1.0 INTRODUCTION TO CIRCUIT BREAKERS

Learning Objectives

Circuit breakers are a component part of a larger system referred to as Switchgear. This chapter will explain the different types and classes of circuit breakers and where medium voltage circuit breakers fit into the Plant Electrical Distribution System.

As a result of this lesson you will be able to:

1. State the main function of a circuit breaker
2. Understand the difference between a circuit breaker and a switch
3. Explain the three main breaker voltage groups
4. Name the 4 main methods used for arc extinguishing
5. Describe the attributes of the following breaker types:
    a. Oil circuit breaker
    b. Air circuit breaker
    c. Air Blast breaker
    d. Gas Circuit breaker
    e. Vacuum breaker
6. Understand how the breakers current ratings determine function of the breaker
7. Understand the function of a medium voltage circuit breaker in a power plant distribution system

1.1 DEFINITION OF A CIRCUIT BREAKER

The American National Standards Institute (ANSI) defines a circuit breaker as: “A mechanical switching device, capable of making, carrying and breaking currents under normal circuit conditions. Also capable of making and carrying for a specified time and breaking currents under specified abnormal circuit conditions, such as those of a short circuit.”

The National Electric Code (NEC) defines a circuit breaker as “a device designed to open and close a circuit by non-automatic means, and to open the circuit automatically on a predetermined over-current without damage to itself when properly applied within its rating.”

The first circuit breakers looked very much like a knife switch (Figure 1-1); these switches would be closed and opened by hand. Modern circuit breakers operate like a switch when turning on and off power to equipment, but as the ANSI definition indicates they also have to provide protection to the systems they are supplying power to. When a fault or short circuit occurs a circuit breaker becomes a protective device and will automatically disconnect and isolate the affected part of the system. The ability to protect the equipment it supplies is what separates a circuit breaker from a simple switch

1.2 WHAT IS THE FUNCTION OF A CIRCUIT BREAKER

A medium voltage breaker performs the following functions:

- Allows buses and components to be energized and de-energized as needed during normal switching operation.
- When a system component develops a short circuit or other problem activating a protective relay, it must interrupt current and voltage to associated loads and from power sources to protect the system.

1.3 HOW ARE CIRCUIT BREAKERS CLASSED

Circuit breakers are classed or referred to by their <u>voltage size</u> and <u>arc extinguishing method.</u>

1.3.1 Voltage Class:

Circuit breakers are grouped by voltage classes that are normally defined as **LOW, MEDIUM, and HIGH**. You will find some texts refer to only two classes, Low Voltage and High Voltage, but the breaker industry generally use three voltage size groupings.

- Low Voltage (0-600V): Generally includes Molded Case breakers (figure 1-2), Power Metal clad breakers (Figure 1-3) and the new design large molded frame power breakers (Figure 1-4).

- Medium Voltage (600V through 15KV): this includes 4160V, 6.9KV and 13.8KV. Sometimes 34KV breakers are included.
- High Voltage (Above 15KV): These are usually breakers associated with transmission and first line step down coming off transmission. Also anything above 34KV is generally outdoor gear.

1.3.2 Arc Extinguishing:

All circuit breakers have contacts, and when the contacts separate during an opening operation they draw an arc, assuming that power is flowing through the device. The electric arc forms between the contacts and is drawn out in length as the contacts open. Therefore, circuit breakers require a device to control or remove the arc; the 4 common mediums used to extinguish an arc during breaker contact separation are Oil, Air, Gas, and opening in a Vacuum.

- Oil Circuit Breakers (OCB): Oil circuit breaker contacts are immersed in oil. Current interruption takes place in the oil, which cools the arc developed, and quenches the arc. All three phases of small oil circuit breakers can be placed in one oil tank; however, large high-voltage circuit breakers have each phase in a separate oil tank. The oil tanks in oil circuit breakers are normally sealed and the electrical connections between the contacts and external circuits are made through porcelain bushings similar to oil transformers.

- Air Circuit Breaker (ACB): ACB contacts open in air and use a combination of the characteristic of the arc, air and a magnetic field to extinguish the arc. Figures 1-5 through 1-11 show an example of arc extinguishing in an air magnetic design breaker.
  - Figure 1-5 the breaker closed current flowing through the contacts.
  - Figure 1-6 the main contacts open arc contacts are closed.
  - Figure 1-7 arcing contacts separate and arc strikes.
  - Figure 1-8 the arc transfers to the runners and is drawn out horizontally simultaneously, the blowout coil provides a magnetic field to draw the arc into the arc chutes. This design does not use a puffer assembly but most medium voltage breakers do use a puffer to help direct the arc into the arc chute.

- Figure 1-9 the arc is transferred to splitter plates to form a number of short series arcs.
- Figure 1-10 small arcs are stretched into loops where it is cooled.
- Figure 1-11 arc is extinguished.

