Electrical Equipment - Course PI 30.2

DISCONNECT SWITCHES AND CIRCUIT BREAKERS

OBJECTIVES

On completion of this module the student will be able to:

1. Briefly state, in a few sentences, why a disconnect switch is only used for isolation of electrical circuits.

2. State, in writing, the common voltage range for which the following circuit breakers are used in NGD:
   a) Air
   b) Air blast
   c) Vacuum
   d) Oil
   e) Sulphur Hexaflouride (SF_6)

3. For an air circuit breaker:
   a) List, in writing, the three sets of contacts used.
   b) Discuss briefly, in three or four sentences, the purpose of each set of contacts.
   c) Discuss briefly, in three or four sentences, what metal is used to make each set of contacts and why.
   d) In point form, list the sequence of operation for opening and closing the breaker.

4. Briefly explain in writing, the terms list below, as applied to a circuit breaker.
   a) Voltage rating;
   b) Continuous current rating;
   c) Interrupting current rating;
   d) Interrupting capacity.

5. In writing, list the advantages and disadvantages of:
   a) Air circuit breaker;
   b) Air blast circuit breaker;
   c) Oil circuit breaker;
   d) Vacuum circuit breaker;
   e) SF_6 circuit breaker.

6. In three or four sentences, differentiate between the two types of air blast circuit breaker.

7. Briefly, in writing, identify the type of air blast circuit breaker used at Bruce N.G.S. A & B and state how additional isolation is provided and why.

8. Briefly, explain, in writing, the purpose of the interrupting and isolating contacts on a non-pressurized type circuit breaker.

9. If given a simplified diagram, list, in writing, the opening sequence for a fully pressurized type of air blast circuit breaker.

10. Briefly, explain in writing, and using simple diagrams how the arc is quenched in an:
    a) Air blast circuit breaker;
    b) Oil circuit breaker.

1. Introduction

This lesson will introduce the reader to:

(a) Standard electrical symbols.
(b) HV disconnect switch and its purpose in NGD.
(c) Circuit breakers; their ratings and their purpose.
(d) Types of circuit breakers used in NGD.
(e) Advantages and disadvantages of each type of circuit breaker.

2. Disconnect Switch

2.1 Electrical Symbols

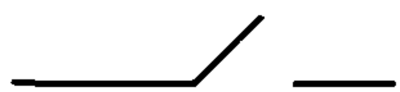


Figure 1(a): Disconnect Switch Manually Operated

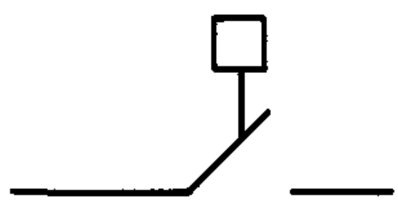


Figure 1(b): Disconnect Switch Motor Operated

2. Disconnect Switch (continued)

2.2 Construction and Operation

The current carrying parts of the disconnect switch are mounted on insulators. The switch operation is based on lever action. Figure 2 shows a HV disconnect switch.

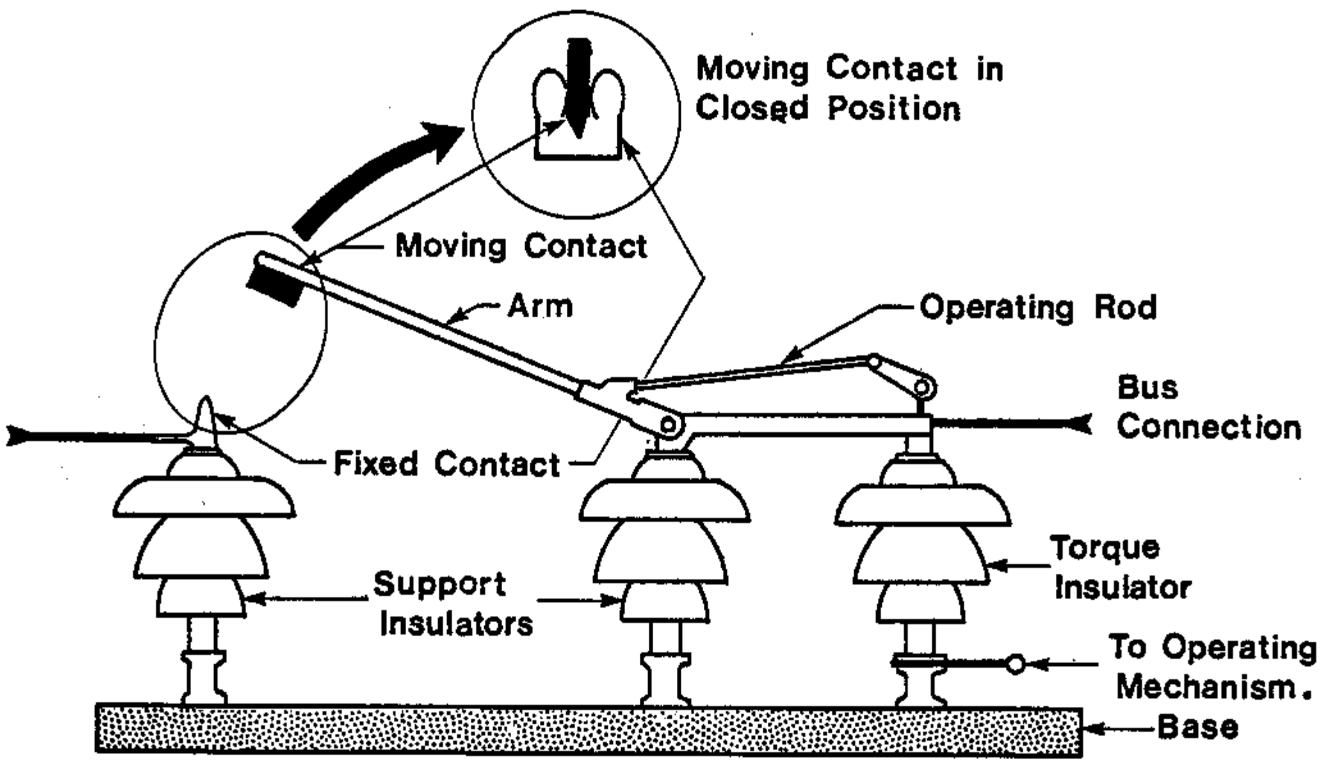


Figure 2: HV Disconnect Switch

To open (or close) the switch, the operating mechanism is operated by a hand wheel or a motor (not shown). This turns the torque insulator and causes the operating rod to pull (or push) the moving contact arm, for the opening (or the closing) of the disconnect switch. HV disconnect switches:

(a) are not capable of making or breaking the load or fault currents because they have no arc quenching mechanism.

(b) are used for isolation purposes only and are quoted as such on work permits in NGD.

3. Circuit Breakers

3.1 Electrical Symbols

Circuit Breaker
(Manual)

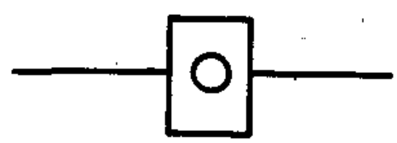
Figure 3(a)

Circuit Breaker
(Rack Out Type)

Figure 3(b)

Circuit Breaker
(Electrically Operated)

Figure 3(c)



Power Circuit Breaker
(Above 15kv)

Figure 3(d)

Figure 3

3.2 Circuit Breaker Types

Circuit breaker types are classified, depending on the medium of arc quenching used. Table 1 lists the various types of circuit breakers used in NGD. Listed, also, are some typical operating parameters for each breaker type.

Circuit Breaker Types

Table 1

Type of Breaker	Arc Extinguished by	Medium of Arc Quenching	Remarks
Air	Arc contacts and arcing horns operating in air.	Air	Used in NGD for voltages up to and including 13.8kV.
Air Blast	A blast of compressed air	Air	Used in NGD for high voltages, 115kV 230kV and 500kV.
Oil	Oil	Oil	Uses in NGD at 115kV, 230kV
Vacuum	Vacuum	Vacuum	Used at BHWP at 2.4kV.
Sulphur Hexa-fluoride (SF_6)	SF_6	SF_6	Gaining acceptance by OH. Available in range of voltages up to 500kV.

