

**Basics of Transformers and  
Ground Fault Monitors**

Instructor's Copy

Mining Extension Service  
West Virginia University  
College of Mineral and Energy Resources  
Morgantown, West Virginia

Human Factors Group  
U. S. Bureau of Mines  
Pittsburgh Research Center  
Pittsburgh, Pennsylvania

## **Contents**

Introduction	3
Exercise summary	3
How to use this exercise	4
Performance objectives	5
Instructor discussion notes	6
List of Materials for the demonstration apparatus	10
References	10
Scoring Key	11
Appendices	
Appendix A: Problem Booklet (duplicate this for use in class)	
Appendix B: Answer sheet (give one of these to each person in the class)	

## Introduction

This instructor's package contains all the materials needed to administer the exercise. It tells how to use the exercise, presents the objectives, the question and feedback pages, and discussion notes to be used following the exercise.

## Exercise Summary

Read this section first. It determines if the exercise is appropriate for your classes. If you choose to use the exercise, examine the table of contents and review the remainder of this document.

- Type: Problem book with question and feedback pages, with a paper and pencil answer sheet
- Audience: Mine electricians and miners who wish to better understand ground monitor systems
- Length: Six questions (can be completed and discussed in a total of 45 minutes)
- Skills: Predicting the current flow in a primary circuit when switches in both the primary and secondary circuit are in various combinations of being open and closed.  
Recognizing the role of greatly increased impedance in the primary circuit when the resistance in the secondary circuit is increased.  
Generalizing these relationships to understand how ground-monitoring systems on mining equipment operate to protect workers from electrocution when faults are present in the main power grounding system.
- Location: Underground coal mine (the principles apply to any situation where electrical equipment is protected by ground monitoring systems)
- Problem: A series of questions asks the trainee to make judgments about the presence or absence of current flow in the primary circuit of a transformer, and the changes in the primary circuit resistance (impedance) when switches in the primary and secondary circuits are in various open and closed positions. The last questions ask the trainee to select from among a list of statements those that are true about how ground monitor systems on a shuttle car operate when there are resistance changes in the secondary monitoring circuit.

### **How to Use This Exercise**

1. Look at the performance objectives. Decide if the exercise is relevant for your annual refresher class.
2. Using the problem booklet, work the exercise. Then score your answers using the instructions on the bottom of the answer sheet.
3. Read the "Instructor's Discussion Notes" for the exercise.
4. Become thoroughly familiar with the problem before class so you can present it effectively.
5. Use the specifications in the discussion notes to construct a classroom demonstration apparatus to be used following the exercise.
6. When you present the exercise to the class:
  - Have class members work in groups of 3 or 4 persons
  - Give every person an answer sheet and a pencil.
  - Give each person a problem booklet.
  - Go over the instructions for doing the exercise with the whole group.
  - Have the miners in each small group work through the exercise with each person marking his or her answers on their own answer sheet.
  - When the class members finish, have each person figure up their score using the instructions on the answer sheet.
  - When everyone has finished, ask class members to discuss the merits of each answer. Then use the physical apparatus to demonstrate each step in the problem. Ask the miners to discuss how the apparatus works and why the primary circuit responds as it does to changes in resistance in the secondary circuit. Then relate the principles involved to ground monitor systems on mining equipment. The figures provided may help you do this.

**Performance Objectives for Basics of Transformers and Monitors**

Objective number	Capability verb(s)	Description of required performance and conditions under which it is to occur
1. BEC <sup>1</sup>	Predict Explain	The absence of current flow in a closed primary circuit in a transformer when the secondary circuit is open.
2. BEC	Predict Estimate Calculate	The change in impedance in the primary circuit of a transformer when the resistance in the secondary circuit changes slightly given a primary to secondary turns ratio of 10:1.
3. BEC	Recall Recognize	The underlying principle that the impedance in the primary and secondary circuits of a transformer increase as the square of the primary to secondary turns ratio, e.g. (10:1) <sup>2</sup> in this case.
4. BEC	Manipulate Experiment with	A physical bench model of a transformer by making changes in the primary and secondary circuits' resistance and observing the effects.
5. SW	Generalize Apply	The principles demonstrated in the exercise and in the classroom demonstration to the operation of a ground monitor system on a shuttle car or other electrical equipment.
6. SW	Recognize	The risks to workers from electrocution when ground monitor systems are tampered with or otherwise rendered inoperable.

---

<sup>1</sup> Skill and knowledge domain abbreviations:  
 BEC = basic electrical concepts  
 SW = safe work practices

## Instructor's Discussion Notes

Use the information presented here and in the problem booklet, your own ideas and experience, and that of the miners in your class to discuss the exercise after it is completed. Group discussion can strengthen knowledge and skills, correct errors, and relate the exercise content to the experiences of the miners. After they have worked the exercise, miners enjoy discussing the problem. They also frequently think of better ways to respond to a problem than those listed among the answers. The purpose of the exercise is to help miners think about and remember basic knowledge and skills they may someday need to deal with a mine emergency. The discussion following the exercise can contribute to this goal and tailor the exercise content to the needs of the group you are training.