- Air Blast Circuit Breaker: Generally these breakers are used in high voltage applications. They also are used in high voltage DC applications. As the name implies, the contacts of an air blast breaker separate in air. Whereas the medium voltage ACB's have a mechanical device which displaces air into the arc during opening operation, the air blast breaker use a stream of compressed air directed toward the separable contacts of the breaker to interrupt the arc formed when the breaker is opened (Figure 1-12).

- Gas Circuit Breakers: Gas breakers are commonly called SF6 breakers for the Sulphur hexafluoride gas used. The arc generated during opening is extinguished in a chamber filled with pressurized sulfur hexafluoride gas. One advantage SF6 over vacuum breakers is that even if the gas bottle loses pressure the residual SF6 gas is normally enough to allow the breaker to open safely under a normal load. There are environmental concerns with the SF6 gas if it leaks.

- Vacuum Circuit breakers: The vacuum circuit breaker interrupts the current in a vacuum. The contacts of a vacuum breaker are enclosed in a ceramic envelope or "bottle" that is evacuated to an extremely low atmospheric pressure, approximately .0023 in. Hg absolute. Although the physics of interruption are quite complex, the vacuum interrupter works because the arc requires a conducting path to sustain it, but within the vacuum bottle there are no gasses to ionize; therefore, for all practical purposes, there can be no conducting path and the arc cannot be sustained.

Figure 1-13 shows a cutaway view of a single pole vacuum interrupter. The vacuum bottle has a stationary contact firmly mounted on one end of the enclosure, and a moving contact, which travels a very short distance from open to close (1 inch or less), is sealed to the other end of the envelope with a flexible bellow.

1.4 CIRCUIT BREAKER RATINGS

Common current ratings for medium voltage breakers are 1200 Amp, 2000 Amp and some applications also have a 3000 Amp rating. As the current rating is increased the breaker will require: larger copper bus and additional contacts to carry the increased load (amps), stronger operating springs are required to provide additional acceleration for the contacts closing and opening, and larger arc chutes to dissipate the additional fault currents. Vacuum and SF6 breakers will have larger interrupters.

Most manufacturers provide the breaker rating information on the breaker nameplate and will indicate the following:

1.4.1 Circuit Amperes

This is the maximum value of the steady state current which the contacts and conductors are designed to carry.

1.4.2 Interrupting Capacity

The interrupting rating is given in mva. This is the maximum amperes the breaker is designed to interrupt, times a specified circuit voltage.

1.4.3 Maximum Momentary Amperes

This is the maximum instantaneous current for which the breaker has been designed to close and latch successfully in the event a fault exists on the circuit when a closing operation of the breaker is initiated.

1.5 BREAKER DESIGNATIONS

Each breaker manufacturer uses alpha designators for the breakers. The numbering system is tied to the Voltage and MVA rating. Figure 1-14 gives a comparison of the various manufacturers designations.

1.6 POWER PLANT DISTRIBUTION SYSTEM

Circuit breakers are a very essential component of a power plant distribution system.

A power plant utilizes all breaker voltage sizes to produce and distribute electricity.

The sample one line diagram in Figure 1-15 is a typical power plant distribution system, with additional components not shown, such as diesel generators and battery banks. The diagram shows the flow of power from generation to the motor control center.

At a minimum, a distribution system will have the following components:

1) Power Distribution Grid and Switchyard
2) Station startup transformer
3) Main electrical generator
4) Isolated phase bus duct
5) Step-up transformer
6) Station auxiliary transformer
7) Protective bus duct
8) Medium voltage switchgear
9) Secondary unit substations
10) Motor control centers

The following provides a general explanation of these components.

1.6.1 Power Distribution Grid and Switchyard

The **grid** is a term used to describe the high voltage transmission network that distributes electrical power from power plants to consumers. The **Switchyard** is the point of entry and exit for electric power entering and leaving the plant. Common switchyard bus voltages are 22 kV, 161 kV, 235 kV, 345 kV, and 500 kV.

1.6.2 Start-Up Transformer

Startup Transformer is the common name for the transformer used to power the plant equipment while starting the unit up from cold conditions (i.e. no fire in the boiler, or the reactor is shutdown). The Startup Transformer is energized from an incoming transmission grid voltage, normally operating at 235kV, 345kV, or 500kV.

The Startup Transformer is also a three winding transformer with a Primary winding at grid voltage and two secondary windings stepping the voltage to the plant voltage of 13.8kV, 6.9kV or 4160V.

1.6.3 Main Electrical Generator

The main generator is normally driven by steam for most large power plants, produced from gas, oil, coal or nuclear. Nuclear power plant main generators normally generate power at 22.5kV.

The output of the generator is connected to an isolated phase bus duct commonly referred to as Isophase Bus Duct.

1.6.4 Isophase Bus Duct (Figure 1-16)

The Isophase Bus Duct connects the generator output to the Step-Up Transformer and the Station Auxiliary (Service) Transformer.

There is one duct for each of the three generator phases coming from the generator; the duct provides physical separation of the phases to prevent phase-to-phase faults. For larger bus ducts a forced air-cooling system is used to reduce the heat generated due to power losses.