Notes

3.2.1 Air Circuit Breakers

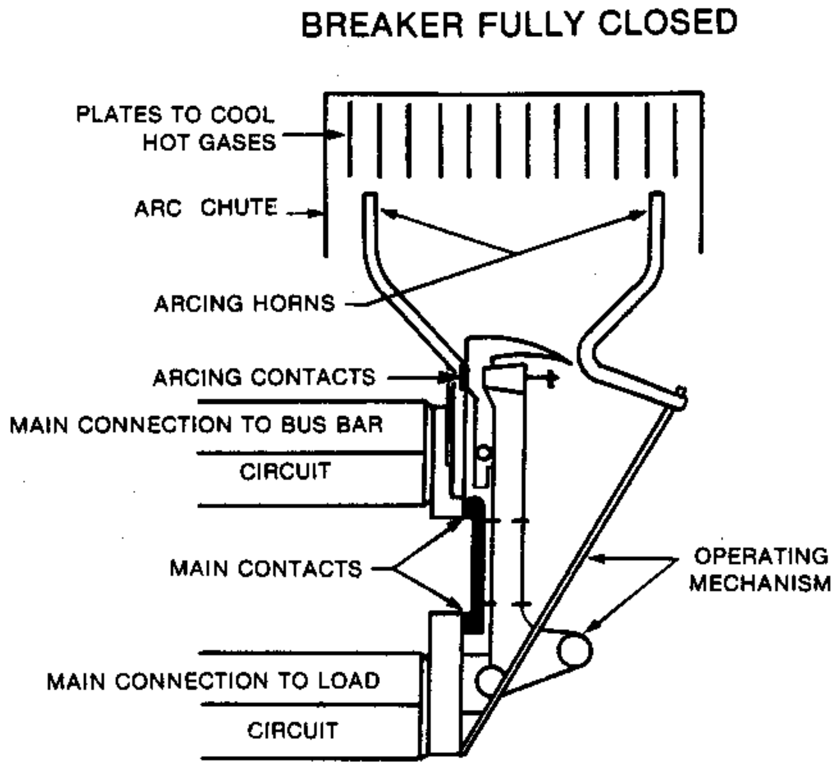


Figure 4(A): Breaker Fully Closed

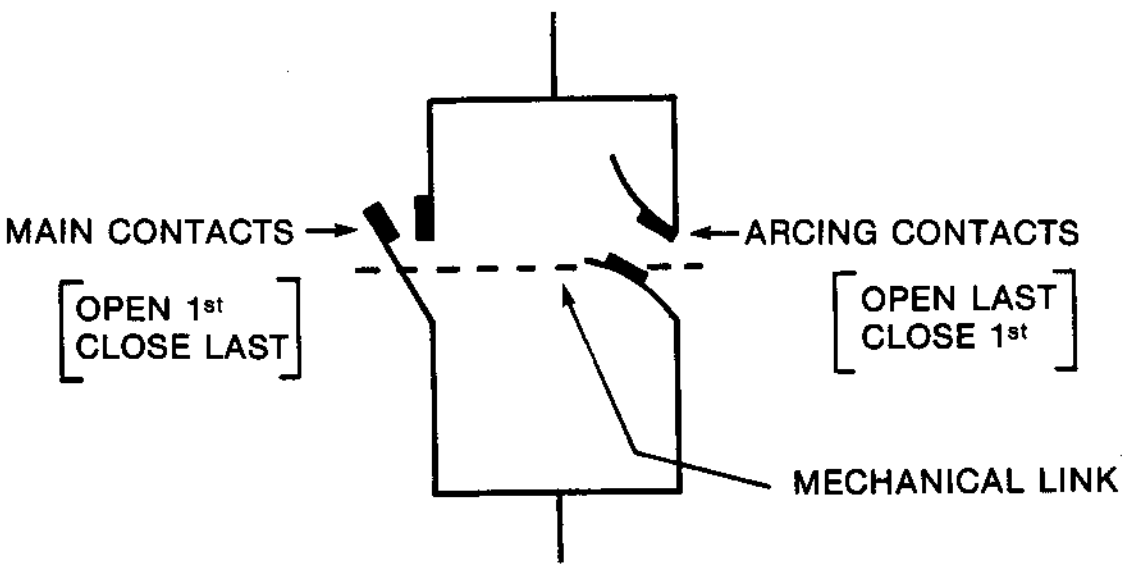


Figure 4(B): Breaker Contacts Opening

3.2.1 Air Circuit Breakers (continued)

(a) Construction

Each phase of a 3 phase air circuit breaker consists of three types of contacts, namely; main contacts, arcing contacts and the arcing horn. Their operating mechanisms are shown in Figure 4(A).

(i) The main contacts carry the load current under normal operation. Main contact resistance, at the point of contact, must be low to prevent overheating, when current is flowing through it. The main contacts are therefore made of a good conducting material such as copper, silver or copper with silver plating. Since these metals have relatively lower melting points, they can be damaged if arcing occurs. To prevent this damage, the main contacts do not make or break the current.

(ii) Arcing Contacts

Since no arcing must occur at the main contacts, arcing contacts are provided, which make or break the circuit current. This causes the arcing to occur at the arcing contacts. These contacts are constructed of a harder material with a higher melting point (eg. tungsten). Arcing contacts and the main contacts are connected in parallel, as shown in Figure 4(B).

(iii) Arcing Horns

Arcing horns are made from hard copper. After the arc is established on the arcing contacts, it is transferred to the arcing horns during the opening of the arcing contacts. Their shape is designed to stretch and weaken the arc.

(iv) Arc Chute

The arc chute is a cooling chamber located at the top end of the breaker. It cools the hot gases which are produced when arcing occurs.

(v) Operating Mechanism

The operating mechanism is designed to actuate the moving parts of the air circuit breaker during the opening or closing operation. The operating mechanism can be operated manually or electrically

3.2.1 Air Circuit Breaker (continued)

(by energizing a close coil for closing or a trip coil for opening). The push button controls for the electrical operation of circuit breakers may be located in the control room.

(b) Operation

To understand the sequence of operation of various contacts in the air circuit breaker, one must realize that arcing must never occur at the main contacts.

(i) Opening Cycle

Refer to Figure 5.

When the breaker is closed, the load current passes through the low resistance main contacts. See Figure 5(a).

As the breaker opens, the main contacts open first, transferring the current to the arcing contacts. See Figure 5(b).

The arcing contacts open and an arc is established across them through the air medium. See Figure 5(c).

As the arcing contacts continue to open, the arc is transferred to the arcing horns. The arc rises to the top of the arcing horns. This is because hot gases rise due to the convection principle. At the same time the arc is being lengthened, the arc enters the arc chute, see Figure 5(d), where it is rapidly cooled by the cooling plates. Cooled gases are deionized and cannot conduct electricity, and consequently the arc is extinguished.

(ii) Closing

For the breaker closing cycle, the arcing contacts touch first, making the circuit. The main contacts close a short time afterwards, completing the closing operation.

3.2.1 Air Circuit Breaker (continued)

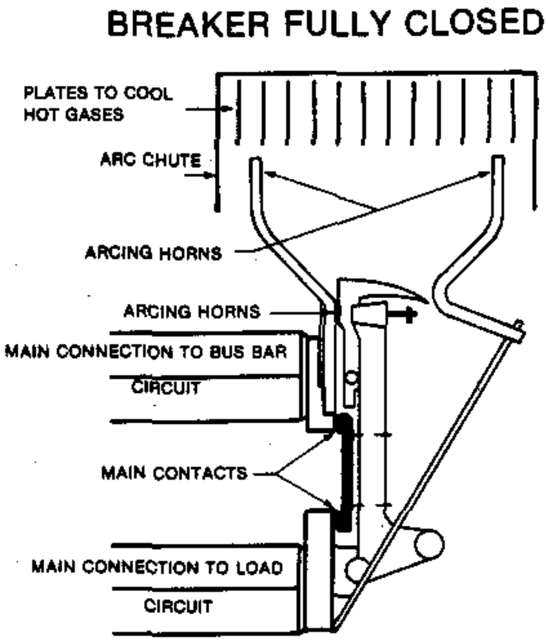


Figure 5(a)

