Electrical Grid

Urban infrastructures throughout the United States are aging. As our demand for electricity grows, so does our need for uninterrupted service for more than 130 million homes, 8 million businesses, 450 thousand churches, 140 thousand schools and universities, 6 thousand hospitals, thousands of law enforcement and safety services, hundreds of sports stadiums and arenas, and thousands of miles of lighting for urban and rural streets and parks.

Post-apocalyptic science fiction television series and movies often show a world without electricity and how people might survive without it. In the United States, we don't have to imagine this life because all it takes are recurring days of super-hot temperatures or a severe storm to bring down power to thousands of people. During a power outage, when everything we expect to operate effortlessly with the flip of a switch no longer functions, we suddenly realize how important electricity is to our daily lives. Few people know that our three national power grids are engineered to work in synch, even when faced with increased energy consumption or broken transmission lines.

What most people don't realize is that a problem in one area of a grid can cause outages quite far from the source of the problem. The situation that occurred on Thursday, August 14, 2003 is a prime example. A widespread power outage occurred throughout parts of the Northeastern and Midwestern United States and the Canadian province of Ontario. At the time, it was the second most widespread blackout in history. Imagine the number of people without power in some of the most densely populated areas of the United States and Canada. A software bug in an alarm system at a control room of the FirstEnergy Corporation in Ohio was the cause of the problem. Operators were unaware of the need to re-distribute power after overloaded transmission lines touched tree branches. What should have been a manageable local blackout cascaded into widespread distress on the electric grid and affected an estimated 10 million people in Ontario and 45 million people in eight states.

It is impossible for engineers to prevent all problems on the three grids that help supply electricity to the United States. However, blackouts are rare. The challenge for your team is to create a smart "relay" that will reroute power effortlessly when a part of the grid is affected in an effort to prevent future power outages.

Background

Power is the rate at which energy is transported and is calculated with the equation $P = IV$, where P represents power that is measured in watts, I represents current in amperes, or amps, and V is the electric potential measured in volts. This equation can be used to compute the amount of power drawn by home appliances. Running too many appliances off of one circuit will easily trip a 15-amp circuit breaker.

Assumptions and Givens

- A standard U.S. outlet is about 110 volts.
- P = IV

$$\text{Percent decrease} = \frac{\text{original value - new value}}{\text{original value}} \times 100$$

- 1 volt (V)= 1 joule per coulomb; 1 V = 1 J/C
- 1 watt (W) = 1 joule per second; 1 W = 1 J/s
- 1 ampere (A) = 1 coulomb per second; 1 A = 1 C/s

Questions

1. What is the flow of current when a lamp containing a 60-watt bulb is plugged into a standard U.S. outlet?

   a. 6600 volts

   b. 5.5 volts

   c. 0.66 amps

   d. 0.55 amps

   e. 6600 amps

2. Theoretically, how many lamps like that in question 1 could be on the same circuit before tripping the 15-amp circuit breaker?

   a. 5 lamps

   b. 15 lamps

   c. 20 lamps

   d. 27 lamps

   e. 55 lamps

3. How much power is generated by the number of lamps calculated in question 2?

   a. 0.165 watts or less

   b. 1400 watts or more

   c. 1650 watts or less

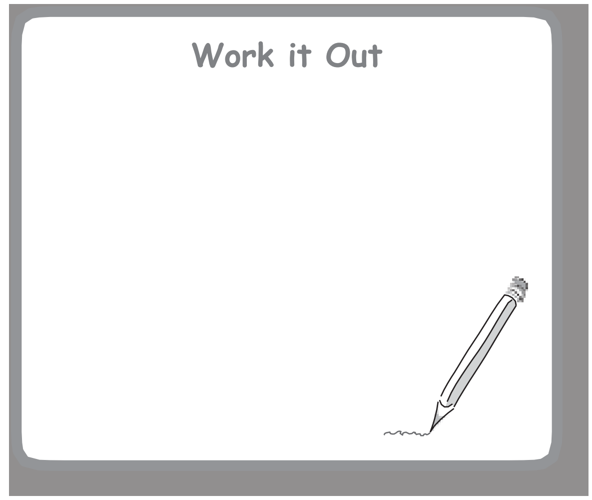
   d. 0.14 watts or less

   e. 1650 watts or more

Work it Out

4. A hair dryer draws a current of 10 A on its “Hot” setting and a current of 4 A on its “Cool” setting. What percent decrease in power occurs when you switch the hair dryer from the “Hot” setting to the “Cool” setting?