1.6.5 Step-up Transformer

The Step-up Transformer increases the generator voltage from lower generator output voltage to the higher transmission voltage required to travel over the transmission lines. The transmission voltage is a function of the existing transmission system used in that area of the country the plant is located.

1.6.6 Station Auxiliary (Service) Transformer

The Auxiliary Transformer is the power transformer that provides power to the station's auxiliaries during normal operation. This transformer is connected directly to the Main Generator through the Isophase bus.

The transformer in our one line diagram is a three winding transformer having one primary winding rated at generator output voltage and two secondary windings that can be rated 13.8 KV, 6.9KV or 4.2KV.

Each secondary winding from the transformer is connected to a Protective Bus Duct. This bus work conveys the power to two different voltage switchgear line-ups in the plant.

1.6.7 Protective Bus Ducts

The protective bus ducts consist of copper or aluminum bus bars, which are normally insulated and held in place with a non-conductive material within a metal housing. In Figure 1-16 the auxiliary transformer output is delivered to the switchgear cubicle via protective bus ducts. Metal housings that contain electrical bus work and circuit breakers are called switchgear.

1.6.8 Medium Voltage Switchgear

The medium voltage used will be based on the transformer outputs, typically 4.16 KV, 6.9 KV or 13.8 KV.

The breakers are housed in a switchgear lineup of a series of cubicles, which are bolted together in a row. Each cubicle contains a rear section where the bus bars are located and where the cables are connected from the loads, a lower front compartment where the circuit breaker is housed and an upper compartment where the protective relays and breaker control wiring are located. The type of relay varies depending upon the breaker application. Typically, each breaker will have as a minimum some type of over-current relay and ground fault relay.

Switchgear (figure 1-16) refers to a line-up of equipment to house circuit breakers, protective relays and control wiring. The switchgear is completely enclosed in a metal structure that prevents individuals from coming in contact with the lethal voltages within this equipment.

The incoming or feed breakers are normally a higher amperage breaker and are located on the ends of the switchgear line-up. Pairs of switchgear (Two Sided switchgear) can be connected together via a tiebreaker. These breakers are normally open; however, in the event of a problem with protective bus duct or incoming feed breaker, the tie breakers can be closed and both buses energized from the same feed breaker.

1.6.9 Secondary Unit Substation

The Secondary Unit Substations is essentially a repeat of the configuration of the station auxiliary (service) transformer and the Medium Voltage Switchgear but at a lower voltage normally 480V. These breakers in turn feed smaller switchboards called the Motor Control Centers.

1.6.10 Motor Control Centers

Motor Control Centers are located throughout the power plant and are placed near groups of loads for convenience. They are normally comprised of removable sections containing molded case breakers, contactors and protection devices for the equipment they feed.

1.7 Electrical System Design Requirements.

The nuclear plant has redundant circuits and back up systems to provide the assurance of safely shutting down the plant. The basic requirement for the design of nuclear power plant electrical distribution systems is provided in General Design Criterion 17 from 10 CFR 50 Appendix A. Criterion 17 is quoted below, in part:

"The onsite electric power supplies, including the batteries, and the onsite electric distribution system, shall have sufficient independence, redundancy, and testability to perform their safety functions assuming a single failure.

Electric power from the transmission network to the onsite electric distribution system shall be supplied by two physically independent circuits designed and located so as to minimize to the extent practical the likelihood of their simultaneous failure under operating and postulated accident and environmental conditions.

A switchyard common to both circuits is acceptable. Each of these circuits shall be designed to be available in sufficient time following a loss of all onsite AC power supplies and the other offsite electric power circuit, to assure that specified acceptable fuel design limits and design conditions of the reactor coolant pressure boundary are not exceeded.

One of these circuits shall be designed to be available within a few seconds following a loss-of-coolant accident to assure that core cooling, containment integrity, and other vital safety functions are maintained.

Provisions shall be included to minimize the probability of losing electric power from any of the remaining supplies as a result of, or coincident with, the loss of power generated by the nuclear power unit, the loss of power from the transmission network, or the loss of power from the onsite electric power supplies."

Four essential requirements are derived from Criterion 17.

- The onsite electrical distribution system must have at least two separate parts, either of which is capable of providing power to all components required for safe shutdown of the reactor.
- The two parts of the onsite distribution system must be sufficiently separated to preclude the loss of both parts if one part should suffer a loss of power or severe fault, such as a bad ground or short circuit.
- The onsite distribution system shall be provided with two independent power supplies from the offsite transmission network that are promptly available after a loss of all onsite AC power supplies (one offsite supply shall be available within a few seconds). Many nuclear plants operate with the offsite power supply continuously in use for safety-related loads, while other plants have a fast-transfer capability to satisfy this requirement.
- Both of the two separate onsite parts shall have a backup power source available within a few seconds following a loss of coolant accident or loss of offsite and onsite power supplies.

