

Chapter 2

Electrical Principles

Notes

Purpose and Description of this Chapter:

The topic is electrical circuit principles with application to electrofishing.

Goals:

- Familiarize students with electric circuit principles important to electrofishing equipment and operations.
- Provide a foundation for understanding electrical field theory.

Objectives

Correctly:

- State Ohm's Law and power equations;
- Simplify more complex circuit diagrams;
- Calculate current, voltage, and power in a circuit;
- State where maximum power transfer occurs;
- State second form of Ohm's Law and power equations;
- Describe the three principle wave forms.

Description:

This chapter incorporates a series of short narratives, problems and graphics. Graphics include series and parallel circuit schematics, electrical waveform graphics, Ohm's Law graphic, mine-conveyor belt-power plant illustration, power correction factor graphic, and boat electrofisher illustration.

CBT:

The CBT module I may be used in place of or as a supplement to this chapter.

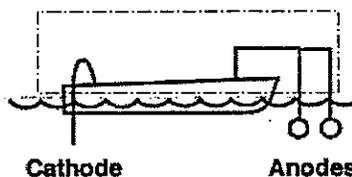
Introduction

In the electrical topics portion of the overall "Principles and Techniques of Electrofishing" course, we cover electricity in three phases.

Phase 1:

Electricity in circuits; electrons; circuit theory. Phase 1 deals with electrofishing equipment. Most of the understanding in electrofishing has been concentrated in this phase, that is, with the equipment. This also is the manufacturers primary area of concern.

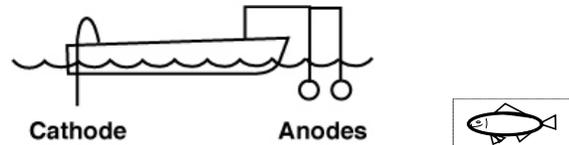
Figure 2.1
Phase 1



Phase 2:

Electricity in water; ions; electric field theory; power transfer theory. Little investigation or emphasis has been directed to Phase 2. Although characteristics of this phase are unknown in many electrofishing operations, knowledge of Phase 2 variables often is integral to successful electrofishing.

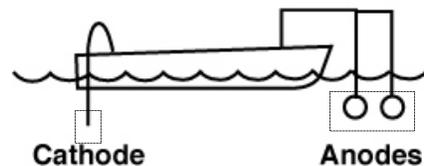
Figure 2.2
Phase 2



Phase 3:

Electricity at and near electrodes; ions and electrons; electrode resistance. From information in Phase 3, one can determine total power demand of the electrofishing system and allocation of available power among the electrodes. This knowledge, in turn, is important for equipment design—particularly electrode design.

Figure 2.3
Phase 3



A working knowledge of phases 1, 2, and 3 will assist you in attempts to

- 1) increase the efficiency and standardization of your electrofishing operations,
- 2) improve crew safety, and
- 3) minimize the potential for fish injury and stress.

Phase 1 electrical principles covers

- | | |
|--------------------------|----------------------------|
| A. Electric Field Theory | C. Electric Circuit Theory |
| B. Electrode Design | D. Field Mapping |

ANSWER: C





Equipment metering (e.g. volt and amp meters on your pulsator) is primarily meant for

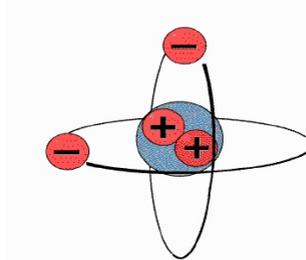
- A. Phase I
- B. Phase II
- C. Phase III
- D. None of the above

ANSWER: A

B. What is Electricity?

Matter consists of charged particles. Atoms contain proton(s) in a nucleus that is orbited by electron(s). Protons are positive charge carriers and electrons are negative charge carriers.

Figure 2.4
Atom Schematic



An important characteristic of charged particles is that like charges (electrons and electrons or protons and protons), repel each other. Unlike charges attract each other.

An ion is an atom or molecule that has acquired a net electric charge by either gaining or losing electrons. An ion may be positively charged or negatively charged.

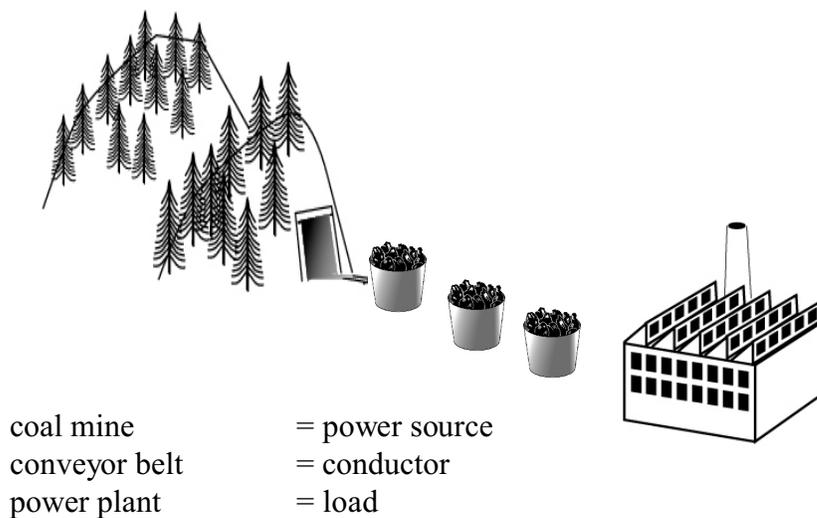


Electrons are the most important charge carriers in circuits whereas ions are the most important in water. Ions in fresh water include calcium, bicarbonate, sodium, magnesium, chloride, and sulfate.

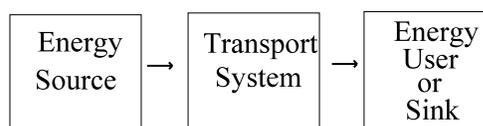
HOW A CIRCUIT WORKS

To illustrate how a circuit works, we will use a conveyor belt analogy. The conveyor belt moves energy (coal) at an invariant speed from the coal mine to the power plant.

Figure 2.4
Conveyor belt analogy of an electrical circuit



The analogous flow diagram is



If we consider that each bucket = electrical charge, then voltage may be defined as energy (coal) / bucket and current as buckets / unit time. By this analogy, an ammeter (instrument that measures current) would monitor buckets / unit time.

QUESTION:

How would you increase the energy per unit time delivered to the power plant?

- A. Increase the number of buckets
- B. Increase the amount of coal (energy) per bucket
- C. Increase the speed of the conveyor belt
- D. Both A & B

ANSWER: D



To increase the energy per unit time delivered to the power plant, you must increase the number of buckets and/or increase the amount of energy per bucket. From a circuit perspective, you are increasing the current and/or voltage. Also remember that the conveyor belt and charge carriers in a circuit move at an invariant speed. In the case of electricity, movement is at the speed of light.

We will use a flashlight to illustrate a simple circuit.

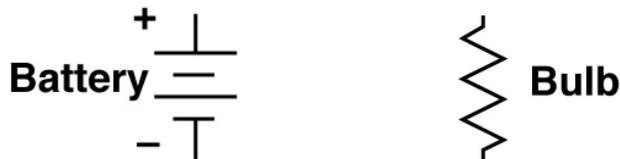


QUESTION:

What is the power source of a flashlight?

ANSWER: Battery

Figure 2.5
Battery and bulb circuit symbols



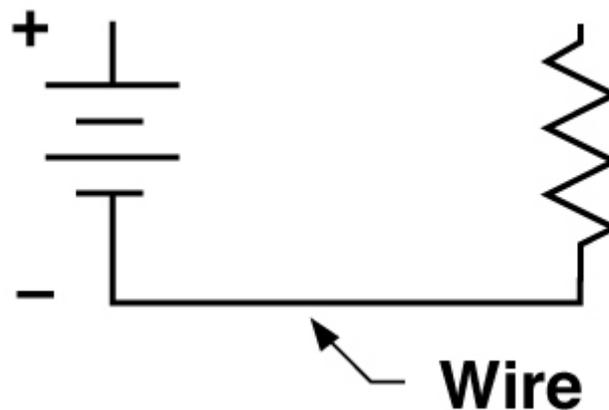
QUESTION:

What is the load?

ANSWER: Bulb or lamp

Figure 2.6
Partial flashlight circuit diagram

Wire connects the battery to the bulb



A switch is used to interrupt the circuit (on-off).

Figure 2.7
Complete flashlight circuit diagram

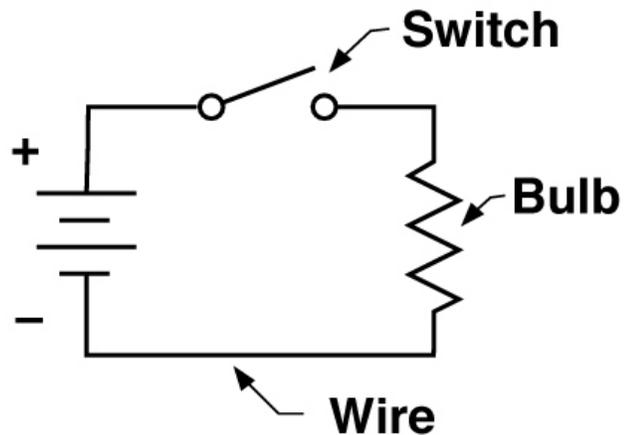


Figure 2.8
Electron flow theory

The primary charge carriers in a circuit are electrons. Electrons move from the cathode to the anode; this movement is known as electron flow theory.

