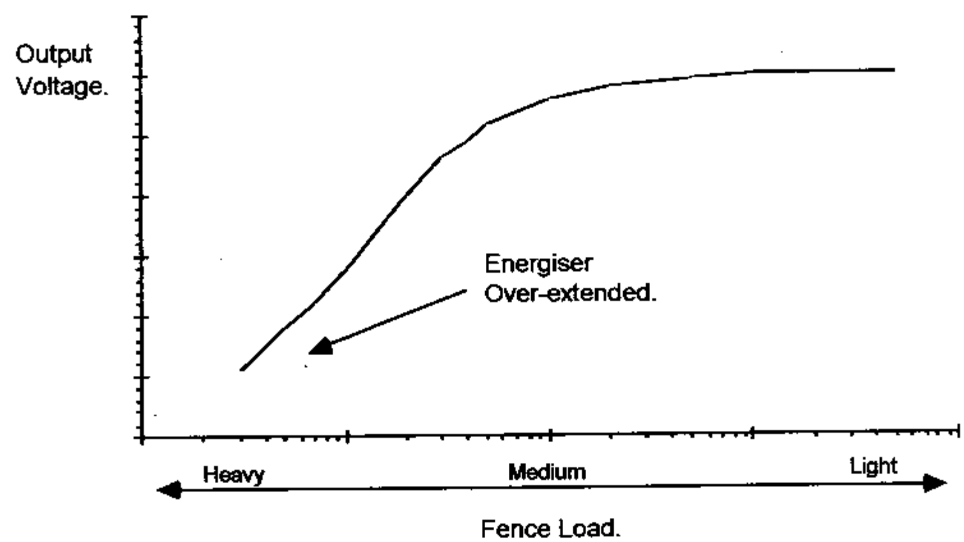

Figure 11. Output Voltage versus Load.

A good rule-of-thumb to follow is to always maintain at least 2-3 kV (2000-3000 V) on all parts of the fence (under worst conditions). It's an indirect indicator, but in most situations it works extremely well.

A Contradiction ?

If we compare Figures 9 and 11 then we see that is possible for the output-energy to go up as peak-output-voltage goes down.

This may seem strange but can be explained by referring back to our definition of energy. Voltage is only one of three sides to our "box" - we still have to consider both current and time.

Remember that it is the *volume* of the "box" which represents the energy.

The Limitations of Voltage Measurement

What peak voltage readings cannot be used for is comparing one fence with another (or one energizer with another). So if your neighbours have 6 kV on their fences don't feel that your fence is substandard because you only have 4 kV - chances are that your fence is just as good (and it may even be better).

To really check the quality of your fence you need a device which can measure the shock energy that an animal would feel if it had made contact with the fence. In other words directly measures the fence's "shockability". Such as device is called a Pulse Energy meter.

Pulse Energy meters are made by a small number of manufacturers (though they may give it a different name). They are not widely available because a good understanding of electric fence theory is required for them to be useful.

6 Energizer Technology

Energizer Efficiency

Energizer efficiency refers to how well an energizer makes use of the energy it has available.

One of the fundamental laws of the universe is that energy cannot be created or destroyed - energy can only be converted from one form to another. This is referred to in engineering and science as *The Law of Energy Conservation.*

For example, an electric heater converts electrical energy into heat energy, a solar panel converts solar energy into electrical energy, fire converts chemical energy (in the fuel) into heat energy, a motor converts chemical energy (in the fuel) into movement (or "kinetic") energy. Any time we want energy we must convert it from something else. In plain words - 'there ain't no such thing as a free lunch'.

For any energy process :-

$$E_{out} = E_{in} \qquad \text{Equation 6}$$

where E_{out} = energy out (Joules, J)
E_{in} = energy in (Joules, J)

However it is usually impossible to convert all the available energy into a form which is useful. For example a motor also produces energy in the form of heat, a fire also produces energy in the form of light, and so on. Such energy is not generally useful and we consider it lost.

This means that the *useful* energy we get out is less than the energy we have put in. It is convenient to talk about the efficiency of such a process. We can write the relationship this way :-

$$E_{out} = E_{in} * \eta \qquad \text{Equation 7}$$

where E_{out} = useful energy out (Joules, J)
E_{in} = energy in (Joules, J)
η = efficiency

Note that we cannot have an efficiency figure greater than 100% since that would mean getting more energy out than we have put in (which is impossible). In general an efficiency figure much less than 100% is the best that we can hope for.