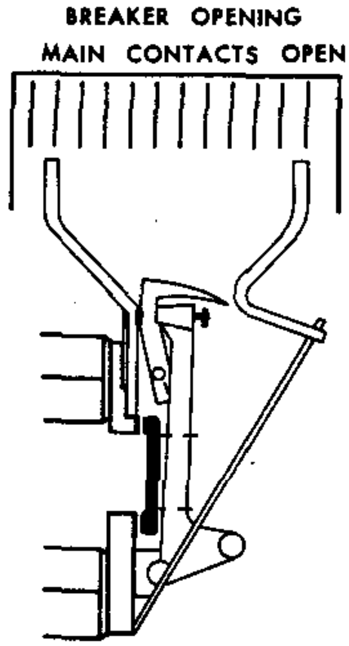


Figure 5(b)

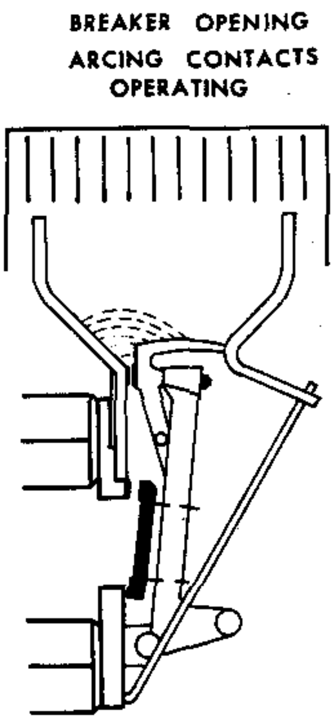


Figure 5(c)

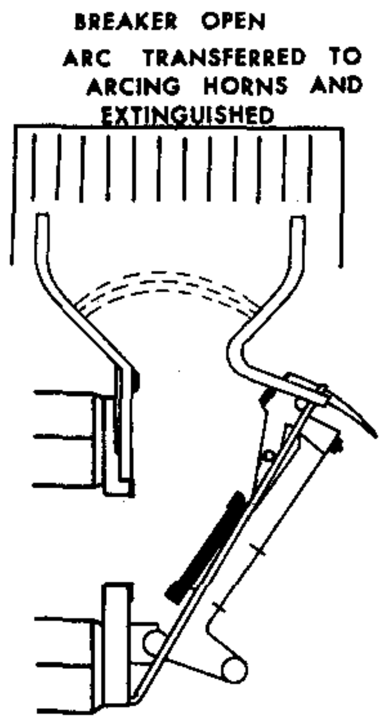


Figure 5(d)

Figure 5: Air Circuit Breaker Operating Sequence

3.2.2 Circuit Breaker Ratings

In common with fuses, circuit breakers also have three basic ratings. They are:

(a) Voltage Rating

Breakers are supplied by the manufacturer to operate at a specified voltage. This voltage rating indicates the maximum application voltage, at which arcing will not occur between the contacts, when the circuit breaker is open.

(b) Continuous Current Rating

Breakers are constructed to operate continuously at a specified value of load current. The current carrying components are designed to be able to carry the load current continuously, without overheating.

(c) Interrupting Current Rating

This is the mazimum fault current which can be safely interrupted. A breaker must have the capability to interrupt a large value of short circuit or fault current without damage. Typically, the fault current is 20 times the continuous current rating. Because of the large amount of heating associated with 20 times normal current, it follows that the breaker can only be subjected to this value of current, for a very short time. Therefore, the breaker must be able to rapidly clear a fault or short circuit. Typical fault clearance times are 5 to 8 cycles, at 60 Hz (80-100 milliseconds).

In addition to the three basic ratings as mentioned, theinterrupting capacity rating of a circuit breaker is sometimes mentioned. (ie - the MVA rating)

$$\text{Interrupting Capacity [MVA]} = \sqrt{3} \times \frac{\text{Rated Voltage [KV]} \times \text{Rated Interrupting Current [KA]}}{10^6}$$

(Do not memorize)

3.2.3 Advantages and Disadvantages of Air Circuit Breakers

Advantages

(a) Relatively inexpensive.
(b) Simple construction.
(c) Simple maintenance requirements.

Disadvantages

(a) Normally limited to a maximum voltage rating of 15kV.
(b) Normally limited to an interrupting capacity of about 1000MVA.

Type of Circuit Breaker	Nominal Voltage Class	Nominal Three Phase Interrupting Capacity (rounded off)	I Continuous	I Interrupting
Air	13.8kV	890MVA	2000	37.5kA
	4.16kV	208MVA	2000	29kA
	600V	43MVA	1600	42kA
	600V	25MVA	600	25kA
Airblast	230kV	25000MVA	2500	63kA
	500kV	69000MVA	4500	80kA
Oil	242kV	26000MVA	3000	63kA

Typical Rating of Air, Air Blast & Oil Circuit Breakers Used at NGD

Table 2

3.3 Air Blast Circuit Breaker

The medium used to extinguish the arc created in airblast circuit breakers is a blast of very dry, clean air, at a high pressure. The air pressure is high enough to actually open or close the contacts.

3.3.1 Types and Construction

There are two types of air blast circuit breakers:

(a) Fully Pressurized Type

In this type, the moving contacts after opening, are kept open by maintaining the air pressure in the main chamber (interrupting head). The contacts in this type of breaker make or break the line current and also provide isolation, provided no loss of air pressure occurs. However, if air pressure is lost the contacts will close and a disasterous situation may occur. To prevent this, a motorized disconnect switch is used to ensure that isolation is safely maintained under all circumstances. This type of breaker is used at Bruce NGS "A" & "B". Figure 6 shows a simplified diagram of this type of circuit breaker. Figure 6 is repeated in Figure 7 and the major breaker components are identified.

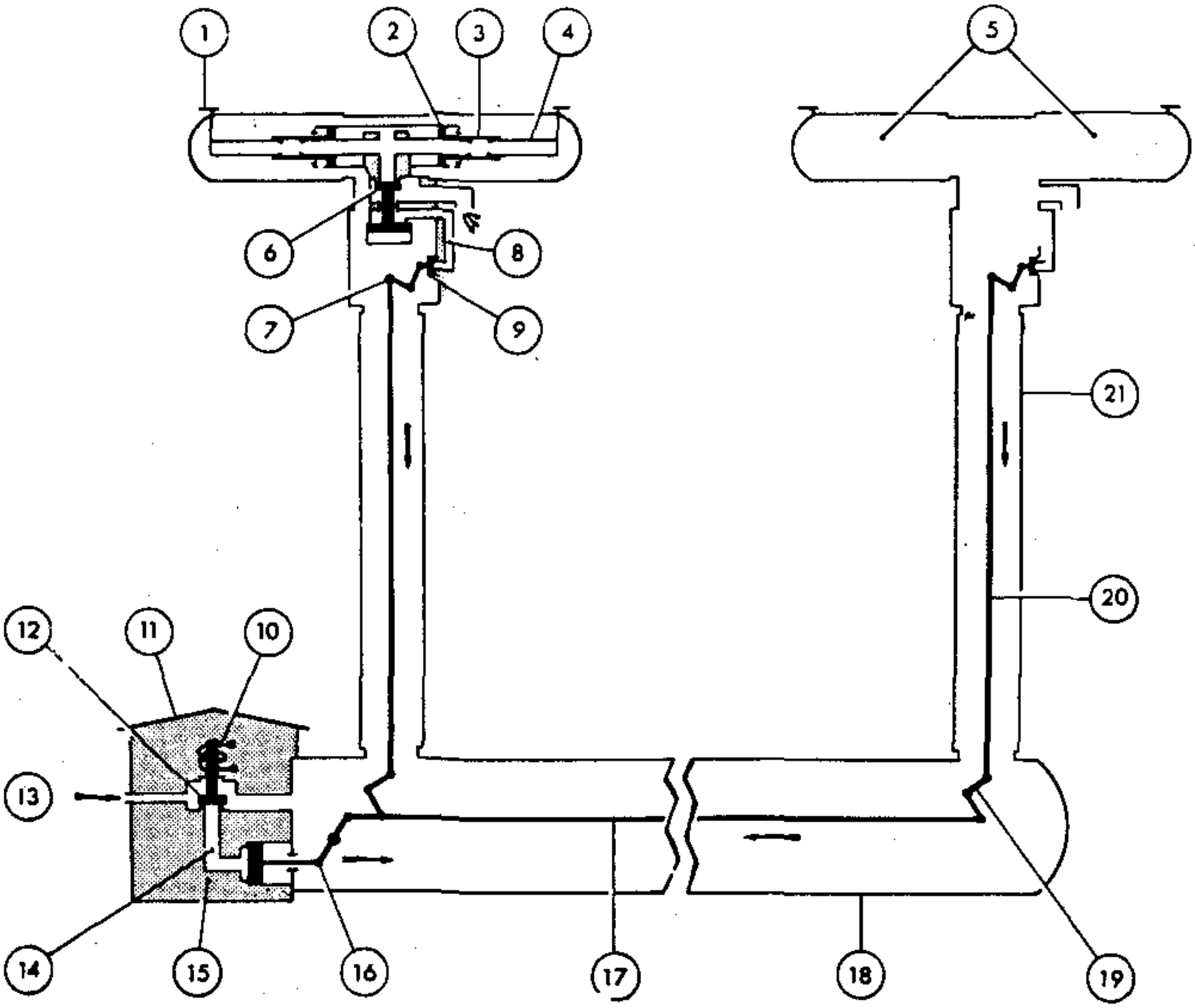


Figure 6: Air Blast Circuit Breaker - Fully Pressurized Type

3.3 Air Blast Circuit Breaker

(a) Fully Pressurized Type (continued)