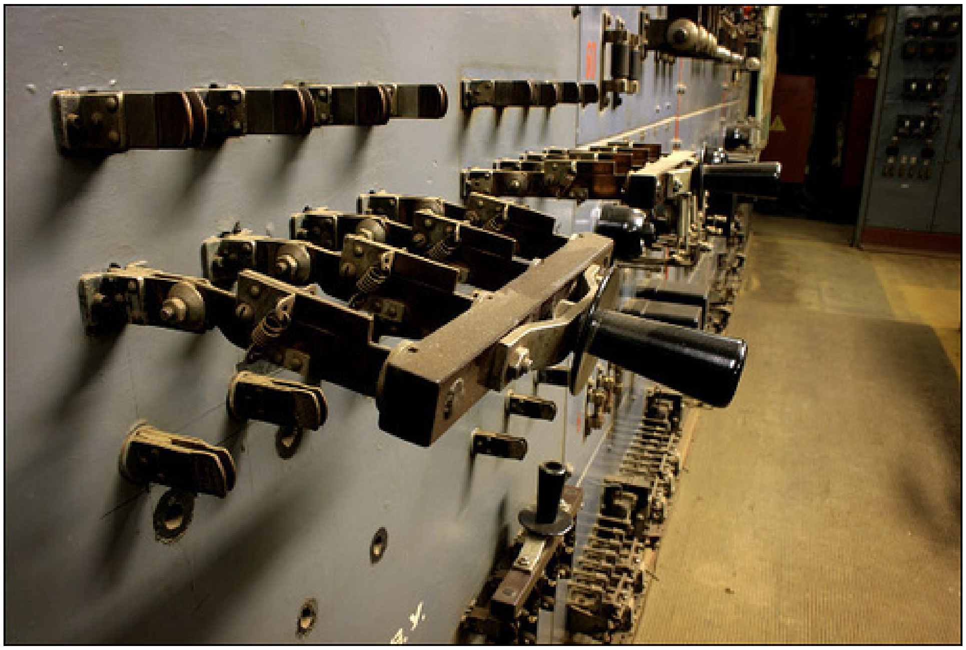

Figure 1-1 / Example of a Knife Switch

Figure 1-2 / Molded Case Breaker

Figure 1-3 / Westinghouse DS 600Amp breaker

Figure 1-4 Large Molded housing 600Volt Power Breaker

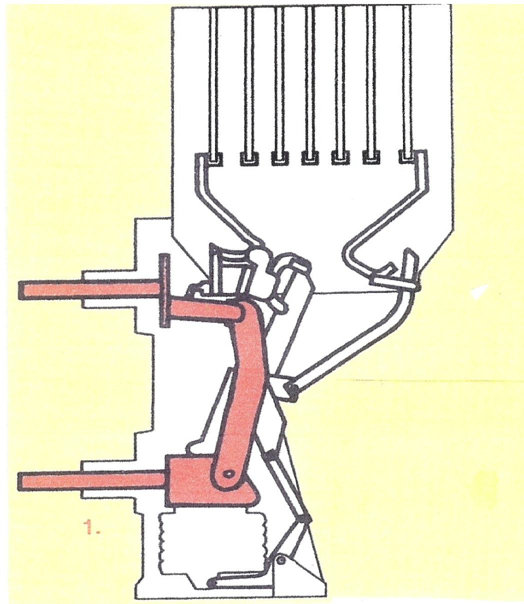

Figure 1-5 the breaker closed current flowing through the contacts.

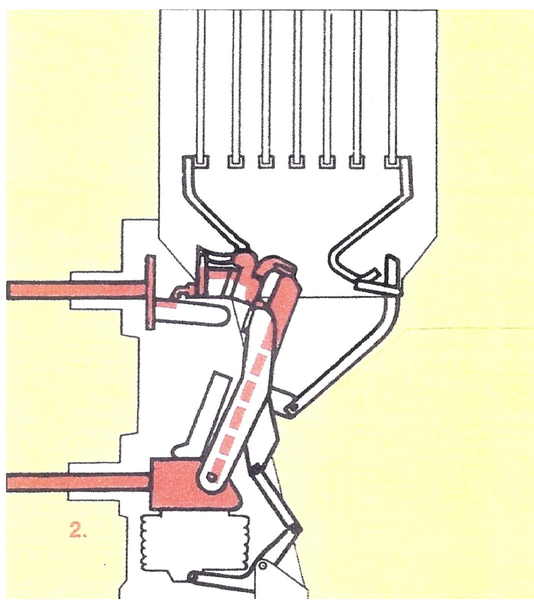

Figure 1-6 the main contacts open arc contacts are closed.

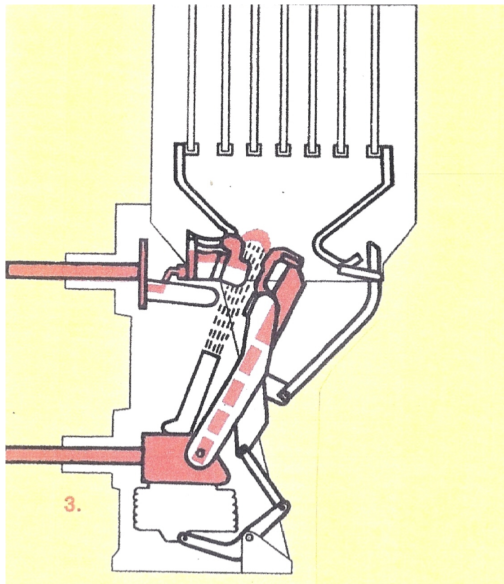

Figure 1-7 arcing contacts separate and arc strikes.