Example

Let's look at how energy balance applies to a typical energizer.

There are two steps to consider :-

- Input Supply to Stored Energy
- Stored Energy to Output Energy

We can also evaluate the overall efficiency from Input Supply to Output Energy.

(a) Input Supply to Stored Energy

Consider an energizer which draws an average current of 200mA while connected to a 12 volt supply. It has a stored energy of 1.2 Joules and a pulse interval of 1.0 seconds.

Over one pulse interval period :-

$$E_{in} = V \times I \times t$$
$$= 12V \times 200mA \times 1.0s$$
$$= 2.4\ J$$

$$E_{out} = 1.2J$$

Therefore :-

$$\eta = \frac{E_{out}}{E_{in}}$$
$$= 50\%$$

This is the approximate efficiency we would expect.

(b) Stored Energy to Output Energy

Consider the same energizer also has a peak output energy of 0.96 J (into 100ohms).

$$E_{in} = 1.2\ J$$

$$E_{out} = 0.96\ J$$

Therefore :-

$$\eta = \frac{E_{out}}{E_{in}}$$
$$= 80\%$$

This is the approximate efficiency we would expect.

(c) Overall Efficiency

We can also calculate the overall efficiency of the energizer from input supply to peak output energy.

$$E_{in} = V \times I \times t$$
$$= 12V \times 200mA \times 1.0s$$
$$= 2.4\ J$$

$$E_{out} = 0.96\ J$$

Therefore :-

$$\eta = \frac{E_{out}}{E_{in}}$$
$$= 40\%$$

Again this is the approximate efficiency we would expect.

Note:

In practice it is often difficult to improve the efficiency of an energizer. If we want greater output energy then we need more energy from the power source. This is very important with battery-powered energizers because it will significantly shorten battery-life.

Careful consideration of battery life is needed when choosing the output energy of an energizer.

Switched-Output Energizers

A new generation of high powered energizers was developed in the late 1980s which had a switched output.

These energizers are able to recognise when they are becoming over-extended and essentially "change up a gear" by increasing their stored energy. (Some manufacturers refer to this as "turbo" mode.) This enables the energizer to remain effective under greater fence loads than it would normally. It also allows the energizer to remain efficiency since it does not use energy unless it really needs it. See Figure 12.

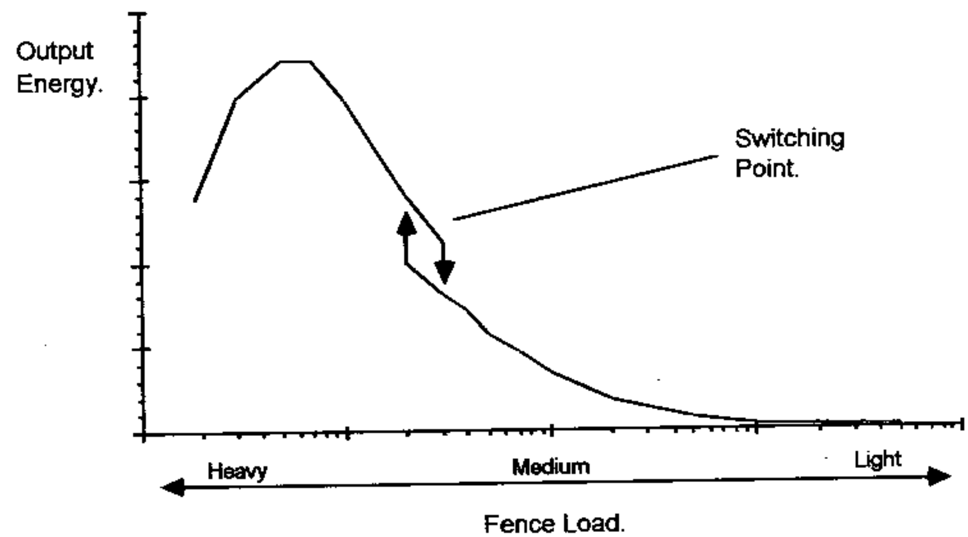

Figure 12. A Switched-Output Energizer.

Adaptive-Control Energizers

The latest generation of energizers using a technique called "Adaptive Control" began appearing in the mid-1990s.

Adaptive-control energizers are similar to switched-output energizers except they can vary very the stored energy to any level (not just between turbo and non-turbo modes). They are designed to provide the optimum amount of energy and voltage to the fence. A well designed adaptive-control energizer will produce an effective shock under all expected fence conditions.