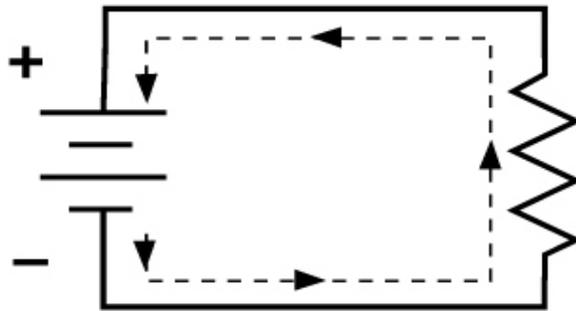
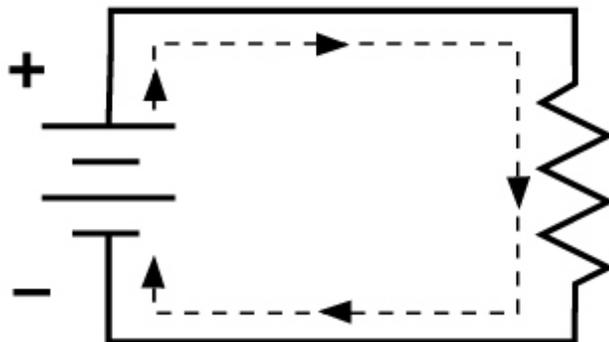


Figure 2.9
Conventional flow theory

Conventional flow theory considers protons as the primary charge carriers and that flow moves from anode to cathode.



Operationally, which flow model is followed does not matter. What does matter is consistency. For this module, we will use conventional flow theory.

Table 2.1
Basic Electrical Terms

The following table lists important electrical terms that you will use in this chapter.

| <u>Term</u> | <u>Definition</u> | <u>Symbol</u> | <u>Unit</u> |
|--------------------------|--------------------------------|---------------------|--------------------------------|
| electrical charge | Fundamental Property of Matter | Q | Coulomb |
| voltage | Energy / Charge | V or E | Volt |
| current | Charge / Time | I or i | Coulomb/sec (Ampere or Amp) |
| resistance | Electrical Friction | R or Ω | Ohm |
| conductance | Reciprocal of Resistance | G or $\bar{\Omega}$ | Mho or Siemen |
| power | Energy / Time | P | Watt |
| energy | Power \times Time | W | Watt-hour |

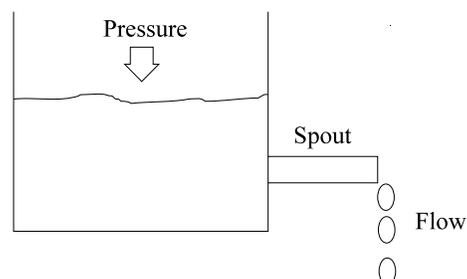
OHM'S LAW

$$\left| \text{Resistance (R)} = \text{Voltage (V)} / \text{Current (I)} \right|$$

This equation applies to circuits only.

Figure 2.10
Vessel of water analogy of
Ohm's Law

To help you visualize Ohm's Law, we will use an analogy with a vessel of water.



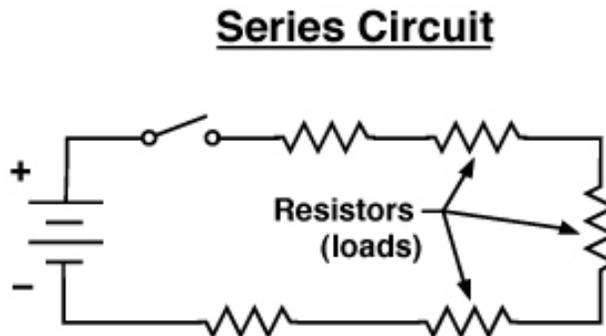
Pressure = voltage
Spout = resistance
Flow = current

For instance, if the spout is increased in length (cross-sectional area remains constant), resistance will increase. This increase in resistance will decrease the flow (current). To return the flow to the original level, pressure (voltage) must be increased. Hence, resistance and current are inversely related whereas resistance and voltage are directly related. Be aware about this analogy because voltage is not pressure, voltage is not a force. Voltage is energy \ charge.

C. Circuits and Their Characteristics

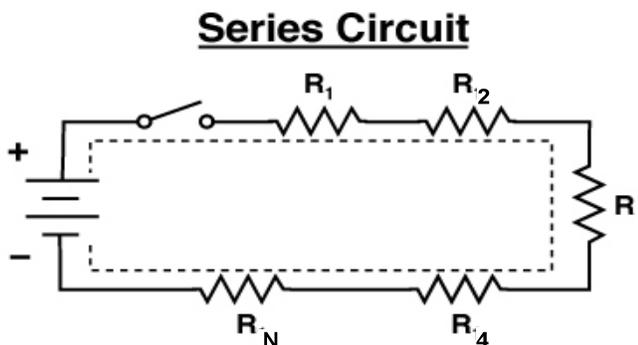
We will cover two types of circuits that are important in electrofishing equipment design, series and parallel.

Figure 2.11
Series Circuit Diagram



A series circuit is so named because the resistors (loads) are sequentially arranged (in a series). The current (charge carriers) from the energy source passes through each resistor in turn without branching.

Figure 2.12
Current flow through a series circuit



Hence, current is constant through each load. In contrast, voltage can be variable among resistors. The sum of voltages for the individual resistors must equal total voltage.

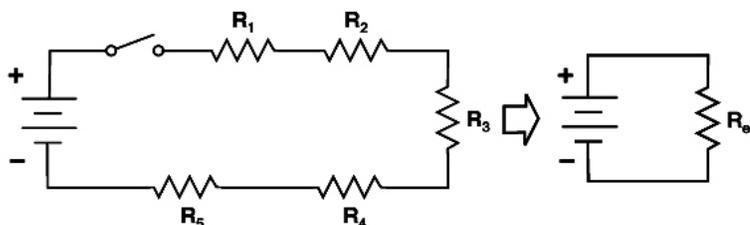
$$V_T = V_{R1} + V_{R2} + \dots + V_{RN}$$

Another characteristic of a series circuit is that each load can act like a switch. For example, old style Christmas tree lights are wired in a series circuit. If one bulb (load) burns out, it acts as an open switch and the current flow is stopped.

Whereas, each resistor (load) has some resistance value, the combined resistance value of all resistors in a circuit is termed equivalent resistance. Equivalent resistance for a series circuit is the sum of the individual resistors.

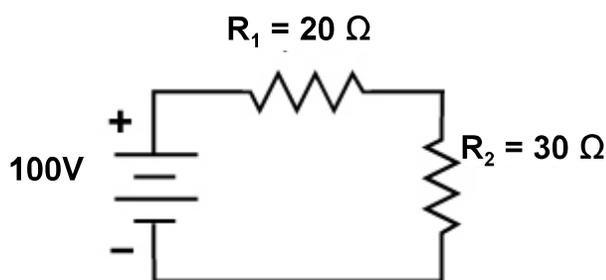
$$R_{eq} = R_1 + R_2 + \dots + R_N$$

Figure 2.13
Simplification of a series circuit by calculating R_{eq}



A series circuit has a 100 V power source with 2 resistors. Resistor R_1 is 20 ohms and resistor R_2 is 30 ohms.

Figure 2.14
Series circuit with two resistors



Determine the A) applied circuit voltage, B) circuit current, C) voltage dissipated at each resistor, and D) current passing through each resistor.

A) Determine circuit voltage. This may be accomplished by noting the power source output voltage or by connecting the volt-ohm meter across the power source.

ANSWER:

B) Determine total circuit current (I). Solve Ohm's Law: $R = V / I$ for I. Although you have information on the other two variables (R & V), the two resistor values must be reduced to one value to use the equation. Hence, you must determine R_{eq} .

1. Determine R_{eq} .

ANSWER:

Now you have the equivalent resistance value and the circuit voltage.

2. Solve for circuit current.

ANSWER:

C) Determine voltage dissipated across each resistor. Use Ohm's law.

1. Determine resistor voltages

ANSWER:

2. What is the sum of the resistors voltage?

ANSWER:

3. What circuit variable is this value equal to?

ANSWER:

D) Determine current through each resistor. Use Ohm's law.
(Remember, you have voltage and resistance values for each resistor).

ANSWER:

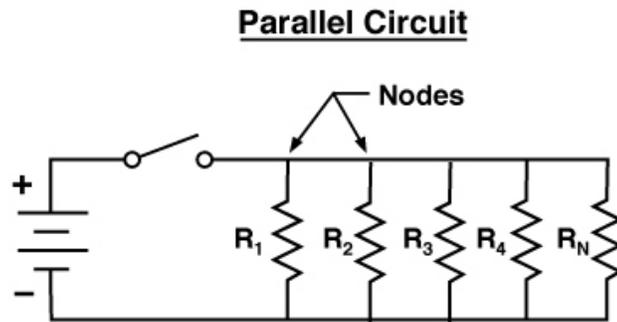
Note that current is constant whereas voltage is different between resistors. When would voltage between the resistors (loads) be the same in a series circuit?



ANSWER: When the resistor (load) resistances are equal

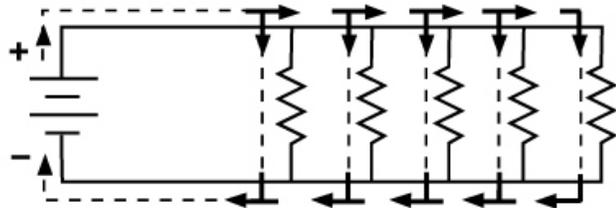
PARALLEL CIRCUIT

Figure 2.15
Parallel Circuit Diagram



A parallel circuit has resistors on different branches. Resistors are not wired sequentially. Thus, current from an energy source must split when coming to a junction of two branches.