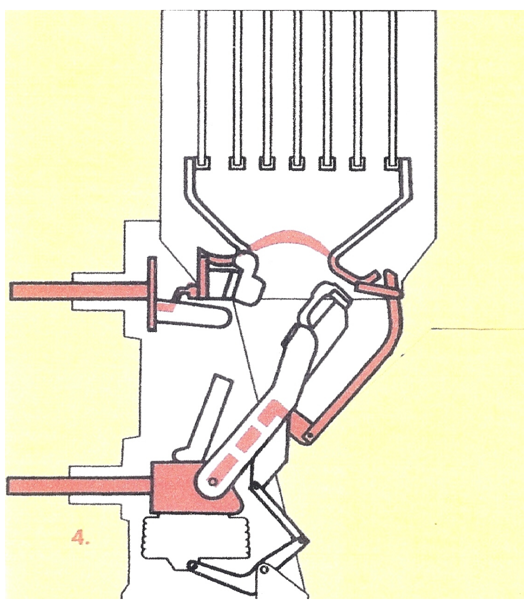

Figure 1-8 the arc transfers to the runners

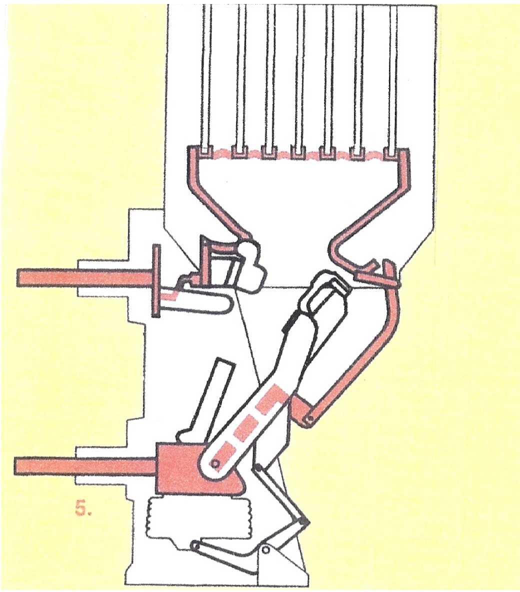

Figure 1-9 the arc is transferred to splitter plates to form a number of short series arcs

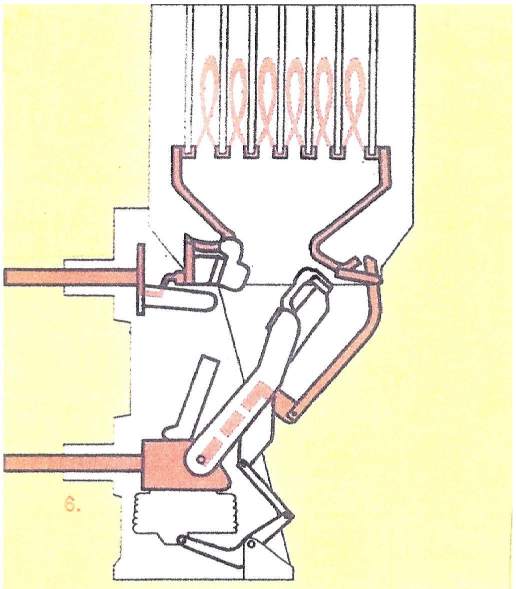

Figure 1-10 small arcs are stretched into loops where it is cooled.

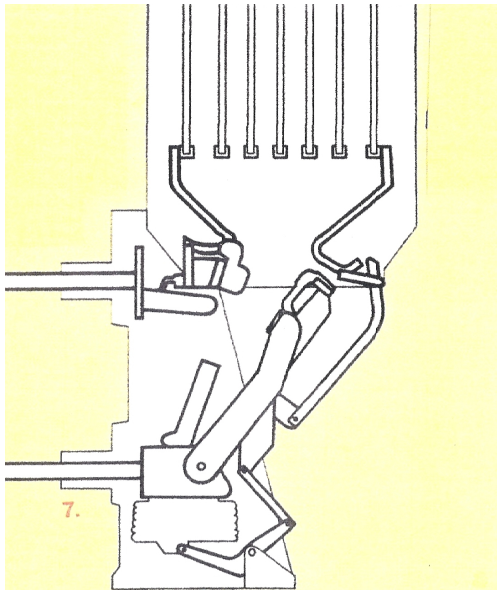

Figure 1-11 arc is extinguished.