It is helpful if the miners look at their problem booklets during the discussion. This allows you to lead the group through the exercise and to discuss all the answers to each question. Most of the information about why particular answers are correct or incorrect is given on feedback pages in the problem booklet. For this exercise it is best to begin the discussion immediately after the miners have completed the paper and pencil portion of the exercise. Some members of the class will argue that the light bulb in Question B (Figure 2) will light up because switch #1 is closed and the circuit is complete and energized. After the members of the class have argued this point for a while, it is a good idea to carry out the physical demonstration.

With the apparatus described later in these discussion notes, you can allow the members of the class to replicate the conditions described in Figures 1 through 3 in the exercise, and to observe the results.<sup>2</sup> This can be a very motivating and effective way to help miners understand the principle of impedance and how this relationship is used to operate ground-monitoring systems on mining equipment. Discussion of the exercise without this physical demonstration is far less effective. Miners sometimes fail to comprehend the information in the paper and pencil version of the exercise. The physical demonstration confronts these miners with the discrepancies between their conceptions and physical reality. This situation usually makes the miner more willing to understand why the system works this way. This better basic understanding of the principles involved can help miners understand the purpose and the operation of the ground monitor safety systems found on the equipment they use in their work.

The following notes provide additional information for you to discuss with your class. Read through and think about the notes before the class. Don't read the notes to the class members. This would be boring and ineffective. Rather, incorporate the ideas you find here with your own ideas and make these points at the appropriate place in the discussion of the exercise.

The last portion of the discussion notes includes a list of the parts, and a schematic diagram from which to construct the physical apparatus to use in the demonstration. Gathering the materials and constructing the apparatus may require a couple of hours,

---

<sup>2</sup> Be careful when you conduct the demonstration. The knife switches and connections on the transformer and light bulb are "hot" when the apparatus is connected to a 120 volt AC outlet.

but once constructed, the apparatus may be used for years. This can be very effective in helping the miners understand the principles involved.

**Question A** - The correct answer is 2. The light bulb cannot light up because the primary circuit is open and no current can flow from the electrical power source.

**Question B** - The correct answer is 4. The light bulb in the primary circuit will not light up, even though switch #1 is closed, and even though the primary circuit is connected to a 120 volt AC power source. When switch #2 in the secondary circuit is open, the resistance in the secondary circuit becomes very high (approaching infinity). When the electromagnetic lines of force from the primary circuit coil attempt to expand and collapse across the coils in the secondary circuit, the electrical impedance (AC resistance) becomes so high in the primary coil, that very little electricity can flow in the primary circuit. The reason for this is that the impedance in the primary and secondary circuits increases as the square of their impedances. With a 10:1 turns ratio between the primary and secondary coils of the transformer, the ratio of increased impedance is  $(10:1)^2$  which becomes 100:1 when the values are squared. Therefore, a very slight increase in the resistance of the secondary circuit produces a 100 times larger resistance in the primary circuit. When switch #2 is open, this induced high resistance (impedance) in the primary circuit prevents the flow of electricity even when switch #1 is closed and the primary circuit is connected to a 120 volt AC power source.

**Question C** - The correct answer is 5. With both the switch #1 in the primary circuit closed, and switch #2 in the secondary circuit closed, the bulb will light. When switch #2 in the secondary circuit is closed, the resistance in that circuit becomes very small. Therefore, even though the resistance in the primary circuit caused by impedance of the secondary circuit coil will be 100 times larger, 100 times a very small number is still small.

**Question D** - The correct answers are 7 and 9. With both switches closed the resistance in the secondary circuit is very low and approaches 0. This means that the impedance (AC resistance) induced in the primary coil will also be low since  $0^2$  is also 0. For example, let's assume that the resistance in the secondary circuit with switch #2 closed is 0.005 ohms. Then the induced impedance in the primary circuit will also be small (0.5 ohms), even though it is 100 times larger than the primary circuit resistance. So the light will still burn. Answer 9 is correct because the law of conservation of energy requires that energy into a system must equal the energy out. Normally the effective energy that can be used for doing work is less than the energy put into the system. Some of the input energy is lost in friction, heat, and noise. The energy efficiency of a machine is simply a ratio of input energy to output energy. In this problem we are told that the transformer is nearly 100 percent efficient. Therefore, we know that the power into the primary circuit must be approximately equal to the power out of the secondary circuit. Electrical power = amperage (I) x electrical potential (E) or voltage.

**Question E** - The correct answer is 14. If the resistance in the secondary circuit increases by 1 ohm, the resistance in the primary circuit has to increase by the square of the ratio of the primary to secondary turns, e.g.  $(10:1)^2$ . When these values are