Figure 2.16
Current flow through a parallel circuit



Hence, current through resistors in a parallel circuit can be different. (Current through loads will be different if the load resistances are different). Sum of current for all the individual resistors must equal total circuit current. Conversely, voltage across loads are equal. Each load in parallel has the same voltage drop.

Another characteristic of a parallel circuit is that interruption at one load does not disconnect the remaining loads. This aspect along with equal voltage among loads is why parallel circuits are used in buildings and electrical projects.

As with series circuits, you can convert the individual load resistances into a single circuit resistance or equivalent resistance. The formula, however, is different for a parallel circuit:

$$R_{eq} = 1 / [(1 / R_1) + (1 / R_2) + \dots + (1 / R_N)]$$

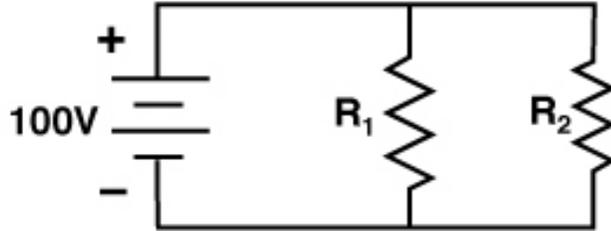
or, if the circuit contains only two resistors:

$$R_{eq} = (R_1 \times R_2) / (R_1 + R_2)$$



A parallel circuit has a 100 V power supply with two resistors (loads). Resistor R_1 is 20 ohms and resistor R_2 is 30 ohms.

Figure 2.17
Parallel circuit with two resistors



Determine the A) total circuit voltage, B) total circuit current, C) current for each resistor (load), and D) applied voltage for each resistor.

- A) Determine circuit total voltage. This may be accomplished by noting the power supply voltage or by connecting a volt-ohm meter across the power supply.

ANSWER:

- B) Determine total circuit current (I). Solve Ohm's Law: $R = V / I$ for I. Although you have information on the other two variables R & V), the two resistor values must be reduced to one value to use the equation. Hence, you must determine R_{eq} . (Remember to use a different formula to determine R_{eq} in a parallel circuit).

1. Determine R_{eq}

ANSWER:

Now you have a circuit resistance value and a circuit voltage value.

2. Solve for circuit total current.

ANSWER:

C)

1. Determine resistor currents

ANSWER:

2. What is the sum of the resistor currents?

ANSWER:

3. What circuit variable is this value equal to?

ANSWER:

- D) Determine voltage dissipated across each resistor. Use Ohm's Law.
(Remember, you have current and resistance values for each resistor).

ANSWER:



Note that currents are different but the voltage is constant for the resistors.



When would current between the resistors be the same in a parallel circuit?

ANSWER: When the load resistances are equal

Table 2.2
Summary of answers from
problems 1 and 2

The following table lists answers from problems 1 and 2

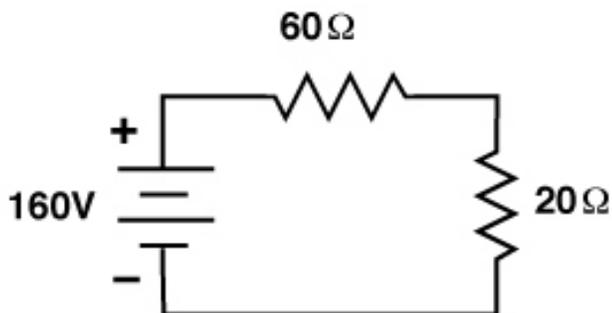
| | <u>Series circuit</u> | <u>Parallel circuit</u> |
|-----------------------|-----------------------|-------------------------|
| Circuit total voltage | 100 V | 100 V |
| Circuit total current | 2 A | 8.3 A |
| Equivalent resistance | 50 Ω | 12 Ω |
| Resistor 1 voltage | 40 V | 100 V |
| Resistor 2 voltage | 60 V | 100 V |
| Resistor 1 current | 2 A | 5 A |
| Resistor 2 current | 2 A | 3.3 A |

The following six problems (numbers 3-8) illustrate circuit principles as applied to electrofishing equipment.



You are electrofishing with one anode and one cathode. The applied voltage is 160 V DC and the anode measures 60 ohms while the cathode measures 20 ohms. Calculate A) equivalent resistance and B) current. Use Ohm's Law.

Figure 2.18
Electrofishing gear series circuit



A) Calculate equivalent resistance

ANSWER:

B) Calculate circuit current

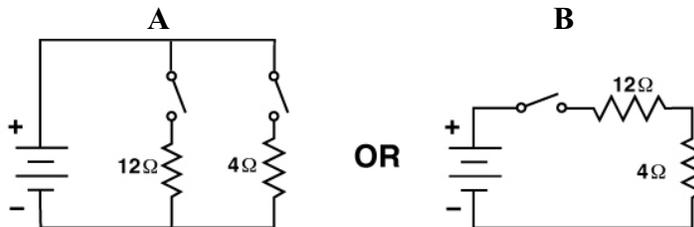
ANSWER:



An electrofishing boat has a 12 volt DC spotlight with a resistance of 4 ohms and a running light with a resistance of 12 ohms. A) Choose the proper circuit diagram, B) calculate equivalent resistance and C) circuit current. Compare equivalent resistance to individual resistances. Finally, determine D) current through the spotlight and running light.

A) choose the proper circuit diagram:

Figure 2.19
Electrofishing boat lights circuit diagram



ANSWER:

B) Calculate the equivalent resistance.

ANSWER:

C) Calculate circuit current

ANSWER:



Which is the smallest, equivalent resistance, spotlight resistance, or running light resistance.

ANSWER: Equivalent resistance



The equivalent resistance is always less than any of the individual resistances making up the parallel circuit.

D) Determine spotlight and running light current.

1. How much current is in the spotlight?

ANSWER: 3 amp

2. How much current is in the running light?

ANSWER: 1 amps

3. What is the total spotlight and running light current?

ANSWER: $3 + 1 = 4$ amps

4. Is the sum of spotlight and running light current equal to total circuit current? (yes, no)

ANSWER: Yes

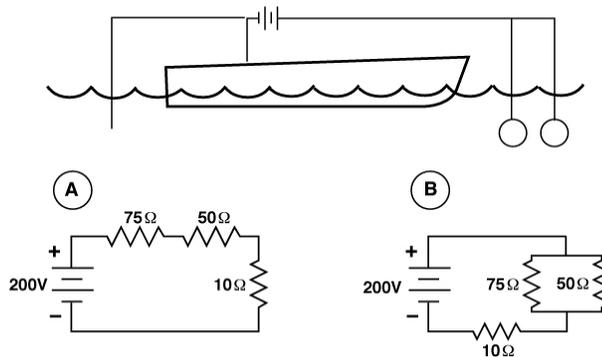
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An electrofishing boat is using two anodes and one cathode. The anodes have resistances of 75 and 50 ohms. The cathode resistance is 10 ohms. Choose the A) correct circuit diagram and B) calculate the circuit current from a 200 V DC generator.

Figure 2.20
Electrofishing boat
circuit diagram
alternatives

A) Choose the correct circuit diagram.

Choose the correct circuit diagram



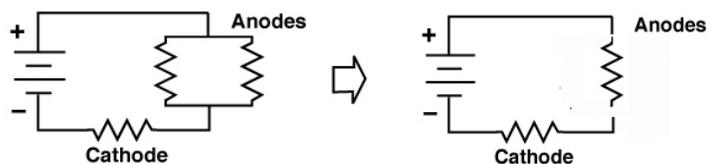
ANSWER:

B) Calculate circuit current

1. First, calculate R_{eq} for the anode

ANSWER:

This changes the circuit from:



2. Now calculate R_{eq} for the entire circuit.

ANSWER:

3. Calculate circuit total current.

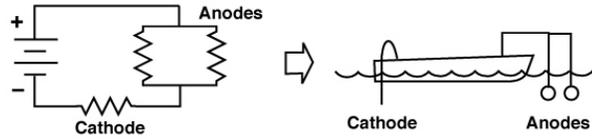
ANSWER:

Figure 2.21
Simplification of parallel
circuit by calculating R_{eq}

The circuit diagram for problem 5 describes this boat setup:

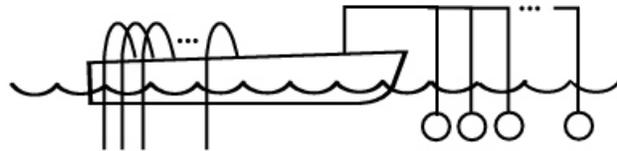
Figure 2.22 a, b, c
Electrofishing boat circuit diagrams

a.



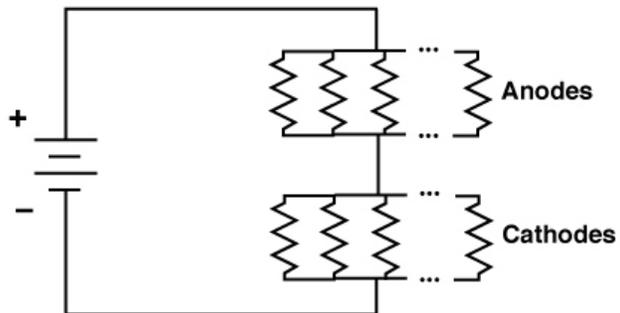
A boat with this electrode array:

b.