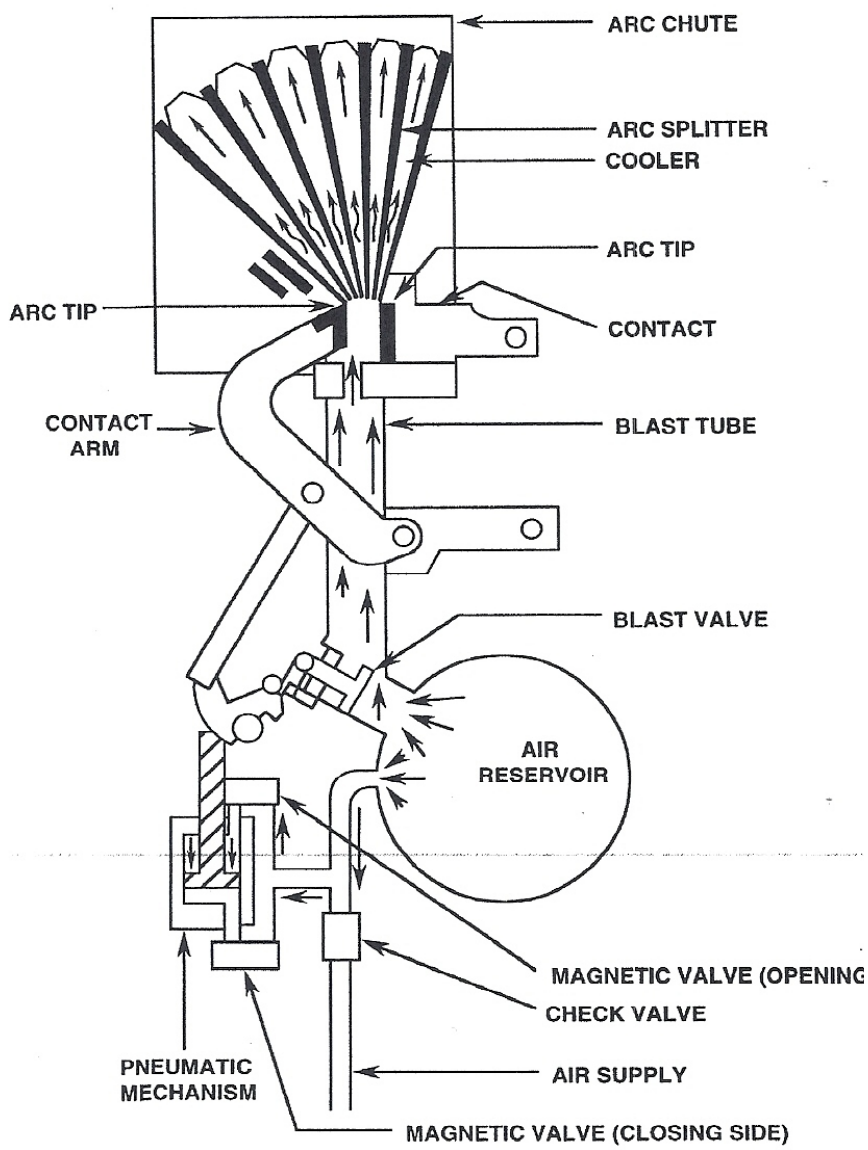

Figure 1-12 Air Blast Circuit Breaker

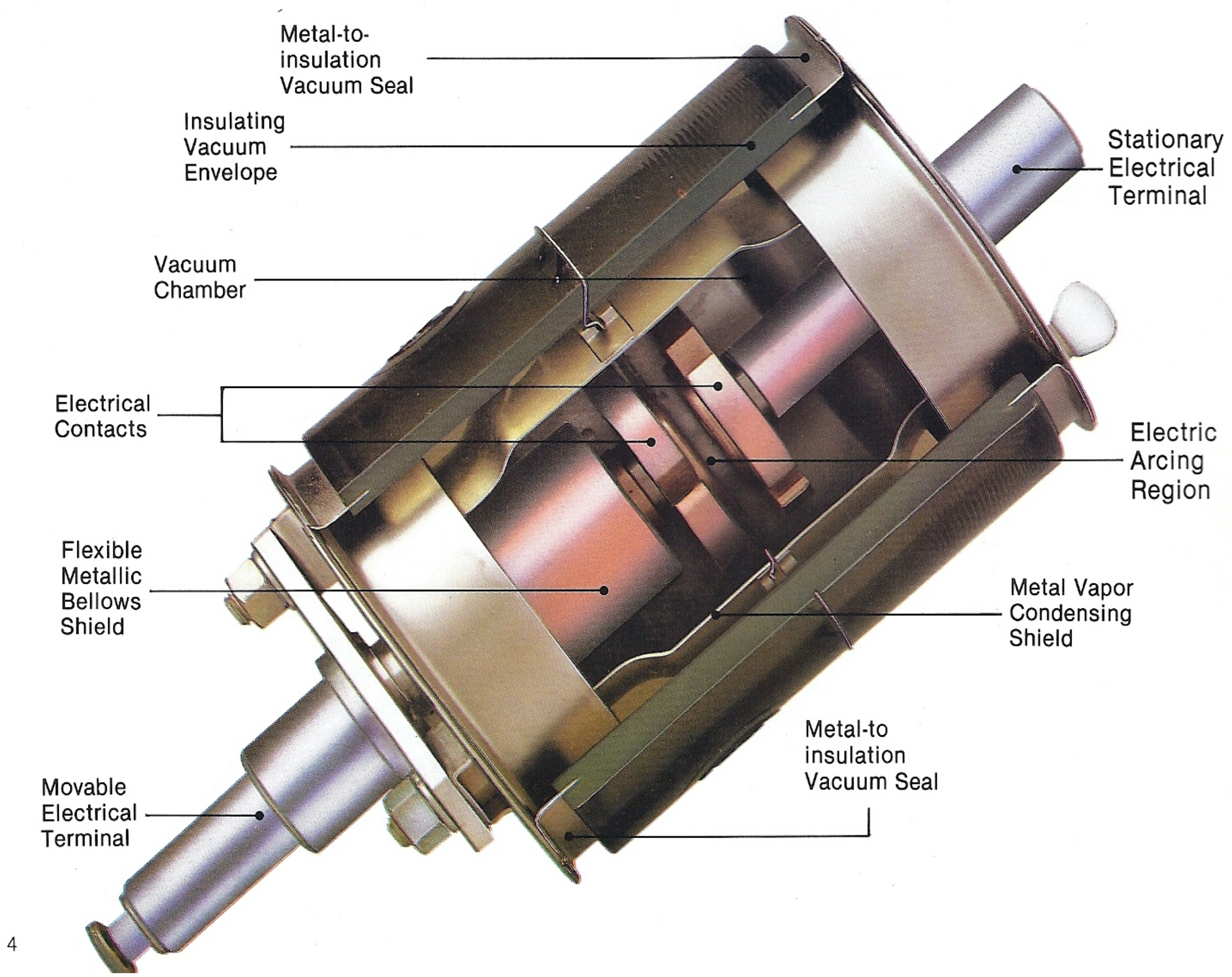

Figure 1-13 Vacuum Circuit Breaker Bottle

Comparative Medium Voltage Circuit Breaker Designation

Air-Magnetic		Siemens	General Electric	Westinghouse	Brown Boveri	Square D
Trade Name:		Ruptair	Magne-Blast	Procel-Line	Type HK	Solenarc
Volt. Class	MVA					
4.76	75	MA-75	AM-4.16-75	50DHP75	5HK75	DSE-21
4.76	250	MA-250	AM-4.16-250	50DHP250	5HK250	DSE-23B
4.76	350	MA-350	AM-4.16-350	50DHP350	5HK350	DSE-25C
8.25	500	FB-500	AM-7.2-500	75DHP500	5HK500	DSE-25CU
15	500	FC-500	AM-13.8-500	150DHP500	15HK500	DSE-65
15	750	FC-750	AM-13.8-750	150DHP750	15HK750	DSE-57
15	1000	FC-1000	AM-13.8-1000	150 DHP 1000	15HK1000	DSE-68
Vacuum		Siemens	General Electric	Westinghouse	Brown Boveri	Square D
Trade Name:		Type FCV	Power/Vac	Vac-Clad	Type HKV	Type HVD
Volt. Class	MVA					
4.76	250	-	VB-4.16-250	50VCP250	-	HVD-0525
4.76	350	-	VB-4.16-350	50VCP350	-	HVD-0535
8.25	500	-	VB-7.5-500	75VCP500	-	HCD-0850
15	500	FCV-500	VB-13.8-500	150VCP500	15HKV500	HVD-1550
15	750	FCV-750	VB-13.8-750	150VCP750	15HKV750	HVD-1575
15	1000	-	VB-13.8-1000	150 VCP 1000	-	HVD-15100
38 kV		Siemens	General Electric	Westinghouse	Brown Boveri	
Volt. Class	MVA					
38	1500	W-1500	VH-34.5-1500	-	38HKV1500	
		Vacuum	Vacuum		Vacuum	