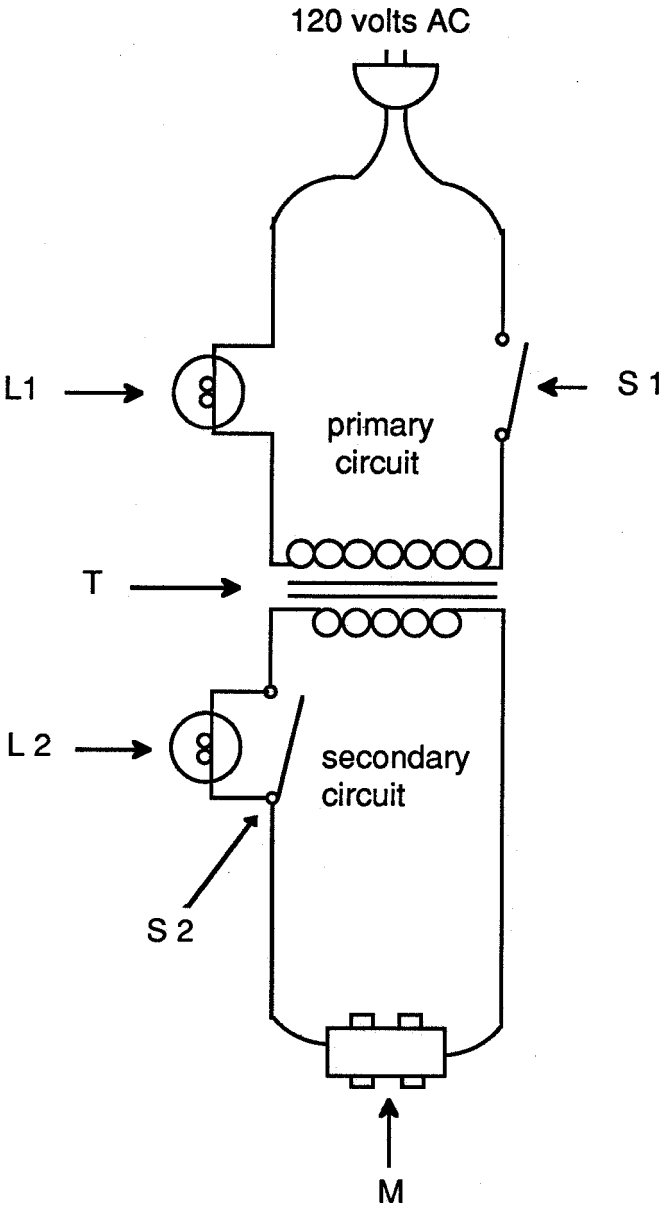
squared we see that the resistance in the primary circuit increases by 100 ohms for each 1 ohm increase in the resistance of the secondary circuit.

**Question F** - All the answers except 20 are correct. Both the pilot wire and the ground wire in the secondary circuit of the monitor must be fully intact if the shuttle car electrical system is to continue operating. A break in either of these wires is like the open switch in the secondary circuit in Figure 2. It increases the resistance of the secondary circuit to a very high value. This causes the impedance in the primary circuit of the monitor to become so high that the current flow stops. This in turn causes the ground check relay to loose power, so it drops out and opens the circuit breaker for the main power lines to the shuttle car (15). This cuts the power to the shuttle car.

Let's review these same points in a slightly different way as we discuss each of the remaining answers for question F. A break in either the pilot wire or the ground wire on the secondary side of the monitor transformer will cause the current in the secondary circuit to cease (16). Such a break is like the open switch in Figure 2 for Question B. The main power to the shuttle car will cut off (20) because the ground check relay loses power and opens the main power circuit breaker (18). The ground check relay must be energized if it is to hold the main power circuit breaker in place. A break in either the transformer's pilot wire or the ground wire in the trailing cable (secondary side of the transformer) increases the resistance of the secondary circuit to a very high level. Because of the 10:1 turns ratio in the transformer, this high resistance in the secondary circuit of the monitor increases the impedance (AC resistance) in the primary circuit by  $(10:1)^2$  or 100:1. With such a high induced resistance in the primary circuit, very little current can flow, the ground check relay drops out, the circuit breaker for the main power to the shuttle car is opened, and the trailing cable and shuttle car are de-energized instantly.

If someone had bridged out the pilot and ground wire at the cathead (plug) at the power center (19), the ground monitor system would be rendered inoperable. The bridge provides the path for a complete circuit on the secondary side of the monitor transformer. Therefore, if the pilot or ground wire in the trailing cable were broken, the resistance in the secondary circuit would not increase. Consequently, the resistance in the primary circuit would not increase. The ground check relay would remain energized and hold the circuit breaker for the main power in place. The shuttle car cable would remain fully energized with 440 volts AC. If there were a ground fault on the shuttle car, its frame would be energized and deadly. Many miners have been killed by just such situations. The victims are often not the person who bridged out the monitor circuit, but some other innocent worker who happened to touch the energized frame of the shuttle car while being grounded through contact with the mine floor, rib, or another piece of equipment. It would be appropriate to ask the members of your class if they have observed ground monitor systems being bridged out, to ask them to discuss the reasons miners sometimes engage in this deadly and illegal practice, and to examine the probable consequences and costs of the practice.





Schematic diagram for the demonstration apparatus

### **List of Materials for the Demonstration Apparatus**

Construct the classroom demonstration apparatus according to the schematic diagram on the previous page and the list of materials below.