Would have a circuit diagram like this (draw a diagram first on paper, then compare with what is shown next).

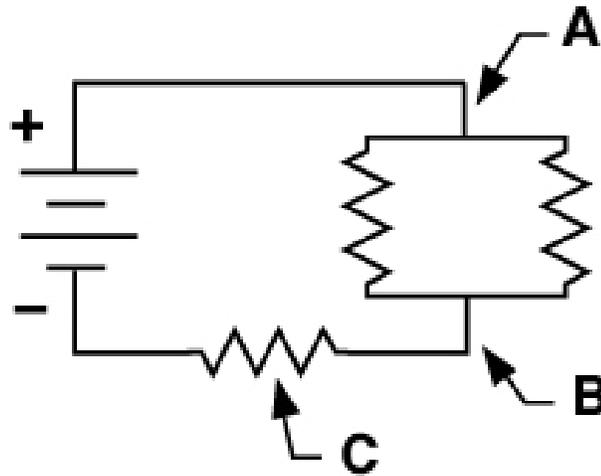
c.





Where on the following boat circuit diagram (2 anodes, 1 cathode), is the in-water electrical connection?

Figure 2.23
Electrofishing boat circuit diagram including in-water electrical connection



ANSWER: B



Circuit diagrams of electrofishing boats are not complicated.

POWER

Power is another term in the basic electrical terms table:

| <u>Term</u> | <u>Definition</u> | <u>Symbol</u> | <u>Unit</u> |
|--------------|-------------------|---------------|-------------|
| Power | Energy / time | P | Watt |

Power is calculated by Joule's Law (3 variants)

$$P = (I)^2 \times R$$

or

$$P = V \times I \quad P = (V)^2 / R$$

Although the watt is the commonly used unit for power, conversion to other units (as horsepower) is easily done. (746 watts = one horsepower)

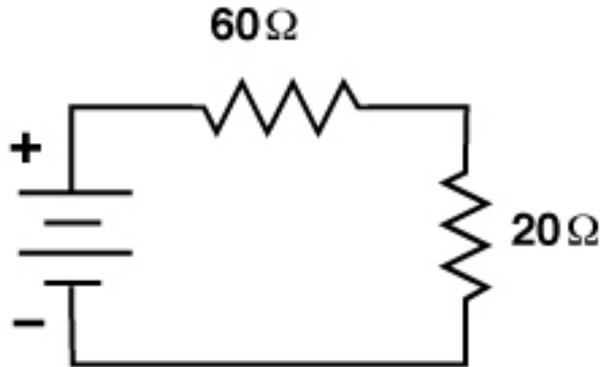
 6

Solve problem 3 for power. In that problem you determined that:

$$\begin{aligned} R_{eq} &= 80 \Omega \\ I &= 2 \text{ amps} \end{aligned}$$

Applied voltage was 160V

Figure 2.24
Series circuit with two resistors



ANSWER: (Calculate using all 3 forms of the power equation)

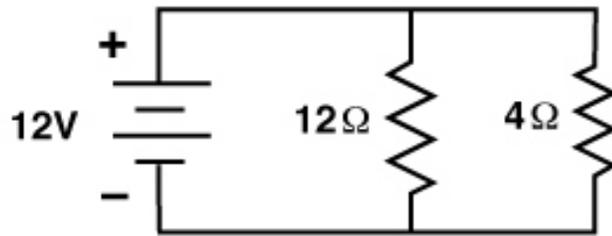
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Solve A) problem 4 on pages 2-16 & -17 for power and B) calculate power dissipated at the spotlight and at the running light. In that problem you determined that

$$\begin{aligned} R_{eq} &= 3 \Omega & R_{spotlight} &= 4 \Omega \\ I_{circuit} &= 4 \text{ amps} & R_{running \text{ light}} &= 12 \Omega \\ & & I_{spotlight} &= 3 \text{ amps} \\ & & I_{running \text{ light}} &= 1 \text{ amp} \end{aligned}$$

Applied voltage was 12V.

Figure 2.25
Parallel circuit with two
resistors



A) Solve problem 4 for power

ANSWER:

B) Which takes the greater power, the spotlight or the running light?

ANSWER:

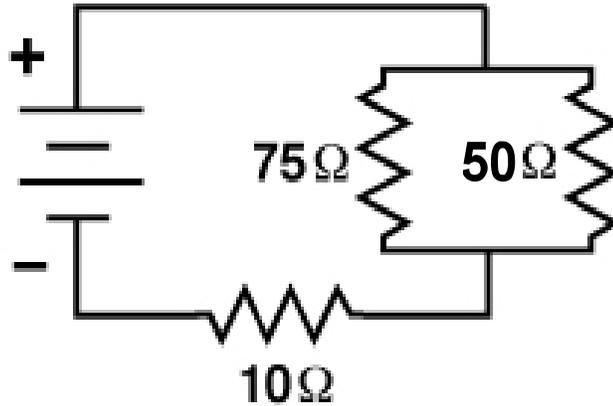
$$P_{\text{spotlight}} = (I_{\text{spotlight}})^2 \times R_{\text{spotlight}} =$$
$$P_{\text{running light}} = (I_{\text{running light}})^2 \times R_{\text{running light}} =$$



Solve A) problem 5 for power and B) convert your answer to horsepower.

In that problem you determined that circuit $R_{eq} = 40 \Omega$ and that circuit total current = 5 amps.

Figure 2.26
A combined series and parallel circuit diagram



A) Solve problem 5 for power

ANSWER:

B) Convert your answer to horsepower
(746 watts = one horsepower)

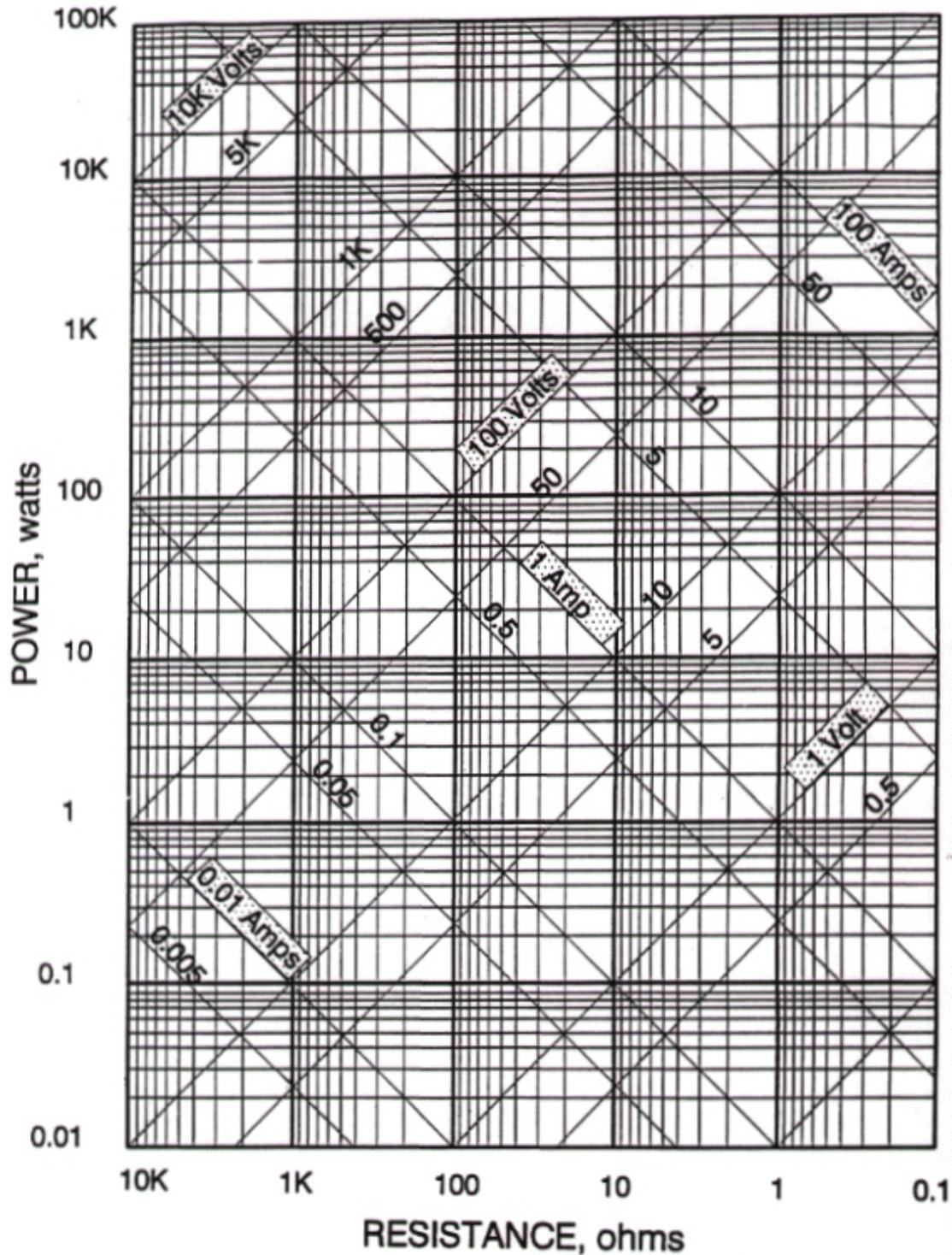
ANSWER:

Horsepower =

At this time it is appropriate to introduce the graphic form of Ohm's/Joule's Law (Figure 2.27):

Figure 2.27

Graphic Form of Ohm's/Joule's Law



This graph can be used instead of the equations to solve for power or to solve for another unknown variable (R, V, or I). There are 4 axes. Please note that all axes are logarithmic.