The circuit breaker is shown in a closed position. The closing and tripping mechanisms are identical. To simplify the diagram, only the tripping mechanism is shown.

Figure 8 is a chart which identifies various breaker components. (Do not memorize diagram).

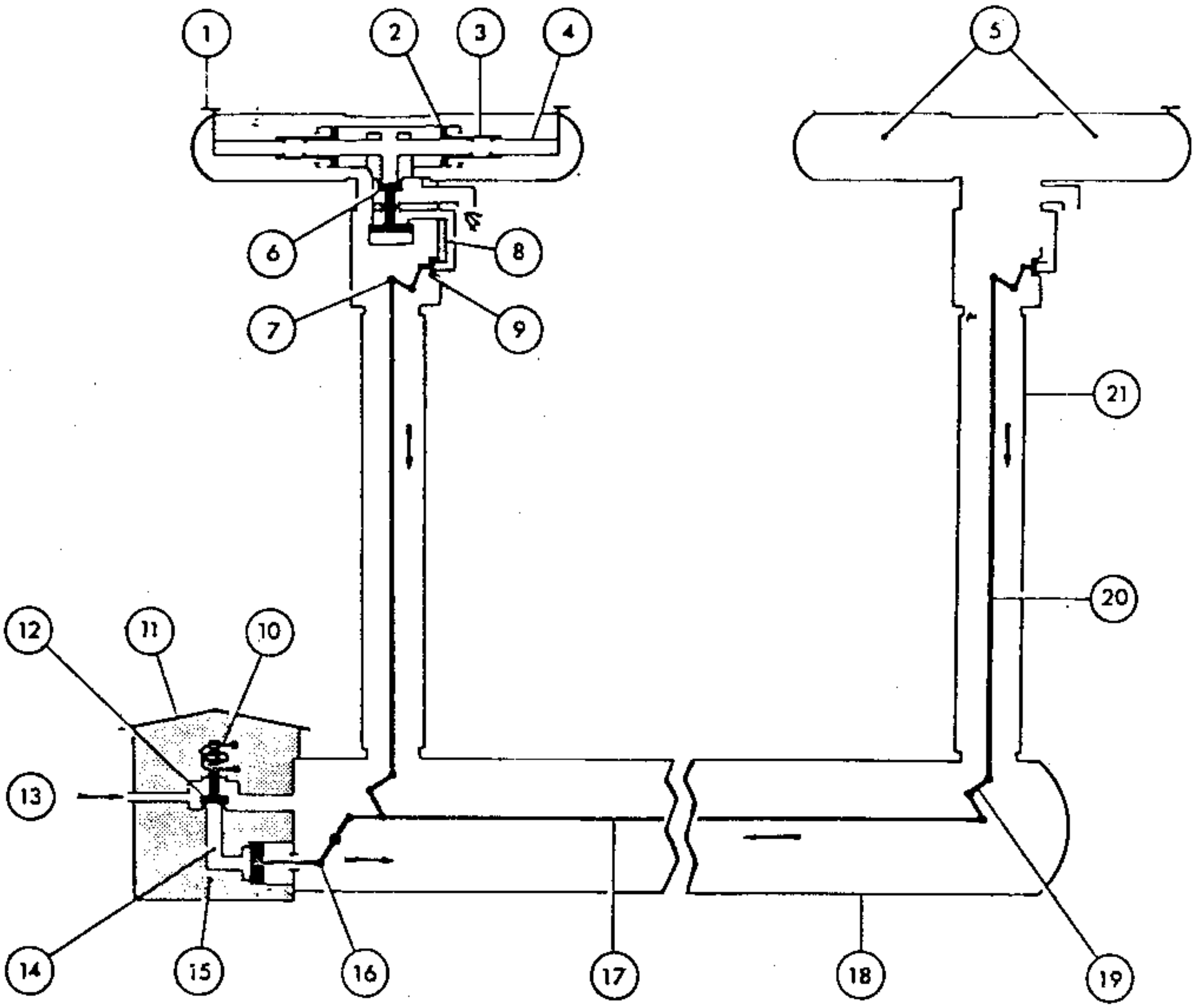


Figure 7: Air Blast Circuit Breaker - Fully Pressurized Type

Item	Designation
1	Terminal
2	Moving contact piston (see 3)
3	Moving contact of main chamber
4	Fixed contact of main chamber
5	Main chamber (extinguisher chamber)
6	Tripping control valve
7	Upper countershaft
8	Control valve channel (see 6)
9	Pilot valve of control valve (6)
10	Electro-valve
11	Single-pole control cubicle
12	Pilot valve of pneumatic control block
13	Intake of compressed air
14	Rod control channel (see 16)
15	Pneumatic control block
16	Rod control system
17	Horizontal metallic rod
18	Frame-tank
19	Lower countershaft
20	Vertical insulating rod
21	Insulting supporting column

Figure 8: Fully Pressurized Type Air Blast Circuit Breaker Components.

3.3 Air Blast Circuit Breaker

3.3.1 Types and Construction (continued)

(b) Non-pressurized Type

In this type of air blast circuit breaker, the fault current is interrupted by the contacts in the interrupting heads and the isolating heads, but isolation is maintained only by the isolating contacts. The isolation contacts are an integral part of the circuit breaker. Figure 9 shows such a circuit breaker.