L1 - Primary light - 15 Watt (obtained from local hardware store)

L1 - Primary light holder - keyless porcelain lamp holder (obtained from local hardware store, similar to Leviton # 9875)

L2 - Secondary bulb - 14 V clear bulb (obtained from Radio Shack # 272-1134)

L2 - Secondary light holder (obtained from Radio Shack # 272-357)

S1 and S2 - Switches - SPST knife-type that will be easy for the class to see so that they can tell when each switch is open or closed (obtained locally or #70020A from World of Science, 1665 Buffalo Road, Rochester, New York 14624, phone 716-426-1540 or #A38,805 from Edmund Scientific, 101 E. Gloucester Pike, Barrington, NJ 08007-1380, phone 609-573-6879)

T - Transformer - 12.6 volt AC, 300 mA power transformer (obtained from Radio Shack # 273-1385)

Jumper leads - optional - (obtained from Radio Shack)

18 gauge, 2 conductor wire with AC quick plug attached (obtained from local hardware store)

20 or 22 gauge wire (obtained from local hardware store)

M - Machine - small metal, rubber-tired piece of machinery (similar to match box size) (obtained from local toy store)

### **References**

Fowler, R. G., & Meyer, D. I. (1964). *Physics for engineers and scientists*. New York: Allyn and Bacon.

Robinson, V. (1972). *Electrical concepts. A self-instructional programmed manual*. Reston, VA: Reston Publishing Company.

Williams, J. E., Trinklein, F. E., Metcalfe, H. C., & Lefler, R. W. (1972). *Modern physics*. New York: Holt.

## Scoring Key for Basics Of Transformers and Monitors

The correct answers are marked with an asterisk.<sup>3</sup>

Question	Answer Number					
A	1	2*				
B	3	4*				
C	5*	6				
D	7*	8	9*	10		
E	11	12	13	14*		
F	15*	16*	17*	18*	19*	20

---

<sup>3</sup> This page is printed in large type and may be duplicated as an overhead transparency.

## **Appendix A: Problem Booklet**

This is the problem booklet containing the instructions for working the exercise, the background information, the problem, the questions, and the feedback for each question.

To prepare the problem booklet for use, first print it on regular 8.5 by 11-inch paper. Keep the pages in order. If desired, laminate each page with plastic. Then put each complete set of pages into a binder. Prepare one problem booklet for each person in your class.

Once you have prepared problem booklets, you can reuse them many times. The plastic lamination allows the booklets to be taken underground or other places where miners work. Because of this, and because the exercise is short, training can take place at the work site during weekly safety meetings or at other convenient times.

**Basics of Transformers and  
Ground Fault Monitors**

**Problem Booklet**

## **Instructions**

Read the information on this page and the next page. Then you will be asked 6 questions about this problem. Each question is on a separate page. Work through the exercise one page at a time. Don't jump ahead, but you may look back to earlier questions and your answers.

When you have finished reading the next page, read Question A on page 4. Think about the situation. Then select the correct answer for that question by circling its number on the answer sheet. When everyone in your group has marked their answer to Question A on their answer sheet, turn to page 5 in this problem booklet and look at the feedback page for Question A. Then talk about the answers.

Continue on and do the remaining questions in the same manner. Both Questions D and F have more than one right answer, so you will want to mark more than one answer on the answer sheet for each of these questions. Follow the directions for each question. When you finish you will learn how to score your performance.

## Background Information

Mining equipment often makes use of AC circuits with transformers.

AC Circuits with transformers are the basis for ground fault monitoring systems that are used on shuttle cars and other equipment. These safety systems are designed to prevent electrical shocks to workers. If miners do not understand ground monitor systems, and if these systems are faulty or bypassed, serious injuries and fatalities can result.

This booklet contains a series of questions and diagrams about the primary and secondary sides in a simple transformer. Work through the questions one at a time. When you have finished the instructor will discuss the exercise and conduct a demonstration of the principles involved.

## Problem

Transformers have primary and secondary sides. If miners and electricians are to work safely they must understand how transformers operate.

Assume the transformer in this exercise is nearly 100 percent efficient.

Turn the page and answer Question A. Then complete the remainder of the questions.

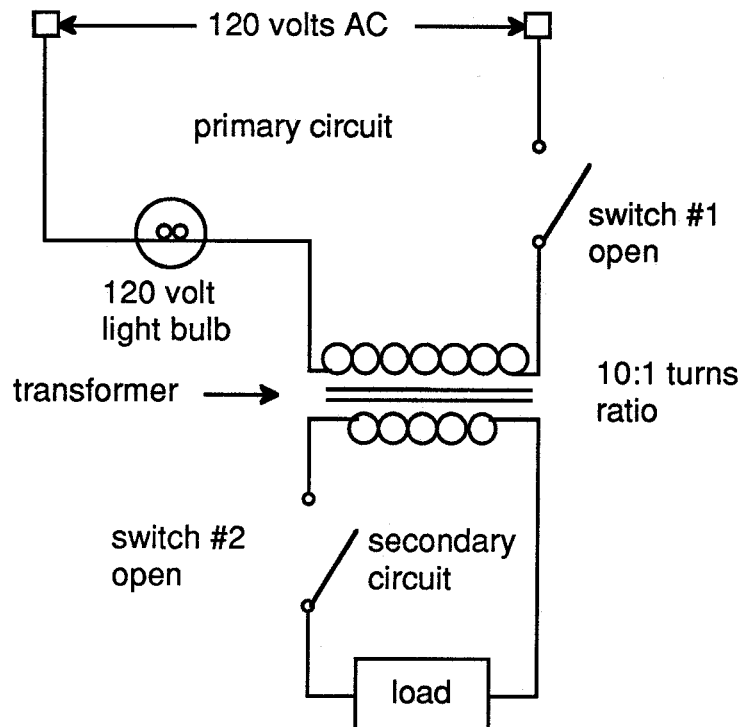
### Question A

Look at Figure 1. It shows a transformer. The primary side of the circuit is plugged into a 120 volt AC outlet. The secondary side is hooked to a load (resistor). Will the light bulb on the primary side light up when the switches in the primary and secondary sides are arranged as shown in Figure 1? (Choose only ONE answer.)