The X axis is resistance starting at 10,000 Ω on the origin and decreasing as you move right to 0.1 Ω .

The Y axis is Power, starting at 0.01 watts at the origin and increasing to 100,000 watts at the top of the axis.

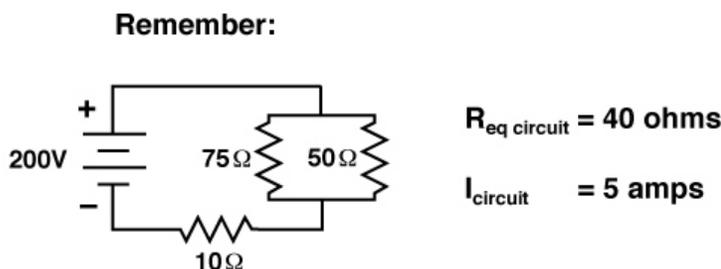
The voltage axis increases logarithmically from bottom right (0.1 V) to upper left (10,000 V).

The current axis increases logarithmically from bottom left (0.005 amps) to upper right (100 amps).

The usefulness of this graph is not so much a replacement for the Ohm's Law or Joule's Law equations but as a template to understand and use the *Power Transfer Theory of Electrofishing* that will be discussed later.

To better understand how to use this graph, we will take the original information from problem 5 and solve for power using the graph.

Figure 2.28
A combined series and parallel circuit diagram

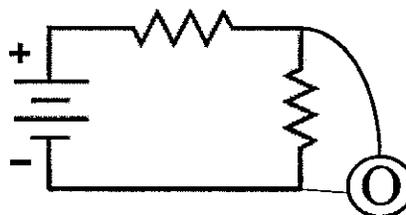


First, find 40 ohms on the X-axis. Follow that 40 Ω line up to the point where it intersects the 5 amp line. Move horizontally across to the Power (Y) axis. Read the result in watts. You should be at $P=(5)^2 \times 40 = 1000$ watts. If you interpolate the voltage, it will be at 200 volts.

IV. WAVEFORMS

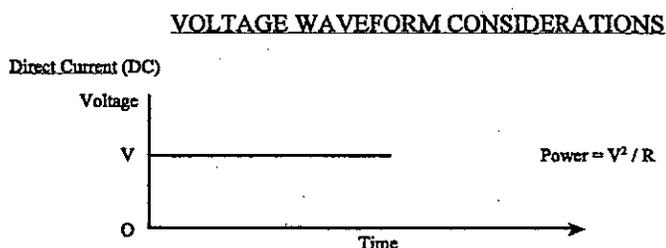
This session demonstrates waveforms by graphing voltage. Current patterns for a particular waveform are the same shape as the voltage pattern. **Continuous DC (=DC)** is the simplest category that we are concerned with in electrofishing.

Figure 2.29a
Oscilloscope attached
across a resistor in a series
circuit



An oscilloscope has been attached to read voltage across the cathodic resistor in the series circuit above. Figure 2.29b illustrates the results of a continuous DC source.

Figure 2.29b
Continuous direct current
readout on an oscilloscope



When DC is initiated, a voltage level is attained and maintained through time (until termination of power). Theoretically, the waveform is a constant level--no undulations or modulations.

Characteristics of DC

Voltage: average voltage = maximum (= peak) voltage

Current: average current = maximum (= peak) current

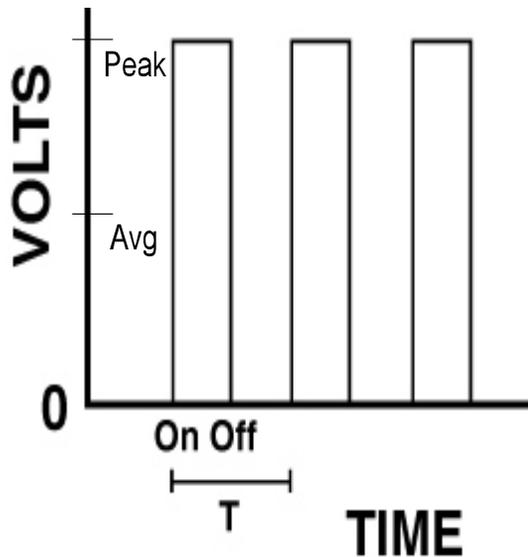
Power: average power = maximum (= peak) power

$$P = (V)^2 / R = I \times V = (I)^2 \times R$$

PULSED DC

Pulsed DC (PDC) is formed by regular interruptions of continuous DC. As you will see, there are many variations (=waveforms) of PDC.

Figure 2.30
Pulsed direct current
readout on an oscilloscope



PDC is a series of on-off cycles. There are many descriptive terms for naming the various parts and parameters of a PDC waveform: period, pulse width, duty cycle, frequency, average voltage, peak voltage, average power, and peak power.

Pulse: That part of the repetitive waveform during which voltage is present.

Period (T): The time from the start of one pulse to the start of the next pulse.

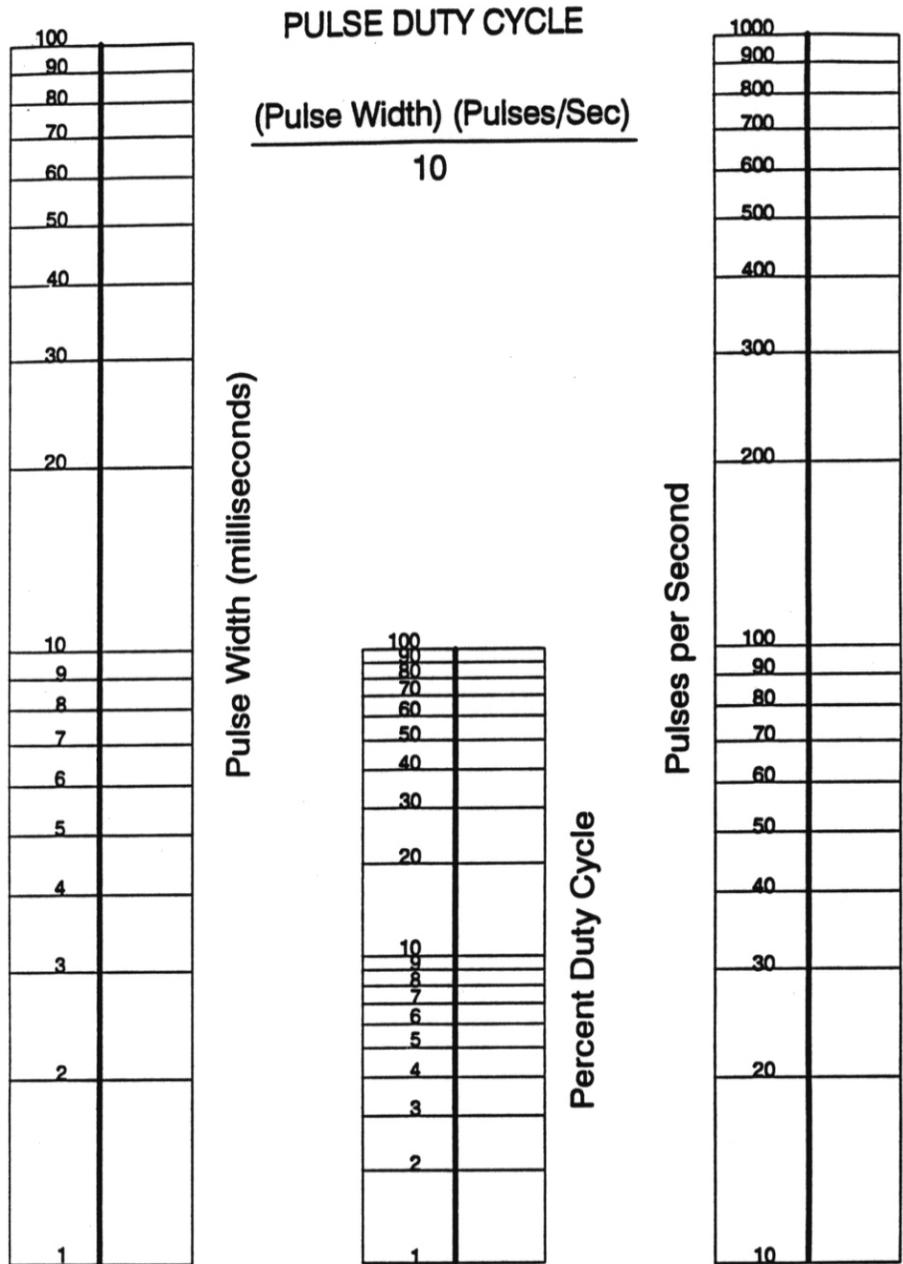
Pulse width (PW): The time duration when the pulse is present.

Duty cycle: The ratio of "on" time (PW) to period time (T) expressed as a percentage.

$$\text{Duty cycle} = (\text{PW} / \text{T}) \times 100$$

A nomograph (Figure 2.31) can be used to calculate pulse width, frequency and duty cycle by knowing any two of the three.

Figure 2.31
Pulse Duty Cycle



Frequency or pulse rate (f):

the number of pulses or cycles per second (Hertz).

$f = 1 / T = \text{Hertz}$ (1 Hertz = 1 pulse / second)
when T is period in seconds

$f = (1/T \times 1,000)$ when T is period in milliseconds

Voltage:

peak voltage is the maximum voltage of a pulse. Average voltage depends upon peak voltage and duty cycle. (Note: this is true only for square pulses).

$$V_{ave} = V_p \times \text{Duty cycle}$$

As Duty cycle increases, V_{ave} nears V_p .