   a. 60%
   b. 150%
   c. 0.6%
   d. 15%
   e. −150%

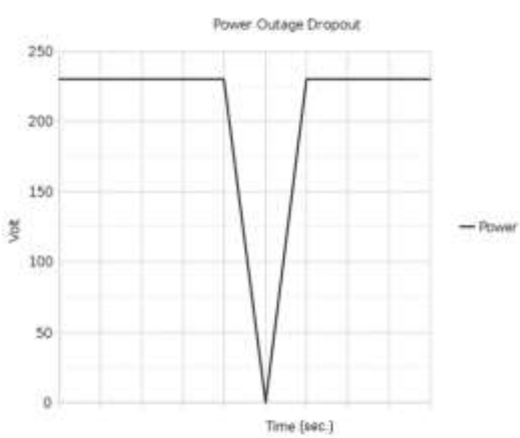


Background

A power outage is a loss of electrical power to an area. There are three types of power outages: transient faults, brownouts, and blackouts. Transient faults are momentary losses of power typically caused by temporary faults on a power line. Brownouts are temporary dips or drops in voltage and usually result in dimmed lights, or poor performance or failure of electrical appliances. Blackouts are the most severe and result in a total loss of power for an area for an indeterminate length of time. Some blackouts have lasted weeks!

Assumptions and Givens

The graph below shows the voltage on an electrical line during a transient fault. The vertical axis shows the number of volts carried along the power line and the horizontal axis shows the amount of time elapsed before, during, and after the event, in seconds.



Questions

5. Referring to the graph of a transient fault, about how much power was the electrical line carrying before the fault occurred?

   a. 200 V

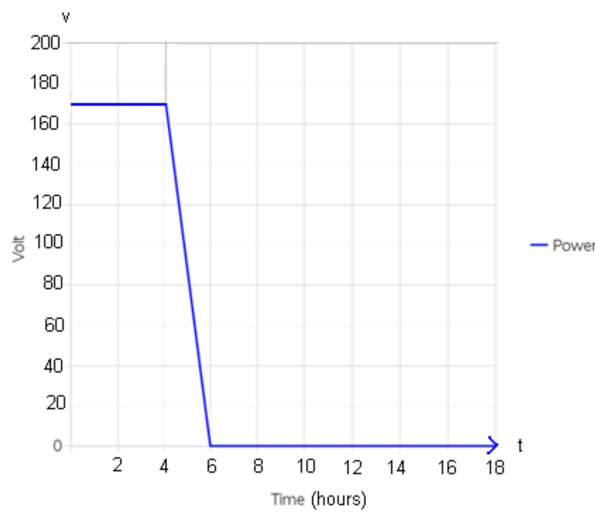
   b. 228 V

   c. 0 V

   d. 50 V

   e. 250 V

6. Which of the following piecewise functions best describes the graph of the blackout event shown below?



   a. $f(t) = \begin{cases} 170 \text{ if } 0 < t < 4 \\ -85t + 510 \text{ if } 4 \le t < 6 \\ 0 \text{ if } t \ge 6 \end{cases}$

   b. $f(t) = \begin{cases} 170 \text{ if t} < 4 \\ 85t - 510 \text{ if } 4 \le t < 6 \\ 0 \text{ if } t \ge 6 \end{cases}$

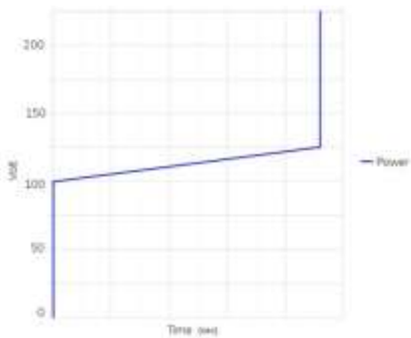
   c. $f(t) = \begin{cases} 170 \text{ if } 0 \le t < 4 \\ -85t + 510 \text{ if } 4 \le t < 6 \\ 0 \text{ if } t \blacksquare 6 \end{cases}$

   d. $f(t) = \begin{cases} 170 \text{ if } t < 4 \\ 85t - 510 \text{ if } 4 < t \le 6 \\ 0 \text{ if } t > 6 \end{cases}$