1. Yes.
2. No.

When you have marked your answers on the answer sheet, turn the page and look at the Question A feedback.

Figure 1: Transformer with switches #1 and #2 open





**Question A Feedback**

1. Not possible!
2. Correct!

**After you have thought about these answers, do question B.**

**Question B**

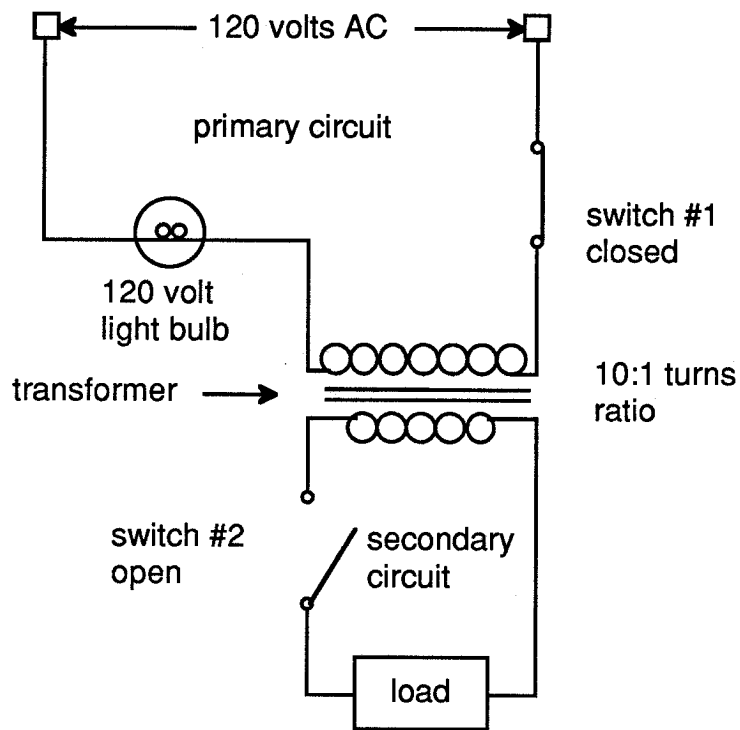
Look at Figure 2. It is just like Figure 1 except that switch #1 on the primary side is closed. (Choose only ONE answer.)

Now will the light bulb on the primary side light up?

- 3. Yes. The bulb will burn brightly.
- 4. No. The bulb will not light.

**When you have marked your answers on the answer sheet, turn the page and look at the Question B feedback.**

Figure 2: Transformer with switch #1 closed and switch #2 open



**Question B Feedback**

3. Even though switch #1 is closed, the bulb will not light.
4. Correct!

**After you have thought about these answers, do question C.**

### Question C

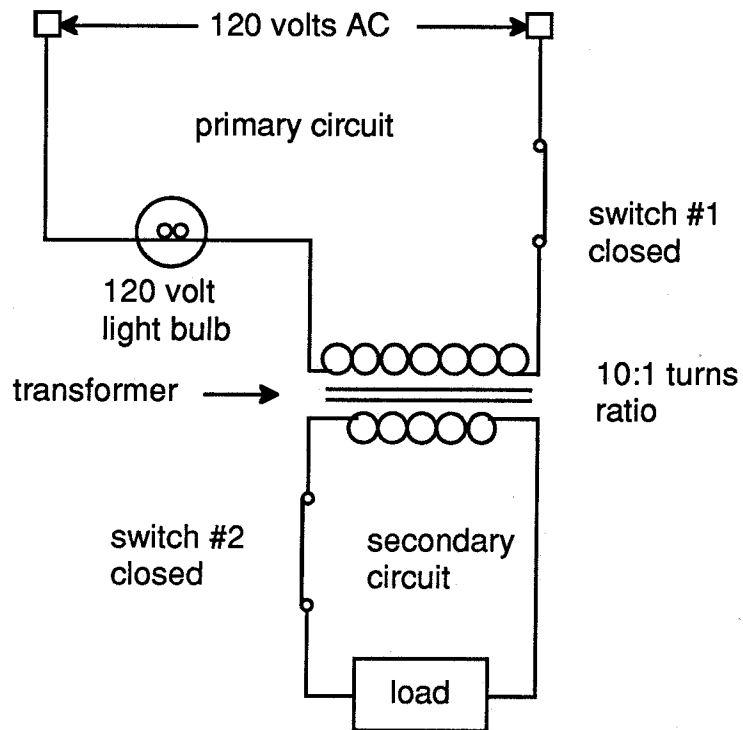
Look at Figure 3. It's just like Figure 2 except switch #2 on the secondary side is now closed. (Choose only ONE answer.)

Now will the light bulb light up?