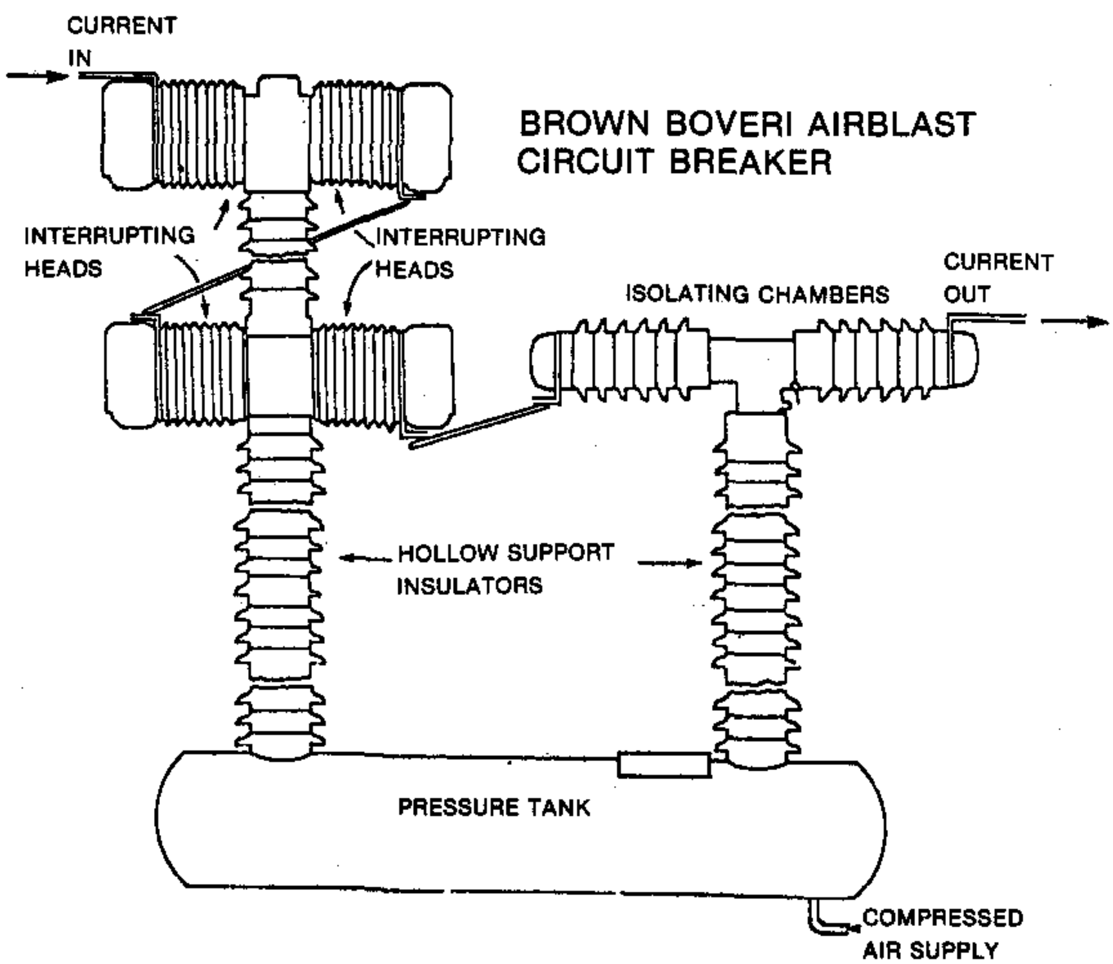


Figure 9: Non-Pressurized Air Blast Circuit Breaker

3.3.2 Operation of Fully Pressurized and Non Pressurized Air Blast Circuit Breakers

The operation of both of these circuit breaker types can be reviewed in Appendix A, which is situated at the end of this chapter. While reviewing this material, the reader should appreciate that both designs incorporate complex air pressurizing systems resulting in necessary extensive and costly maintenance. Other points worthy of note are discussed in the next section.

3.3.3 Advantages and Disadvantages of Air Blast Circuit Breakers

Advantages

(a) By connecting several breaker heads in series the voltage rating of the breaker can be increased.

(b) By careful design, the interrupting capacity rating can be increased to over 50,000 MVA.

(c) Fast clearance of fault currents. Breakers used at Bruce NGS can clear a fault within 2 cycles.

Disadvantages

(a) Expensive.

(b) Complicated construction, requiring air receivers and high pressure pipework.

(c) Maintenance is time consuming, as access is difficult.

(d) A supply of **very dry**, compressed air is required to ensure no condensation or ice formation on the insulators or contacts.

(e) The breaker, when opened, unless fitted with silencers, is very noisy and consequently cannot be used in built-up residential areas.

3.4 Oil Circuit Breakers

3.4.1 Construction

Refer to Figure 10 for the following discussion.

(a) Tank

Houses the electrical contacts, insulated pot and the oil.

(b) HV Bushings and Connectors

HV bushings are insulators made of ceramics. They prevent short circuiting between the current carrying conductors and the tank. HV connectors are the conductors which are conneced to the power lines, via disconnect switches.

(c) Electrical Contacts

Electrical contacts have two parts:

(i) Fixed contact.
(ii) Moving contact.

The fixed contacts are stationary and do not move. The moving contacts can be moved by an operating rod, sometimes referred to as a push-and-pull rod. The operating rod is actuated by an electrically driven, opening and closing mechanism that has both local and remote (control room) controls.

(d) Pots

The pots enclose the electrical contacts, holding them in the arc cooling oil. The pots are made of insulating material and also act as a pressure chamber when the arc is developed. Breather holes are provided in the pots to allow fresh oil to enter the pot.

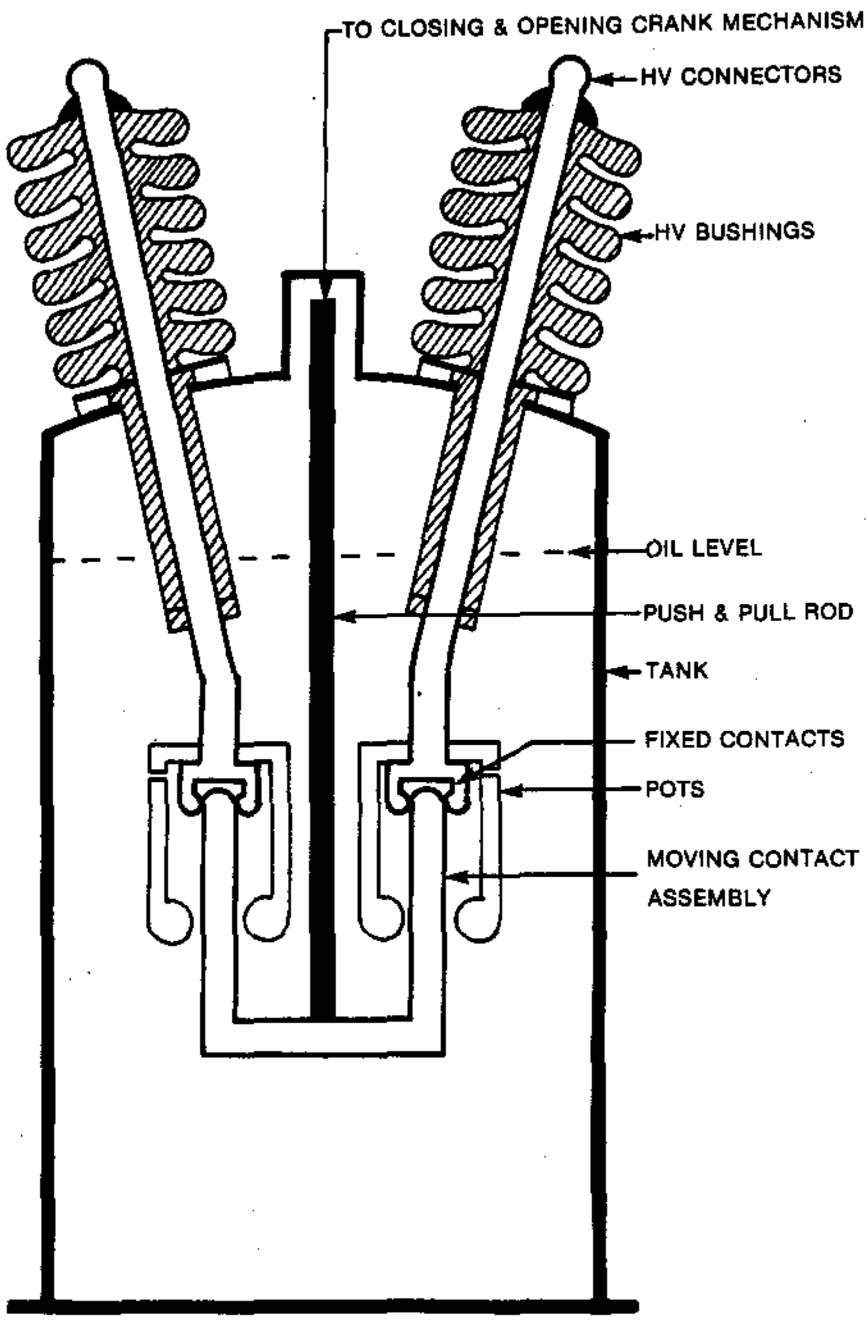


Figure 10: High Voltage Oil Circuit Breaker - Shown in the CLOSED Position

3.4.2 Operation

Refer to Figure 11(a) and 11(b). In Figure 11(a) a breaker pot is shown with the moving contact in the closed position. When a fault occurs or when it is required to open the breaker, an electrical signal is given to the operating mechanism causing the crank mechanism to move forwards. This action causes the moving contact to move away from the fixed contact and an arc is developed.

The process of arc extinguishment in an oil circuit breaker is as follows:

(a) As the moving contact moves away from the fixed contact an arc is developed.

(b) High temperature arc causes the oil in the pot to break down and form gas.

(c) Production of gas pressurizes the pot. Hence, oil in the pot is forced past the electrical contacts and provides cooling. This extinguishes the arc.