If you increased duty cycle to 100%, what waveform would result?

ANSWER: Continuous DC

Current:

when graphing current instead of voltage, peak current is the maximum measured. Average current depends upon peak current and Duty cycle (again, for square waveforms).

$$I_{ave} = I_p \times \text{Duty cycle}$$

As Duty cycle increases, I_{ave} nears I_p .

Power:

calculation of peak power uses peak voltage times peak current.

$$P_p = V_p \times I_p$$

Average power is calculated by:

$$P_{ave} = V_p \times I_{ave} \quad \text{or} \quad P_{ave} = V_{ave} \times I_p \quad \text{or}$$

$$P_{ave} = (V_{ave} \times I_{ave}) / \text{Duty cycle} \quad \text{or}$$

$$P_{ave} = P_p \times \text{Duty cycle}$$

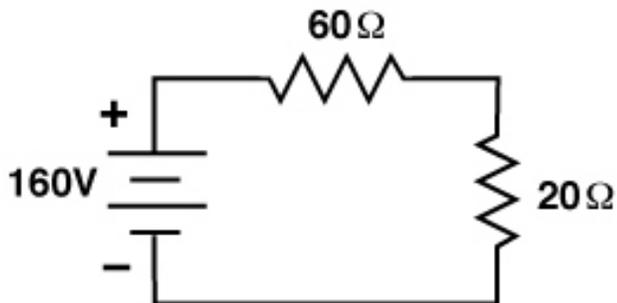


Pulsed DC was developed to conserve power. As you lower the Duty cycle, you reduce total power requirements. This permits the use of smaller power source units for battery operated backpack shockers.



You are electrofishing with one anode and one cathode. The applied voltage is 160 V DC. The anode measures 60 ohms resistance and the cathode has 20 ohms resistance.

Figure 2.32
Electrofishing gear series circuit



From previous calculations in problem 3, you found that the circuit equivalent resistance was $R_{eq} = 80$ ohms and the circuit current was $I = 2$ amps. You further determined that the DC Power = $(I)^2 \times R = (2)^2 \times 80 = 320$ watts. (Remember, for DC powered circuits, the peak and average power are the same).

Now, you start pulsing the DC waveform. You set the pulsator controls to give you a PDC waveform having a 5 millisecond (ms) pulse width and a frequency of 50 pulses / second (pps or Hertz).

Calculate A) duty cycle, B) average voltage, and C) average power requirement of this setting.

A) Calculate the Duty cycle of this setting.

ANSWER: PW =

f =

Duty cycle =

B) Calculate the average voltage.

ANSWER: $V_{ave} =$

C) Calculate the average power requirement.

ANSWER: PDC $P_{ave} =$

PDC $P_{ave} =$

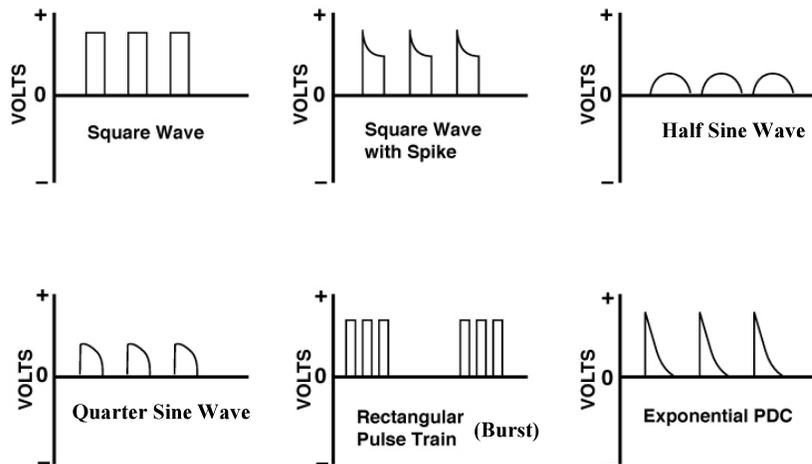


Experimental evidence supports the premise that fish respond more to peak voltage than to average voltage. Many voltmeters on electrofishing equipment, however, only measure average voltages.



There are many kinds of pulsed DC. Depending upon the equipment components, the classical square pulse shape demonstrated previously may or may not be generated. In addition, increasing the load (i.e., increasing the power requirements) often causes the pulse to change shape.

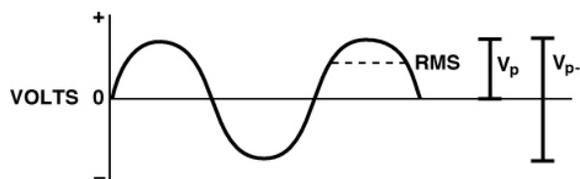
Figure 2.33
Examples of pulsed DC
waveforms



ALTERNATING CURRENT

Alternating current (AC) is another waveform category that is important to electrofishing. AC is the familiar waveform commonly used for powering buildings and many appliances.

Figure 2.34
Alternating current
readout on an oscilloscope



The basic waveform is a sine wave that 1) increases from zero volts to a positive voltage maximum, 2) decreases to a maximum negative voltage, and 3) increases back to zero voltage. This results in the electrodes reversing polarity at the frequency of the generator. That is, the anode and cathode is continually being reversed.

Characteristics of Sinusoidal AC

Voltage: peak voltage can be measured in either direction (+ or -). Peak voltage is the maximum positive or negative voltage excursion of the sine wave.

Peak-to-peak voltage measures the full voltage excursion.
 $V_{p-p} = \text{maximum positive voltage} + | \text{maximum negative voltage} |$

Average AC voltage is zero: $[(\text{maximum } V_{p+}) + (\text{maximum } V_{p-})] / 2 = 0 \text{ volts} / 2 = 0 \text{ volts}$. Therefore, RMS voltage is used. RMS stands for root mean square and it is $(0.707) \times | V_p |$. RMS voltage is the voltage used to calculate AC power.

$$V_p = V_{rms} / 0.707 \qquad I_p = I_{rms} / 0.707$$

$$V_{p-p} = 2 \times V_p \qquad I_{p-p} = 2 \times I_p$$

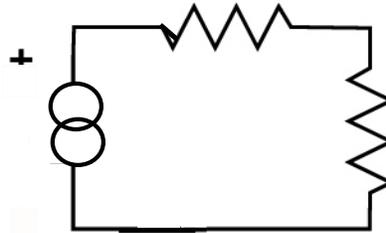
$$AC \text{ Power}_{rms} = (V_{rms})^2 / R = (I_{rms})^2 \times R = V_{rms} \times I_{rms}$$

$$AC \text{ Power}_{peak} = (V_p)^2 / R = (I_p)^2 \times R = V_p \times I_p$$



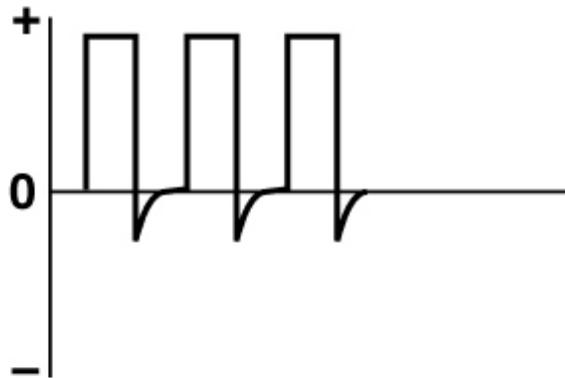
Most AC voltmeters read RMS voltage. They typically do not measure a peak voltage.

Figure 2.35
Series circuit with an AC
power source



Note: In this schematic, the power source is denoted by overlapping rings instead of stacked lines. Overlapping rings represent an AC power source as a generator.

Figure 2.36
What waveform category
is this readout



The above waveform has negative voltage excursions. What category of waveform is it?

- A. DC
- B. PDC
- C. AC
- D. None of the above

Answer: C

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You are electrofishing with 60 Hz AC. The pulsator voltmeter reads 120 V_{rms} .

A) Calculate V_p .

ANSWER: $V_p =$

B) Calculate V_{p-p} .

ANSWER: $V_{p-p} =$

C) Calculate the period.

ANSWER: 60 HZ =

$T =$

 11

A research study is designed to compare capture efficiencies of two waveforms, AC and PDC. The voltages used are AC $V_{rms} = 100$ volts and PDC $V_{ave} = 100$ volts (with a 50% Duty cycle). A) Is the strict AC and PDC comparison valid? B) Why or why not?

A) Is the strict AC and PDC comparison valid?

ANSWER:

B) Why or why not?

1. Calculate DC V_p .

ANSWER: $V_p =$

2. Calculate AC V_{p-p}

ANSWER: $V_p =$
 $V_{p-p} =$

3. Compare voltages.

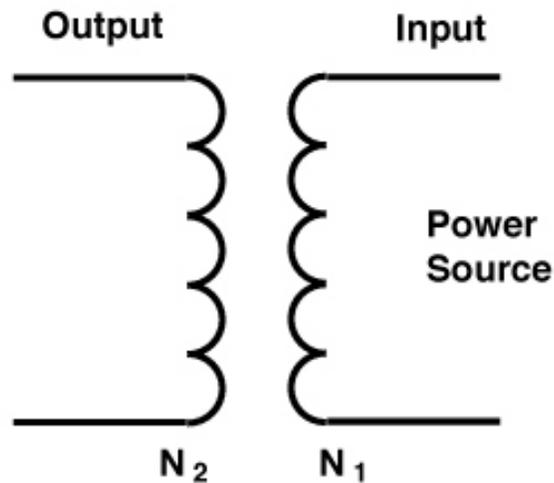
ANSWER:

TRANSFORMERS

Transformers can increase or decrease the voltage of the power source (step-up or step-down). The input current must be a changing current (AC or PDC). Continuous DC will not work and will destroy the transformer.