- 5. Yes, the bulb will burn brightly.
- 6. No, if it didn't light in Figure 2, it won't light now.

When you have marked your answers on the answer sheet, turn the page and look at the Question C feedback.

Figure 3: Transformer with switches #1 and #2 closed



**Question C Feedback**

- 5. Correct!
- 6. It will light now.

**After you have thought about these answers, do question D.**

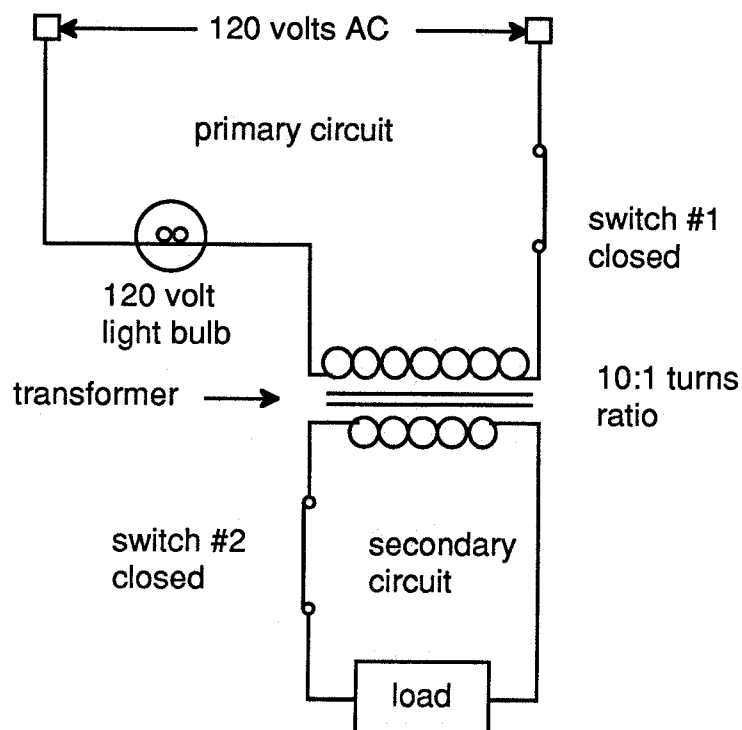
**Question D**

Switches 1 and 2 in the primary and secondary circuits are closed, as shown in Figure 3. Why does the light bulb now burn brightly when it didn't before? (Select ALL the correct answers.)

- 7. The resistance in the secondary circuit is lower with switch #2 closed than with it open.
- 8. The circuit on the primary side is complete when switch #1 is closed.
- 9. When a transformer is nearly 100% efficient, power into the primary circuit must be approximately equal to the power out of the secondary circuit.
- 10. With both switches #1 and #2 closed both the primary and secondary circuits have equal impedance.

**When you have marked your answers on the answer sheet, turn the page and look at the Question D feedback.**

Figure 3: Transformer with switches #1 and #2 closed



**Question D Feedback**

7. Correct!
8. The primary circuit was complete in Figure 2, but the bulb didn't light.
9. Correct! Since  $P = I \times E$ , then primary  $I \times E =$  secondary  $I \times E$ .
10. The resistance in the primary circuit is much larger than the resistance in the secondary circuit.

**After you have thought about these answers, do question E.**

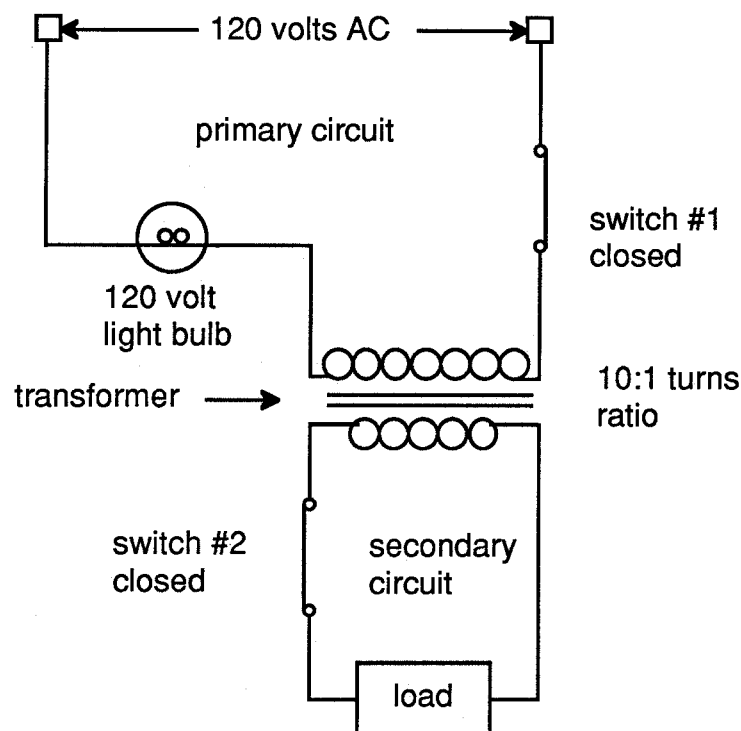
### Question E

Look at Figure 3. If the resistance in the secondary circuit increases by 1 ohm, what will happen to the resistance in the primary circuit? (Choose only ONE answer.)