(d) Cool, fresh oil from the tank enters the pot, via breather holes.

(e) Gases produced, recombine into oil, or become dissolved in it.

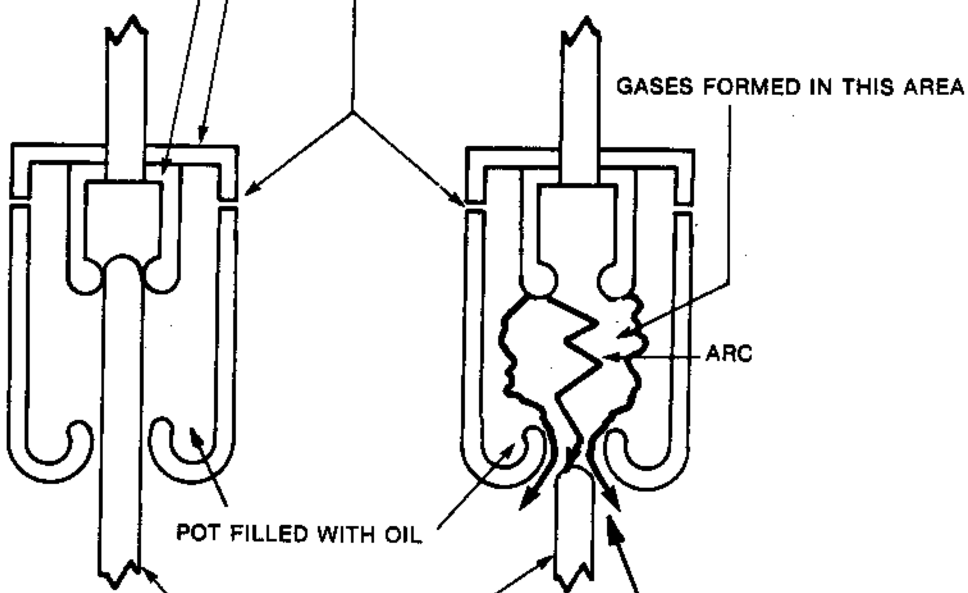


Diagram Showing An Oil Breaker Pot With Contacts in the Closed Position

Figure 11(a)

Diagram Showing How the Arc is Extinguished in an Oil Circuit Breaker

Figure 11(b)

3.4.3 Advantages and Disadvantages of Oil Circuit Breakers

(a) Advantages

(i) By connecting several interrupting mechanisms in series, the voltage rating of the breaker can be increased.

(ii) By careful design the interrupting capacity rating can be increased up to 26,000 MVA.

(iii) Quiet operation.

(b) Disadvantages

(i) The breaker contains flammable oil, consequently it should be located outdoors.

(ii) Oil breakdown at high temperatures forms carbon which gets dissolved in the oil. This increases the oil conductivity. To keep the oil insulating properties at an acceptable level, it must be purified after a predetermined number of breaker operations. This requires oil treatment equipment on site.*

(iii) may become an environmental hazard if spillage occurs.**

* Oil purification standards for the breakers are the same as for the transformer oil.

** Askerol is both an environmental and a health hazard.

Notes

3.5 Vacuum Circuit Breakers

3.5.1 Construction and Operation

A vacuum circuit breaker consists of a sealed vacuum "pot" or flask which contains the contacts. A vacuum provides the insulation and arc extinguishing medium. The moving contact is moved by some moving mechanism and the arc is extinguished at the first "crossing of current" through zero amplitude. Figures 12 and 13 show a vacuum circuit breaker in the OPEN and CLOSED positions, respectively. This design is relatively new and gaining acceptance.

3.5.2 Advantages and Disadvantages of Vacuum Breakers

(a) Advantages

(i) Small size.

(ii) Requires little maintenance as they are "sealed for life".

(iii) Can be operated many tens of thousands of times before replacement is required.

(b) Disadvantages

(i) Loss of vacuum can be dangerous and difficult to detect.

(ii) Normally, no repairs can be done to the breaker. Faulty units are usually discarded.

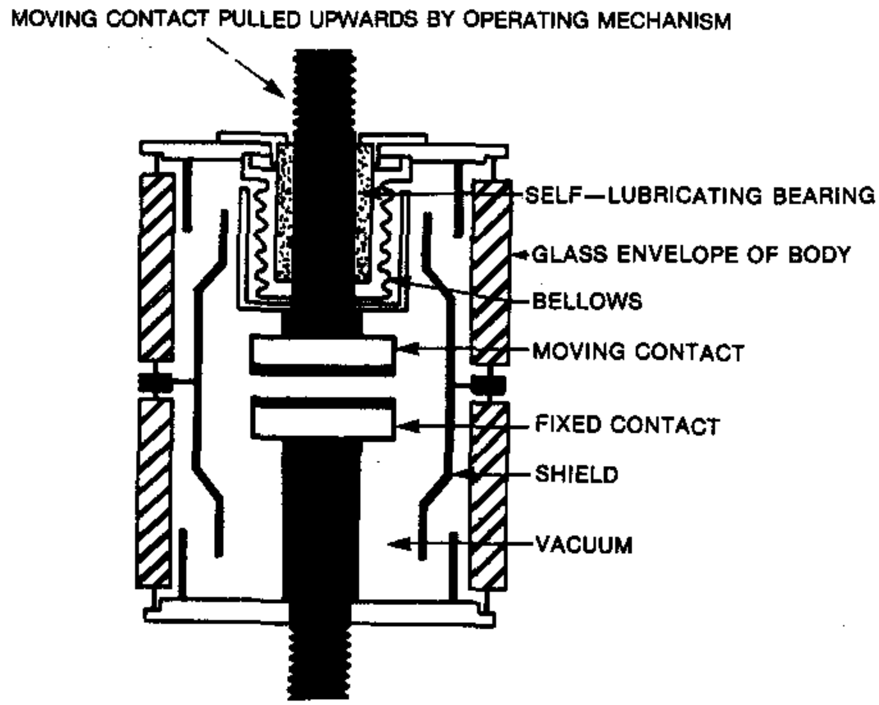


Figure 12: Vacuum Breaker: Open Position

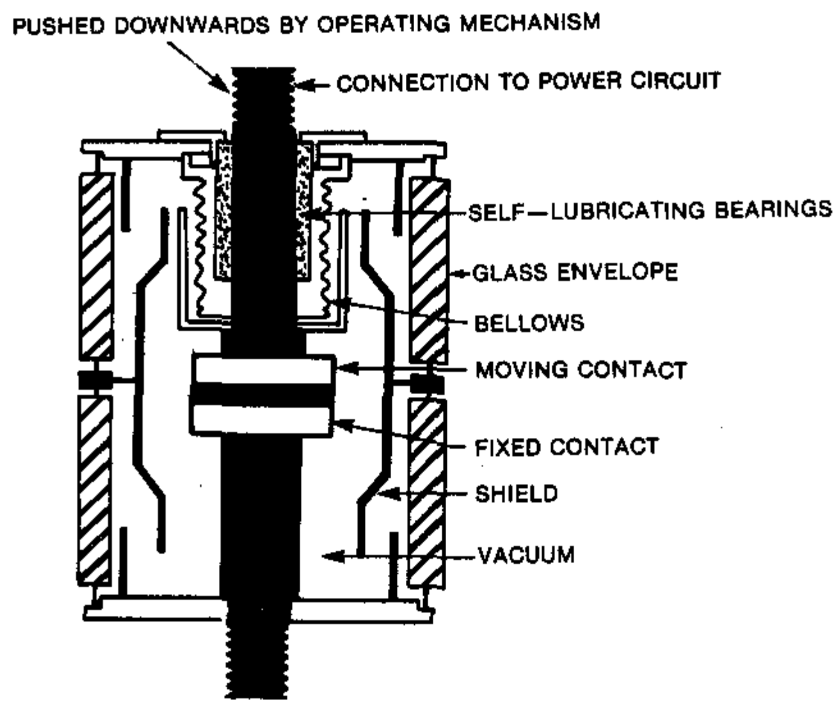


Figure 13: Vacuum Breaker: Closed Position

3.6 Sulphur Hexa Floride (SF_6) Circuit breaker

3.6.1 Construction and Operation

SF_6 gas is a very stable compound. It has high insulating qualities and good interrupting properties. SF_6 gas is inert, nonflammable, non toxic and odorless. It is used as an arc quenching medium in circuit breakers up to 500 kV.