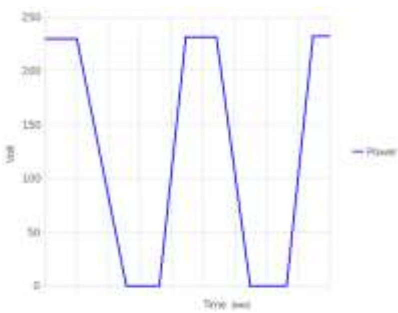
   e. none of the above

7. Which of the following graphs shows what a typical brownout would look like in terms of power supply over time?

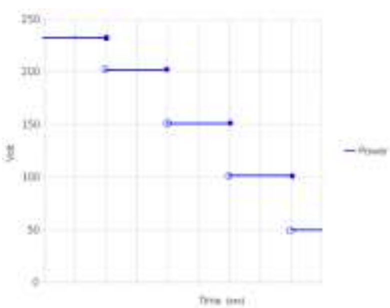
a.



b.



c.



d.

e. none of the above

Work it Out

Background

Transmission lines are protected by “ground wires” that redirect the excess energy into the ground to prevent surges on the line. Electronic surge protectors work in the same manner, sending excess voltage into a ground wire to prevent damage to electronic components. Ground wires are chosen for their ability to conduct an electrical current (conductivity).

Conductivity of a Material

$$\sigma = \frac{1}{\rho}$$

σ (sigma) is the conductivity of a material in siemens per meter (S/m) and *ρ* (rho) is the electrical resistivity of the material in ohm · meters (Ω · m).

Material	Density (g/cm^3)	Resistivity-density product
Magnesium	1.74	76.3
Aluminum	2.70	72.0
Copper	8.96	150.0
Silver	10.49	166.0
Gold	19.30	427.0

Density of Conductive Materials

Additional Assumptions and Givens

- Conductivity is the inverse of resistivity.
- resistivity-density product = resistivity (nΩŸm) × density (g/cm^3)

$$\rho = \frac{\text{resistivity-density product}}{\text{density}}$$

Question

8. Based on the information provided, why would a silver ground wire be chosen over a copper one?

   a. Silver conducts an electric charge better than copper.

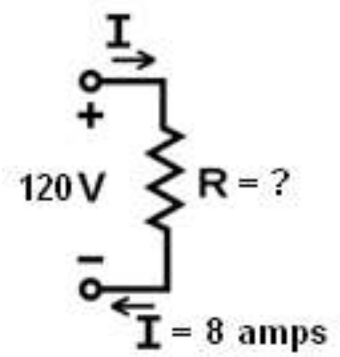
   b. Silver has a higher density than copper.

   c. Silver has a higher Resistivity-density product than copper.

   d. Silver is more resistive than copper.