- 11. It will not change.
- 12. It will increase by 1 ohm.
- 13. It will increase by 10 ohms.
- 14. It will increase by 100 ohms.

When you have marked your answers on the answer sheet, turn the page and look at the Question E feedback.

Figure 3: Transformer with switches #1 and #2 closed





**Question E Feedback**

11. It must increase.
12. It must increase much more.
13. The turns ratio is 10:1, but the resistance ratio will be much greater.
14. Correct! The 10:1 turns ratio will produce a  $(10:1)^2$  resistance ratio. Since  $10^2 = 100$  and  $1^2 = 1$ ,  $(10:1)^2 = (100: 1)$

**After you have thought about these answers, do question F.**

## Question F

Now let's think about how these transformer principles apply to ground fault monitor systems on mining equipment. Study Figure 4 on the next page. Then read the following information.

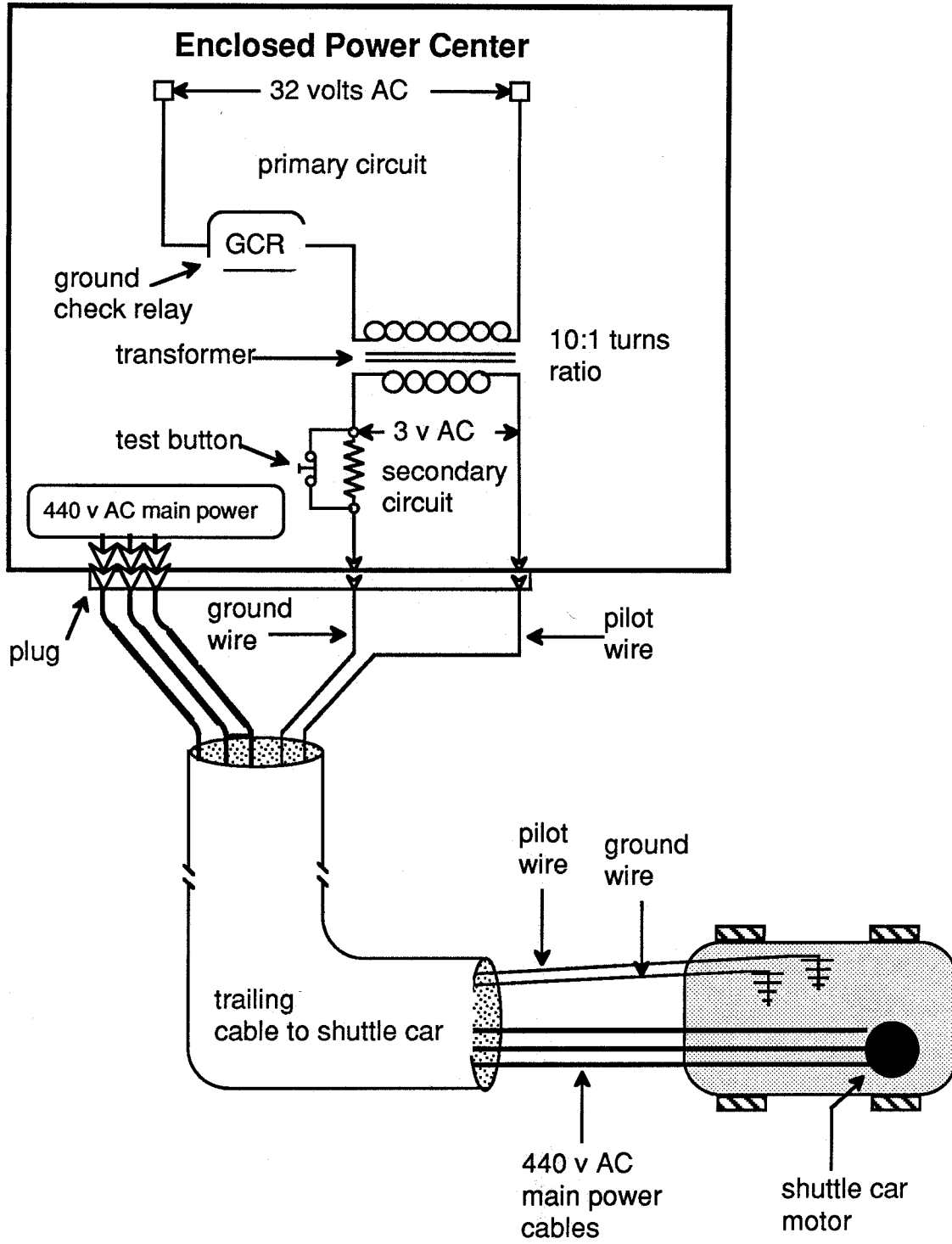
The pilot wire runs from the secondary side of the power center ground monitor transformer to the frame of the shuttle car. The ground wire runs from the shuttle car back to the ground monitor in the power center to complete the secondary circuit. Both conductors run through the trailing cable. The pilot wire is much smaller than any other wire in the cable. Therefore, it can be damaged more easily than the other wires in the cable. Damage may result from running over the cable or too much tension at the anchor point or take up reel.

Suppose the pilot wire in a shuttle car cable is broken. Which of the following statements are correct? (Select ALL the correct answers.)