The SF_6 has high pressure gas which blasts out at the electrical contacts when the breaker is opened. Since the gas is at high pressure, to prevent liquification of the gas, a gas heater is provided. High arc temperatures cause the gas to decompose into atoms, electrons and ions. However, most of it recombines quickly. Before the gas is recompressed, it is filtered, by passing it through activated aluminum to remove gaseous florides.

Figure 14 shows a 230 kV, SF_6 circuit breaker.

3.6.2 Advantages and Disadvantages

(a) Advantages

(i) Relatively smaller size.

(ii) Can be housed in a building to complement the area (environmentally desirable).

(iii) High interrupting capacity.

(b) Disadvantages

(i) Expensive.

(ii) Relatively new development.

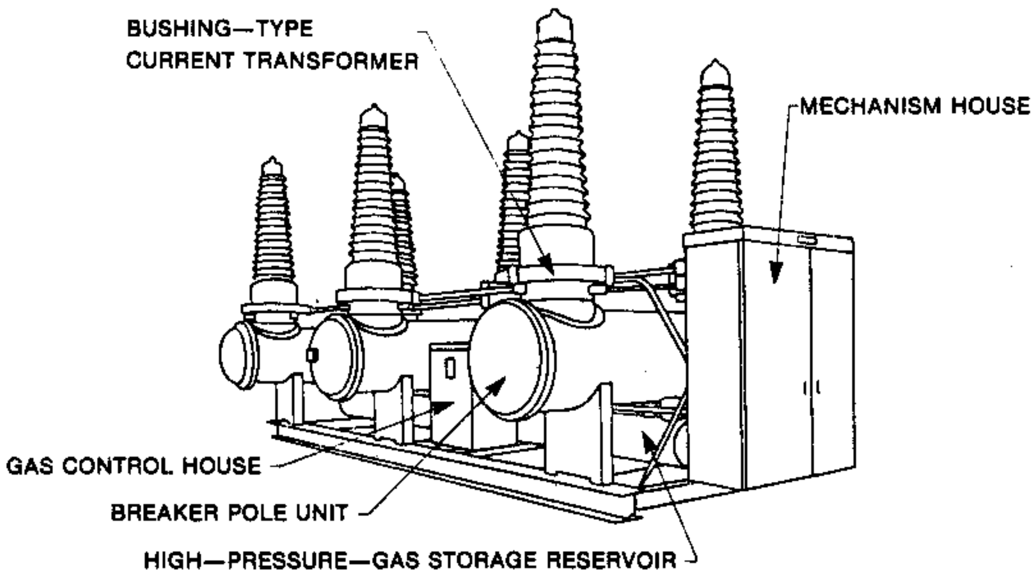


Figure 14: 150kV Sulphur Hexa-Floride (SF_6) Circuit Breaker

ASSIGNMENT

1. Can a disconnect switch be used for making or breaking a fault or load current. Explain (section 2.2).

2. What is the purpose of a disconnect switch in Ontario Hydro applications? (Section 2.2)

3. Complete the following table: (Table 1)

Circuit Breaker	Medium Used for arc Quenching	Voltage at Which it is used in NGD
Air		
Air Blast		
Vacuum		
Oil		
SF_6		

4. For an air circuit breaker:

   (a) List the three sets of contacts used. (Section 3.2.4)

   (b) Give the purpose of each set of contacts. (Section 3.2.1)

   (c) For each set of contacts, what metal is used to make them and why? (Section 3.2.1)

4. For an air circuit breaker (continued):

   (d) List the sequence of operation for opening and closing cycle. Section (3.2.1, ii)

5. What do the following ratings of a circuit breaker mean: (Section 3.2.2)

   (a) Voltage rating

   (b) Continuous current rating

   (c) Interrupting current rating

   (d) Interrupting capacity.

6. List three advantages and two disadvantages of an air circuit breaker. (Section 3.3.3)

7. List two types of airblast circuit breakers and briefly explain what the difference between them is. (Section 3.3.1)

8. For the two types of air blast circuit breakers which are used at Bruce N.G.S. and what additional isolation feature is provided along with them and why? (Section 3.3.1, a and b).

9. What is the purpose of interrupting contacts and of isolating contacts in a nonpressurized air blast circuit breaker? (Section 3.3.1, b).

10. List three advantages and five disadvantages of an airblast circuit breaker. (Section 3.3.3, a,b,)

11. Using diagrams explain how the arc is quenched in an oil circuit breaker. (Section 3.4.2).

12. List three advantages and three disadvantages of an oil circuit breaker. (Section 3.4.3)

13. List the advantages and disadvantages of:
    (a) a vacuum circuit breaker (section 3.5.2).

    (b) SF_6 circuit breaker (Section 3.6.2)

14. Complete the following table by indicating which piece of equipment is suitable for each of the three functions listed. Also state any constraints which may limit that piece of equipment in a specific function. (if any).

Equipment	Interrupt Current	Isolation	Protect Against Fault Current
Fuse			
Disconnect Switch			
Circuit Breaker			

S. Rizvi

Notes

Appendix A

Fully Pressurized Type

Refer to Figure 1. The main chambers (5) are permanently pressurized because they are connected directly to the air tank (18) via the insulating support column. Piston (2) drives the moving contacts (3). Normally, the pressure on the two sides of the piston (2) is the same. Piston (2) is actuated by creating a difference of pressure, between its two faces.

Sequence of Operation

(a) Opening Cycle

An opening signal to the coil of electro-valve (10) causes the opening of pilot valve (12).

Pressure is then established in the channel (14) to actuate the piston controlling the rod assembly (16).

The movement of the piston causes the horizontal metal rods (17) to be pulled, as well as the vertical insulating rods (20), through the counter shafts (19).

On being pulled, the rods (20) open the pilot valve (9). Pressure is then established in the channels (8) and on the piston of each of the opening control valves (6) causing them to open. There is one opening control valve in each main chamber.

As the valves (6) open, the inside of the tubular moving contacts (3) is open to the atmosphere, as well as the annular space on the rear face of the pistons (2).

The pressure on the front face of the piston (2) is greater than the rear face. This causes the contacts to open.

(b) Closing Cycle

For the closing of this type of air blast circuit breaker, there is another set of valves called closing valves (not shown). The principal of operation is similar to the opening cycle, except the closing value will exit the other side of the piston (2) to atmosphere.