The ratio of input voltage to output voltage equals the ratio of the number of turns on each winding of the transformer.

Figure 2.37
Transformer circuit
diagram



$$V_2 / V_1 = N_2 / N_1$$

- $V_1 =$ input voltage
- $V_2 =$ output voltage
- $N_1 =$ number of turns on input winding
- $N_2 =$ number of turns on output winding

The relationship for current is the inverse of that for voltage:

$$I_2 / I_1 = N_1 / N_2$$

- $I_1 =$ input current
- $I_2 =$ output current
- $N_1 =$ number of turns on input winding
- $N_2 =$ number of turns on output winding

An important outcome of the voltage and current relationships is that power in = power out for any transformer. Transformers are 98 - 99% efficient in transferring power.

 12

The power source on your boat electrofisher is supplying 240 V_{rms} and 10 RMS amps to the input of your control box. The transformer windings have $N_1 = 10$ and $N_2 = 20$ (note: a transformer usually has many more turns). What are the A) input AC power, B) output RMS voltage C) output RMS amps, and the D) output AC power?

A) Calculate input AC power.

ANSWER: $P_{ave} =$

B) Calculate output RMS voltage (remember $V_2 / V_1 = N_2 / N_1$).

ANSWER: $V_2 =$

C) Calculate output RMS current (remember $I_2 / I_1 = N_1 / N_2$).

ANSWER: $I_2 =$

D) Calculate the output AC power.

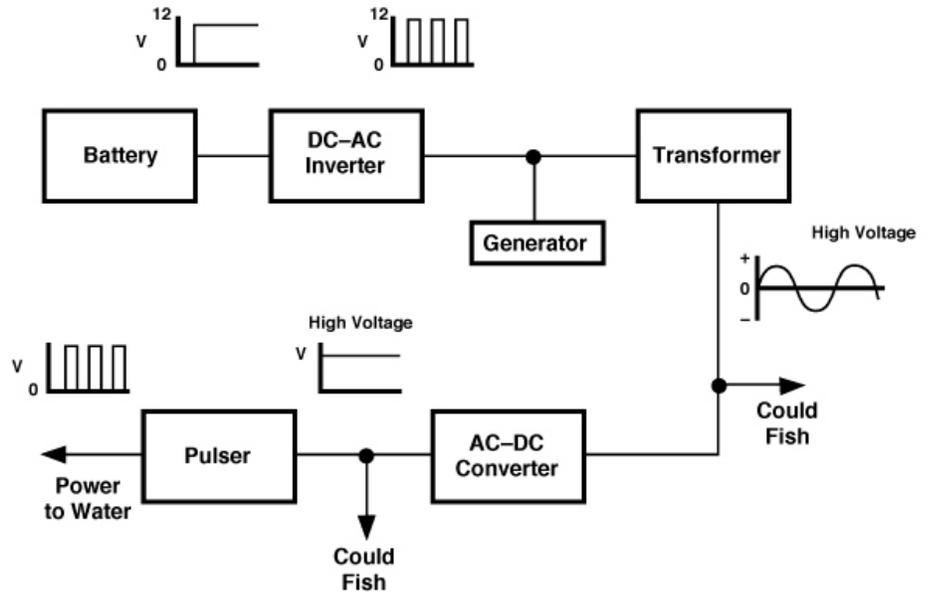
ANSWER: $P_{ave} =$

Thus, input power (2400 watts) = output power (2400 watts). Output voltage was doubled but output current was reduced by one half.



Most meters measure circuit characteristics at the power source. The readings obtained from these meters are valid for calculating power because transformers are 99% efficient (i.e., power in = power out).

VI. Components Of an Electrofishing System
Figure 2.38



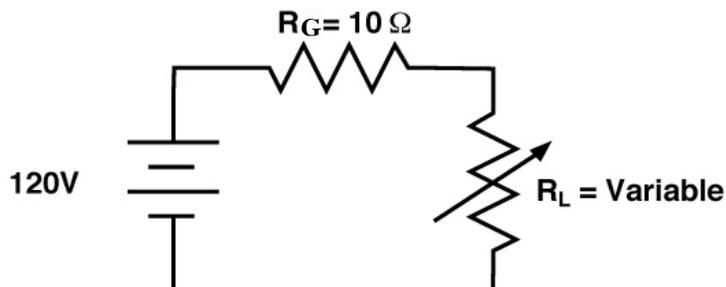
Note that if the power source is a generator, only the transformer, AC-DC converter, and pulser are needed for PDC electrofishing. PDC requires pulser, making this system the most expensive.

VII. MAXIMUM POWER TRANSFER (MPT)

Maximum power transfer (MPT) is the key to much of the unexplained variability in electrofishing. MPT is a founding principle of the Power Transfer Theory of Electrofishing. We now will develop this principle with you.

Firstly, all circuits have internal power loss. This loss can be represented by a resistor. Let's assume a circuit with a 120 V energy source, an internal resistance (R_G) of 10 ohms, and a load with variable resistance (R_L).

Figure 2.39
Series circuit with a variable load



We will change the load resistance value (range 0Ω to $\infty \Omega$) Each time the resistance value is changed, record circuit current (I) and voltage on the load (V_L). Then calculate power to the load (P_L).

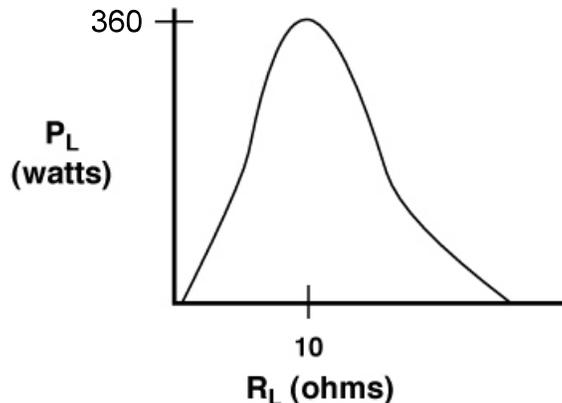
Attempt to fill out current, P_L , and V_L values for at least one load resistance value.

Table 2.3
Results of electrical
measurements on a series
circuit with a variable load

| R_L | $I = V / (10 + R_L)$ | $P_L = I \times V_L$ | |
|----------|----------------------|----------------------|----------------------|
| | | $P_L = (I)^2 R_L$ | $V_L = I \times R_L$ |
| 0 | 12 | 0 | 0 |
| 5 | 8 | 320 | 40 |
| 10 | 6 | 360 | 60 |
| 14 | 5 | 350 | 70 |
| 20 | 4 | 320 | 80 |
| 50 | 2 | 200 | 100 |
| ∞ | 0 | 0 | 120 |

Figure 2.40
Plot of power to the load
as a function of load
resistance

We can plot the results as follows:



From the table and the graph, you will find that maximum power is transferred to the load (MPT) when load resistance is equal to the internal circuit resistance. Note that current or voltage alone is not an indicator of MPT. Rather, the combination of current and voltage is ($P = I \times V$).

MPT relates to electrofishing. Since equipment circuits have low resistance compared to water, water is the primary "internal" resistance when electrofishing.



If water is the primary "internal" resistance (R_G) in electrofishing, what in electrofishing is analogous to the load (R_L)?

ANSWER: Fish

We are making a conceptual jump from circuits to the electrofishing situation. Be aware that the fish is not wired into the circuit as the load is in the previous circuit diagram. MPT in circuits does, however, illustrate that voltage or current by themselves are not good indicators of power transfer. Importantly, to get a response from the fish (e.g., tetany), we must transfer energy. Energy transfer requires power (energy / time). Power requires both voltage and current, not just one or the other.



What does the literature commonly say we electrofish with?

- A. Voltage
- B. Current
- C. Neither
- D. Either A or B

ANSWER: D



Instead, we fish with _____.