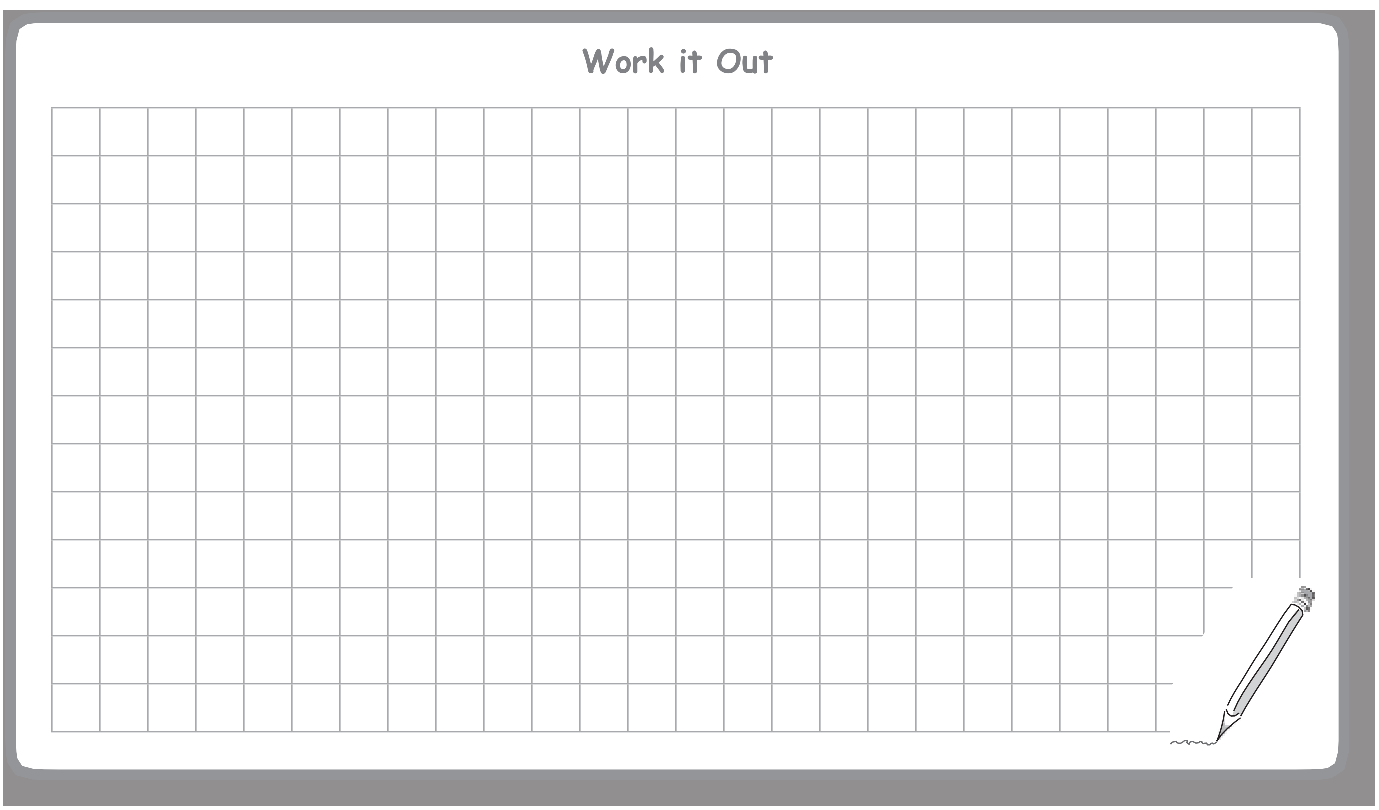
Assumptions and Givens

- Ohm's Law: $I = \frac{V}{R}$
- Current equals voltage divided by resistance.



9. What resistance would be required in the circuit, or network, shown?

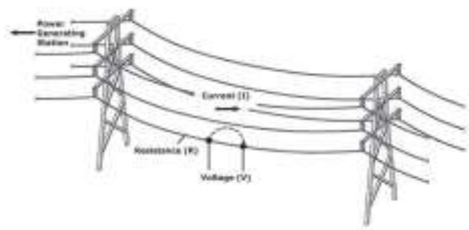
   a. 960 ohms
   b. 12 ohms
   c. 15 ohms
   d. 0.07 ohms
   e. 8 ohms



Background

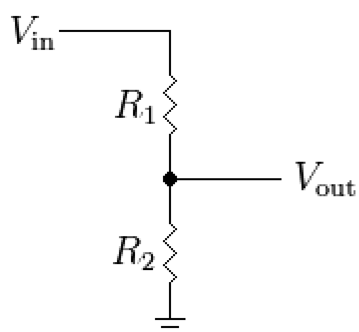
On the power grids (network), digital protective relays are known as the “sentinels or watchdogs” of the system. They are used to detect electrical or process faults by analyzing power system voltages, currents, or other process quantities and comparing those to preset levels. If the digital relay determines that an action should be taken, such as opening or closing a switch because there is too much current or the voltage is too low, the relay will apply its logic to complete the action without input from a human operator. This type of relay is a *smart relay.*

High voltage direct current (HVDC) transmission lines look something like this:



Sketch of High Voltage Transmission Line Network

Because the voltage across the transmission lines in HVDC is so high, it must be reduced before it is input into a digital relay circuit. In order to do this a voltage divider is required.



Simple resistive voltage divider

Once the sampled voltage flows into the relay, it can be input into a logic gate in the relay to compare it to a given voltage. Two-input logic gates work by producing an output through some combination of inputs. In this example assume that Input 2 is always true. If Input 1 (V_{OUT}) in the figure drops to 0 V when a fault occurs on the line, its input into the gate will be false (0). Under normal circumstances, the output from the gate should be 0, which means no warning lights will be activated and the circuit breaker will not be tripped. When a fault occurs, the output should change to true (1).

Type	Transmission Line Input	5 V Input	Gate Output
AND	1	1	1
	0	1	0
NAND	1	1	0
	0	1	1
OR	1	1	1
	0	1	1
NOR	1	1	0
	0	1	0
EX-NOR	1	1	1
	0	1	1

Table 1: Logic Gate Operation

Assumptions and Givens

- A gate output of 0 (false) indicates that the LED warning light will not be activated.
- A gate output of 1 (true) indicates that the LED warning light will be activated.
- When working properly, a logic gate will not activate the LED when no fault is present.
- When working properly, a logic gate will activate the LED when a fault is present.

Question

10. Using the information in the Table, which logic gate should be used when designing a properly functioning relay circuit?

    a. AND

    b. NAND

    c. OR

    d. NOR

    e. EX-NOR