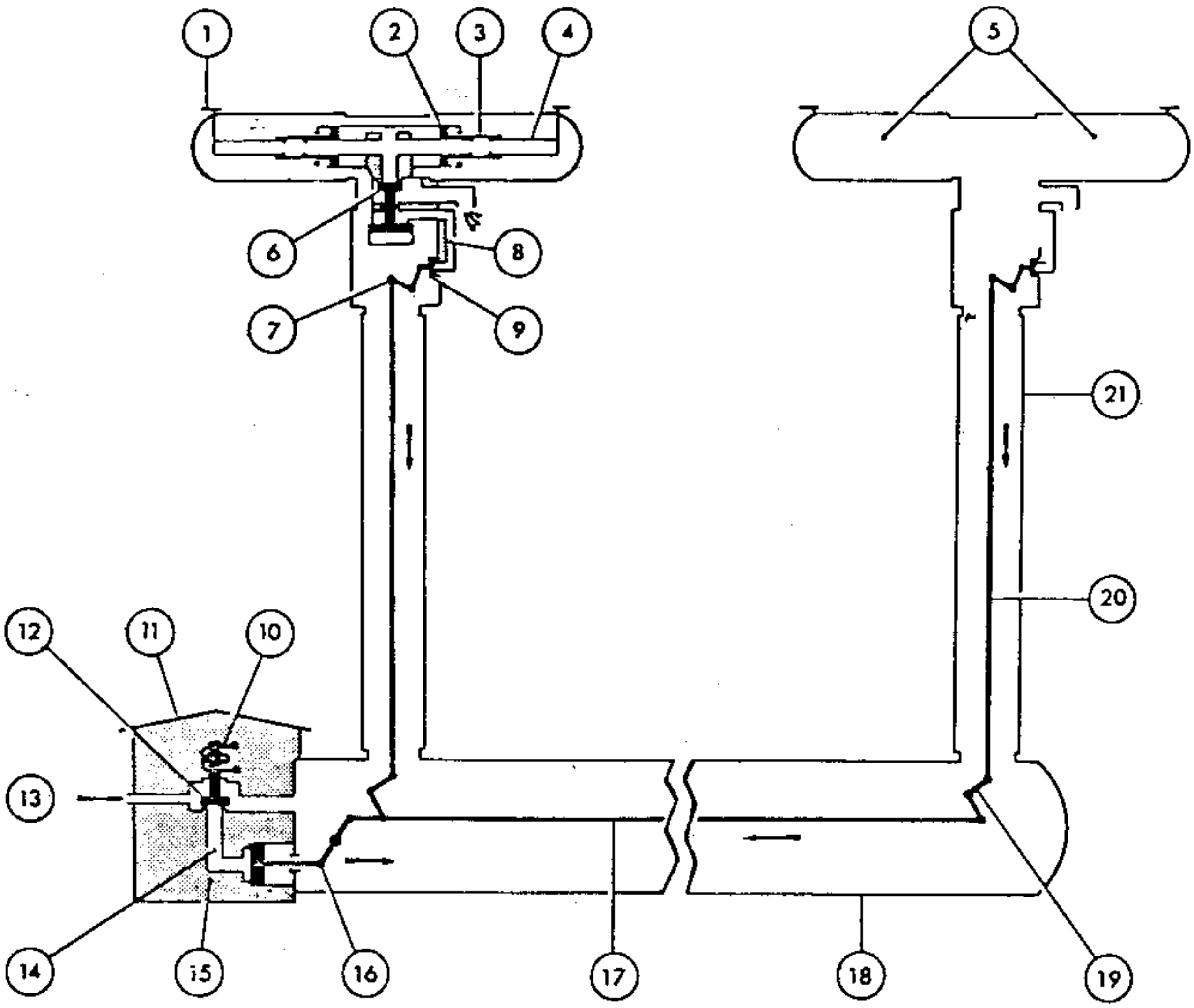


Figure 1: Air Blast Circuit Breaker - Fully Pressurized Type

The circuit breaker is shown in the closed position.

Non-Pressurized Type

Sequence of Operation

Figure 2 shows the operation of this type of circuit breaker. Each interrupting head contains a fixed and a moving contact.

(a) Opening Cycle

An electrical signal to the blast valve opens the valve. Air pressure acts on the lower part of the moving contact and depresses the spring causing the moving contact to move in the cavity. Figure 2(B) shows the interrupting head of an AECB in closed position.

As the moving contact moves away from the fixed contact and arc is developed, Figure 2(C).

A blast of air from the air reservoir rushes past the moving contact and provides cooling. This extinguishes the arc, Figure 2(D).

After the contacts in all of the interrupting heads are open the isolating head contact opens. After the isolating contact has opened, the interrupting contacts reclose. Circuit isolation is maintained by the isolation contacts remaining open.

(b) Closing Cycle

To close a non-pressurized type of air blast circuit breaker, only the isolation contacts need to be closed (with an air blast). Isolation contacts, as well as the interrupting contacts are designed to make or break large currents.

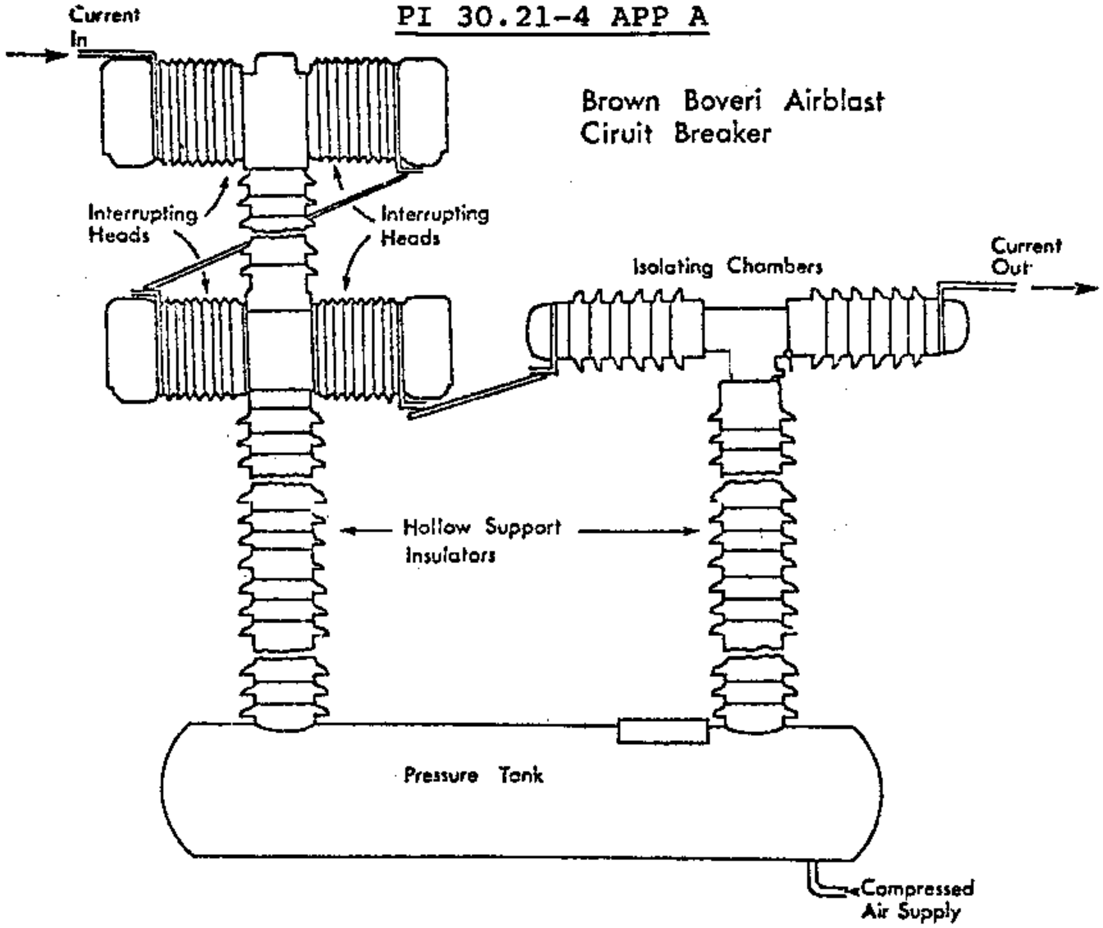


Figure 2(A): Non-Pressurized Air Blast Circuit Breaker

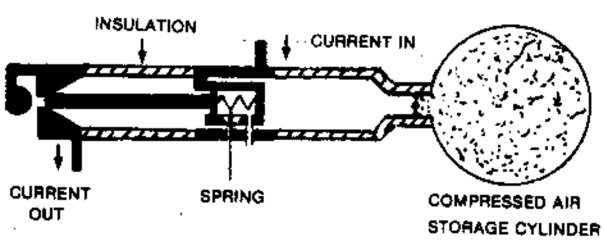


Figure 2(B)
Contacts: Closed

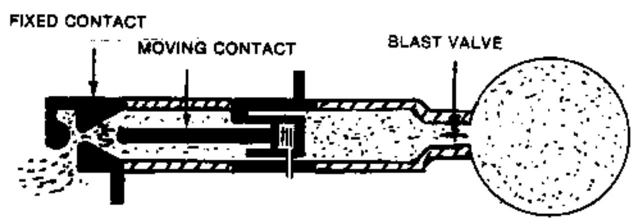


Figure 2(C)
Contacts: Open

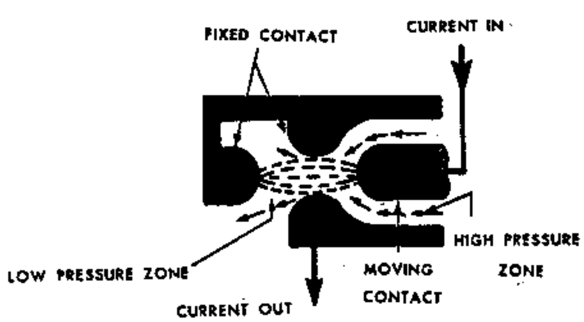


Figure 2(D): Air Blast Extinguishing An Arc

Figure 2: Non-Pressurized Air Blast Circuit Breaker