Figure 1-14

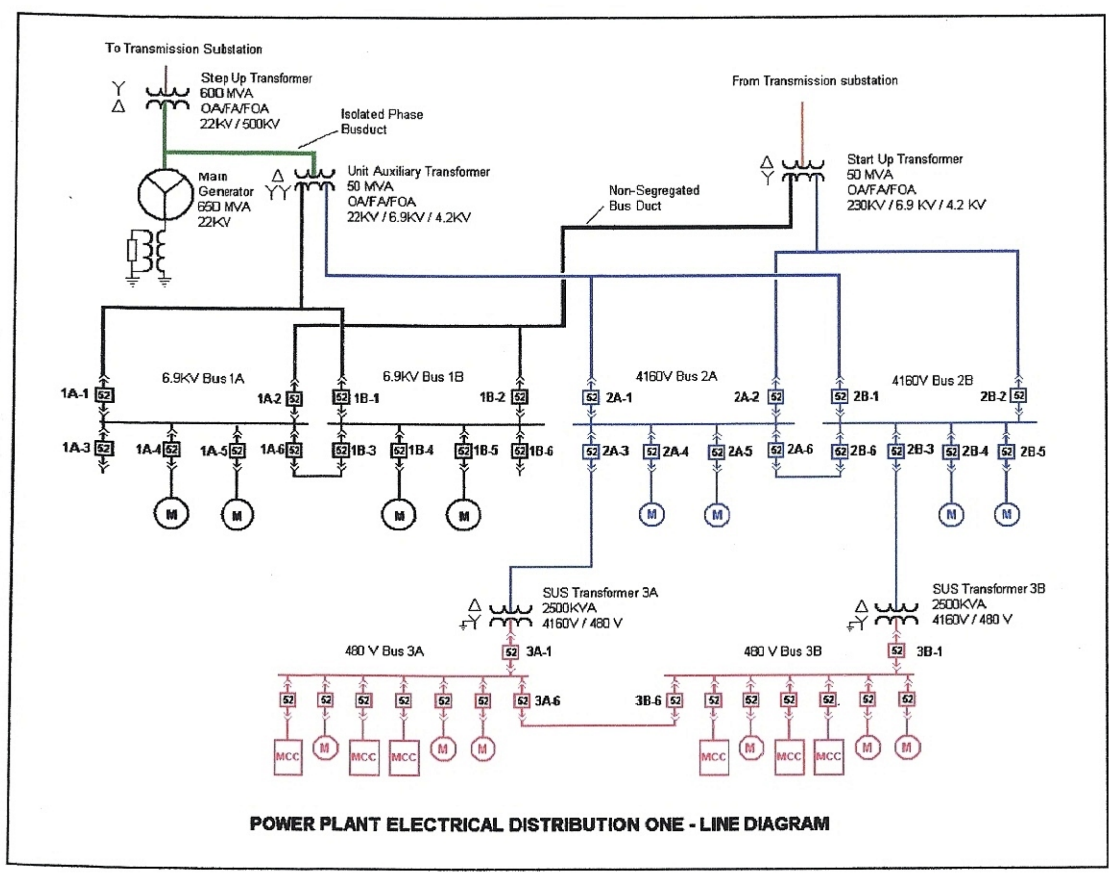

Figure 1-15 Distribution One Line Diagram

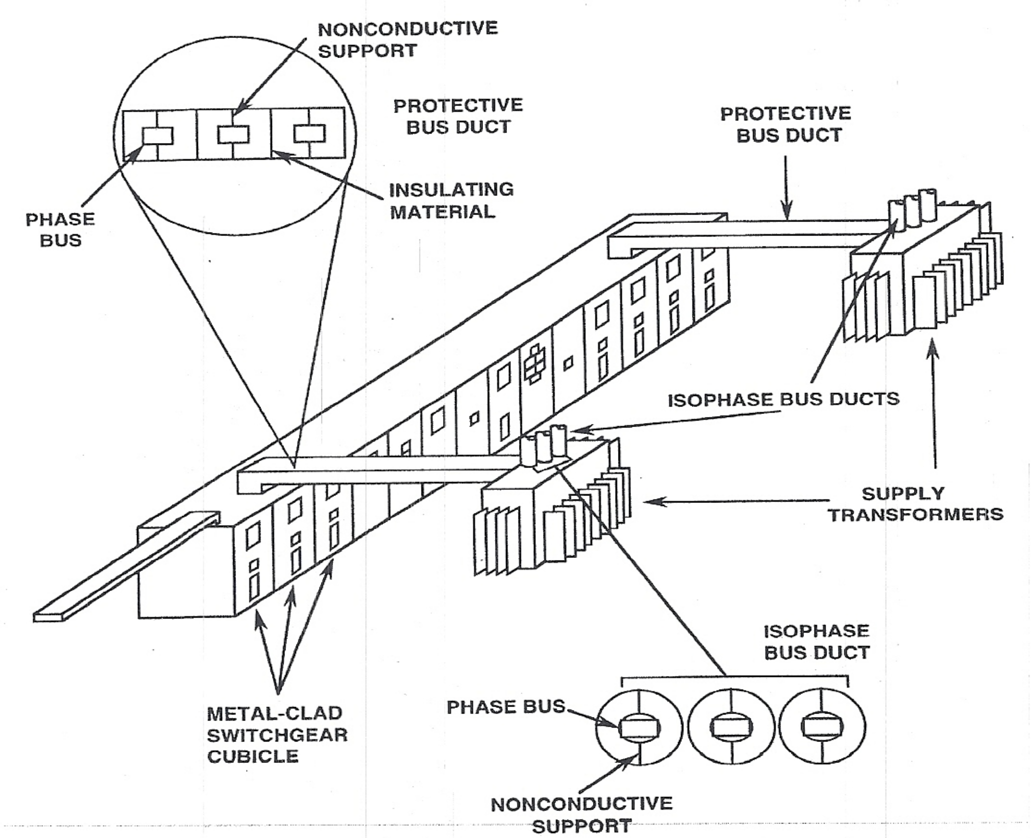

Figure 1-16 Plant Protective Bus Ducts