ANSWER: Power

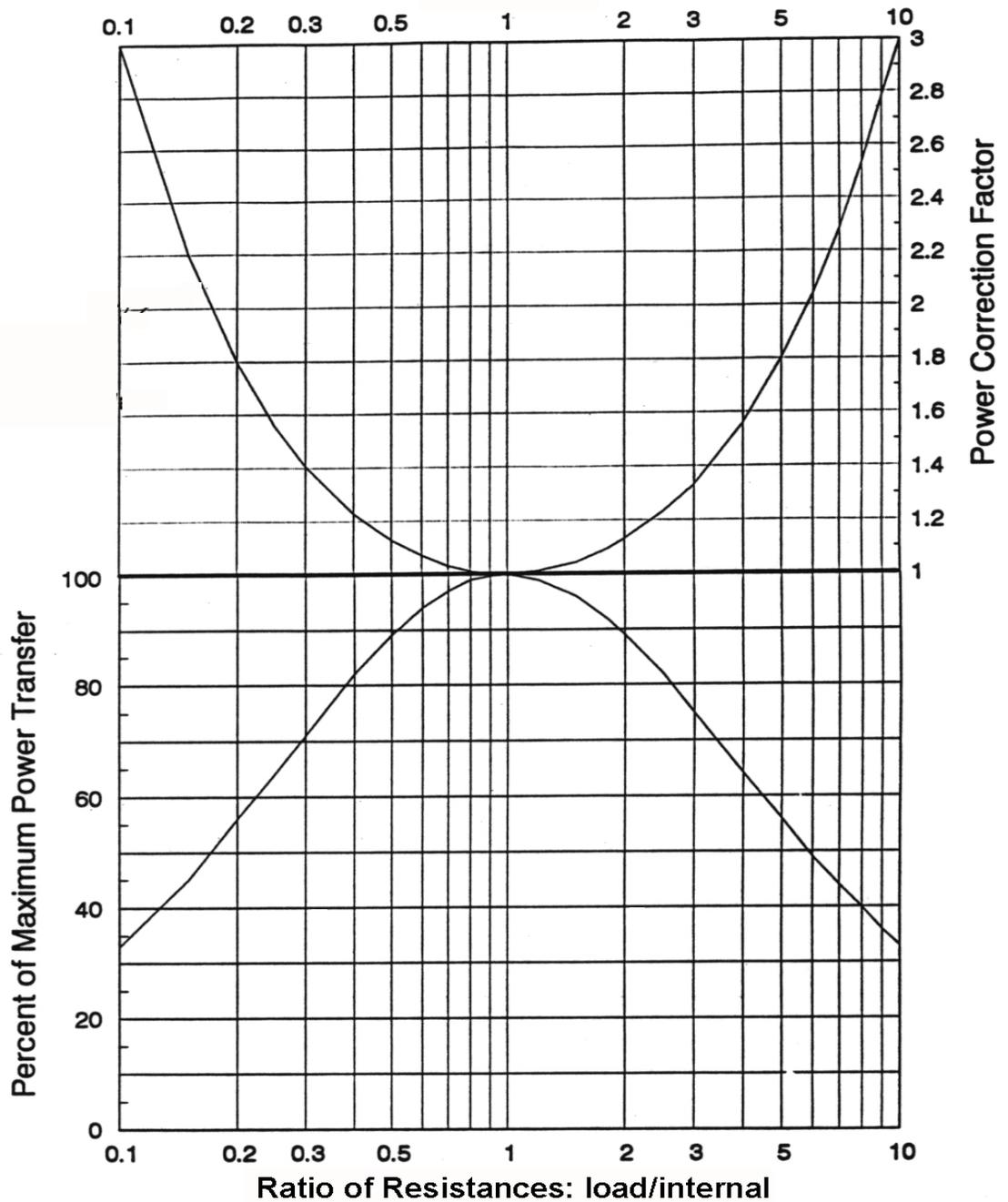
ACHIEVING CONSTANT POWER TRANSFER

We saw from the last section that when the load resistance is different from internal resistance, less power is transferred compared to "matched conditions" (i.e., $R_L=R_G$). So, as we depart from conditions where load resistance equals internal resistance, power transfer to the load becomes less efficient.

To transfer a constant amount of power to the load across a range of load resistances, we need a power correction factor (PCF). The desired power level transferred to the load at matched conditions is multiplied by the PCF. The resulting value is the required applied power to achieve transfer of the desired power level to the load at non-matched conditions. In non-matched conditions, more power will be applied than will be transferred to the load. That portion of applied power not transferred is termed reflected power.

The following graph illustrates the behaviors of transferred power and the PCF over a range of load resistance : internal resistance ratios.

Figure 2.41
Power correction factor and percent of maximum power transfer as a function of the ratio of resistances



$$PCF = \frac{(1+q)^2}{4q}$$

q = fish conductivity / water conductivity

This graph has two curves. The normalized curve for maximum power transfer is at a maximum (100%) when the ratio of load to internal resistance is one (load resistance = internal resistance). The curve is geometrically symmetric. That is, if the load has more or less resistance than the circuit, the impact on power transfer is the same.

The second curve is the curve for constant power transfer. PCF is at minimum (1.0), when the ratio of load resistance to internal resistance is one (matched conditions). This curve also is symmetric. When the ratio of load to internal resistance is greater or less than one, the PCF increases. This is because the inefficiency of power transfer increases as one deviates from matched conditions. In inefficient conditions, more power must be applied to transfer a given power level to the load relative to the matched condition situation.

The PCF also can be calculated by the formula

$$PCF = \frac{(1 + q)^2}{4q}$$

where q is termed the mismatch ratio.

q = load resistance / internal resistance

The mismatch ratio can be expressed either as load/internal or internal/load. The PCF will be the same regardless.



For any ratio of load to internal resistance, the corresponding values of MPT and PCF will equal "one" when multiplied. Try it!



13

Refer to table 2.3 you developed for the condition when the load resistance (R_L) is 20 ohms. The corresponding circuit diagram is:

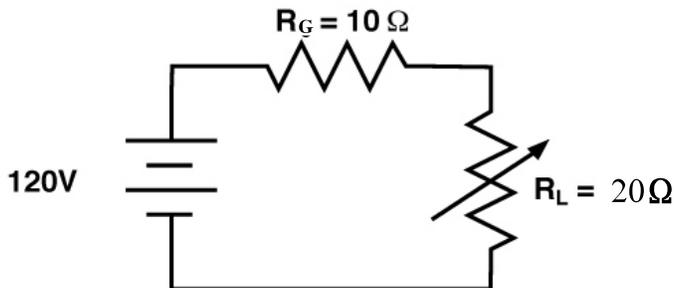


Figure 2.42
Series circuit with variable resistance

From the table, note that the power into the 20 ohm resistor is 320 watts, but an additional power of 160 watts [i.e., Joule's Law: $P = I^2 \times R_g = (4)^2 \times 10 = 160$ watts] is dissipated by the internal resistance (R_g). Therefore, the total power used by this circuit is 480 watts.

A) By what PCF factor must the total power applied to this circuit be increased to dissipate 360 watts in the load resistor (R_L)?

ANSWER:

B) How much total power will now be used by the circuit in order to have 360 watts dissipated in the load?

ANSWER:

You may wish to use the equation instead of the graph for determining the PCF.

The equation is:

$$PCF = (1 + q)^2 / 4(q)$$

where

$$q = \text{mismatch ratio} = \text{load resistance} / \text{internal resistance}$$



Determine PCF for the previous problem using the PCF equation.

ANSWER: $q =$

$PCF =$

Two important recommendations result from this MPT discussion.

1. Measure both current and voltage when electrofishing; always calculate and record power.
2. Always record water conductivity.

Thought Questions



1. An analogy that may assist you in remembering attributes of series and parallel circuits is to think of the circuit conductors (wires) as water pipes. Further, consider current flow through wires as equivalent to water flow through pipes. Thus, in a series circuit, water (current) would flow through each resistor equally. That is water flow (current) through all resistors in a series circuit would be equal because there is only one pipe, one path of flow.

In a parallel circuit the pipes branch. Obviously, water flow (current) also branches and, if the resistance to flow in each pipe varies (loads have different resistance values), the water flow (current) through the resistors would not be equal. So, current is equal among resistors in a series circuit and unequal among resistors in a parallel circuit.

2. Circuit breakers in your electrofishing boat circuitry are rated for maximum currents (e.g., 15 amps). Would you expect to exceed the circuit breaker capacity (i.e., “trip” the breaker) in high or low water conductivity? Why? What are your experiences? (Hint: use Ohm’s Law to help you answer the first two questions).

Quiz Questions:



1. Which waveform will destroy a transformer?
 - 1) AC
 - 2) DC
 - 3) PDC
 - 4) B&C

2. Electricity is energy carried by charged:
 - 1) compounds
 - 2) particles
 - 3) fields
 - 4) neutrons

3. AC and DC are:
 - 1) reference to alternating and direct current circuits
 - 2) the same thing when electrofishing
 - 3) of little importance to electrofishing personnel
 - 4) specifications for safety equipment

4. The rate of flow of electrical charge in a circuit is measured in:
 - 1) volts
 - 2) amperes
 - 3) ohms
 - 4) horsepower

5. Electrical current is defined as:
 - 1) the quantity of electrical charge per unit of time
 - 2) the energy contained per unit of charge
 - 3) the energy dissipated per unit of time
 - 4) the force generated by an electrical charge

6. AC electrofishing is generally:
 - 1) more expensive than DC electrofishing
 - 2) physically more traumatic to the fish than PDC electrofishing
 - 3) more power consumptive than DC
 - 4) more effective in low or high conductivity waters

7. Duty cycle refers to the:
 - 1) relative electrofishing efficiency of a pulsed DC system
 - 2) percentage of time that the voltage is present
 - 3) difference between AC and DC systems
 - 4) none of the above

8. Pulsed DC systems:
 - 1) conserve electrical power
 - 2) are generally more expensive to build than continuous DC or AC systems
 - 3) generally require a smaller battery capacity than a continuous DC system
 - 4) all of the above

9. All of the anodes of an electrofishing boat may be considered to be connected:
 - 1) in series
 - 2) in parallel
 - 3) in a series-parallel combination
 - 4) in a parallel-series combination

10. A full cycle of AC sinusoidal voltage has a mathematical average value equal to:
 - 1) the sum of both peaks
 - 2) the rms voltage
 - 3) 0
 - 4) the peak-to-peak voltage divided by 2.8

11. Pulse width is the:
 - 1) number of inches between consecutive pulses
 - 2) number of pulses per second
 - 3) time duration of a single pulse
 - 4) none of the above

12. The pulse repetition frequency is the:
 - 1) time between consecutive pulses
 - 2) number of pulses per second
 - 3) duty cycle
 - 4) response time between consecutive fish

13. If T is the period of a waveform, then:
 - 1) $1/T$ is the frequency
 - 2) the waveform repeats at time interval of T
 - 3) exact replicas of the waveform occur every T interval of time
 - 4) all of the above