15. The shuttle car will be de-energized immediately.
16. The current flow in the secondary side of the ground monitor transformer will cease.
17. The current flow in the primary side of the ground monitor transformer will drop to nearly zero.
18. The ground check relay in the primary circuit of the ground monitor system will drop out.
19. If someone had bridged out the pilot and ground wire at the plug at the power center, the ground check relay would not drop out.
20. The shuttle car will continue to operate as long as at least either the pilot wire or the ground wire in the trailing cable is not damaged.

**When you have marked your answers on the answer sheet, turn the page and look at the Question F feedback.**

Figure 4: Schematic diagram showing the primary and secondary circuits of a transformer that serves as a ground monitor for a shuttle car.



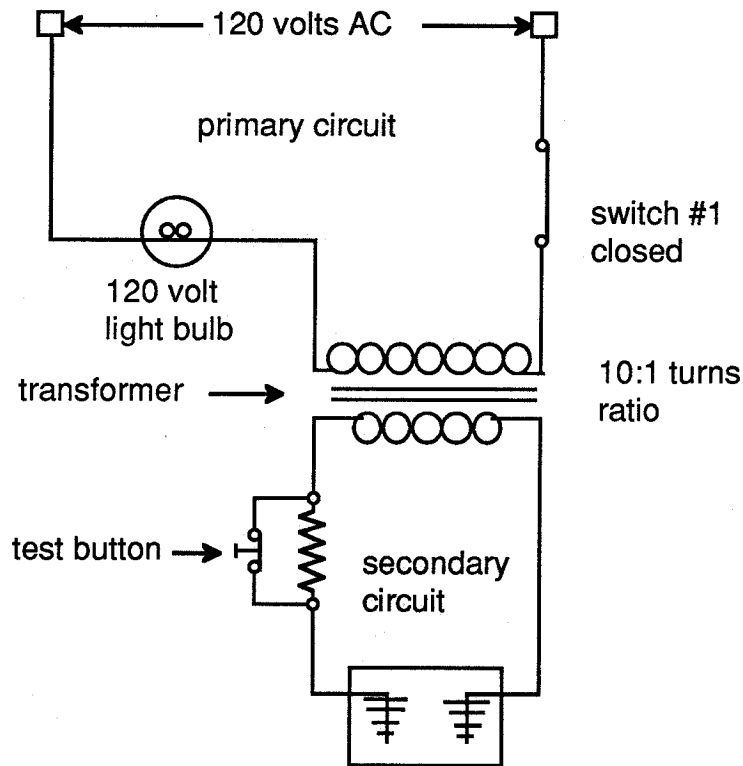
## Question F Feedback

15. Correct! This safety feature protects miners from electrocution in case of a ground fault on the shuttle car.
16. Correct! Because of the broken pilot wire, the resistance becomes very high and the current flow stops.
17. Correct! The turns ratio of 10:1 in the ground monitor transformer will produce 100 times greater impedance (AC resistance) in the primary circuit than in the secondary.
18. Correct! When this relay drops out, it trips the circuit breaker for the shuttle car trailing cable. This cuts the power to the machine.
19. Correct! This is dangerous and illegal. This bridge prevents the ground monitor system from "knowing" what is happening to either the pilot wire or the trailing cable. If there is a ground fault on the shuttle car the frame will be energized and deadly.
20. Both wires must be intact if the secondary side of the ground monitor transformer is to remain a complete circuit. Otherwise the ground check relay will trip the circuit breaker and cut the power.

The transformer shown in Figures 1 through 3 operates the same way as the transformer in the power center that comprises the ground monitor for the shuttle car cable. Look at Figure 5 on the next page. Match the components in Figure 5 to the components in the ground monitor system in Figure 4.

**Question F Feedback (continued)**

Figure 5: Schematic of the transformer, pilot, and ground wire portions of a transformer like the one in the power center ground monitoring system for the shuttle car



**End of Problem**

Now use the feedback pages to score your answer sheet. Then discuss the exercise with your instructor.

## **Appendix B: Answer Sheet**

This is the answer sheet. Unlike the problem booklet, the answer sheet is consumable. You will need a new answer sheet for each person in your class.

Trainees should work the exercise in groups of three or four persons. Each person should have his or her own answer sheet.

After everyone in the small group has marked their answer on their own answer sheet, all the miners in the small group should look at the feedback for the answers to the question and briefly discuss this information. When the discussion is completed, the group should continue on and do the remaining questions in the same way.

## Basics of Transformers and Monitors Answer Sheet

Mark your answers for each question by circling the appropriate numbers on this answer sheet.

Question A	(Circle ONE)	1	2						
Question B	(Circle ONE)	3	4						
Question C	(Circle ONE)	5	6						
Question D	(Circle ALL correct)	7	8	9	10				
Question E	(Circle ONE)	11	12	13	14				
Question F	(Circle ALL correct)	15	16	17	18	19	20		

### Finding your score

Number of "Correct" answers you marked = (1) \_\_\_\_\_

9 minus the number of incorrect answers you marked = (2) \_\_\_\_\_

Add the values in blanks (1) and (2) to get your total score = (3) \_\_\_\_\_

Highest possible score = 20

Lowest possible score = 0