

Protection 1

(read section 13.0 of text)

1.0 Introduction

Faults do not occur that frequently – 1/year/100 miles of transmission is typical. Distribution systems may see more than this.

However, when they do occur, it is imperative that they be removed as quickly as possible, because persistent faults can cause (see notes “Symmetrical faults”):

- Loss of generator synchronism
- High currents and subsequent equipment damage
- Loss of a component and possible subsequent cascading

It is the job of the protection system equipment to recognize and remove the fault.

There are three basic parts of a protection system: circuit interrupter, relays, and transducers.

2.0 Circuit interrupter

There are two basic types of current interrupters.

- Fuses
- Circuit breakers

Fuses are typically used in distribution systems but not in transmission systems. To learn about fuses, take EE 455.

Circuit breakers are switches designed to interrupt fault currents. This is in contrast to switches designed to interrupt only load currents. Since fault currents are typically much higher than load currents, fault current interruption is much more difficult than load current interruption.

Transmission-level circuit breakers are shown in Fig. 1, where the corresponding voltages are 161, 345, and 500 kV, respectively. Videos illustrating CB design & operation is at [1]; arc quenching [2]; and spring-drive operation [3].



Fig. 1

The chief problem in interrupting fault current is that when the circuit breaker just begins to open, an electric arc forms between the contacts as the large current continues to flow across what is becoming a wider and wider air-gap.

A key part of any circuit breaker is the “insulating fluid.” This is the fluid used in insulating between the contacts as they open.

The most common types of insulating fluids are:

Air

Sulphur hexafluoride (SF₆)

Compressed air

Vacuum

Oil

Another important attribute of the circuit breaker operation is that the current goes through zero twice per cycle.

There are two objectives in designing circuit breakers for interrupting fault current as quickly as possible [4]:

1. Increase the insulating fluid during the time of the current zero.
2. Ensure that the dielectric strength of the arc path beyond the time of the current zero increases faster than the electric stress imposed on it by the network, so avoiding re-ignition of the arc.

Circuit breaker design and operation is a deep subject that we cannot do justice to in this course. From here on, we will simply view them as switches that are capable of interrupting currents within their interrupting rating. A good basic book dedicated to this subject is [5].

3.0 Relays

When a fault occurs, currents increase and voltages decrease. These changes can be sensed by the “intelligence” of the protective system, and this “intelligence,” i.e., the relays, is capable of making a decision to either open the breaker or not.

This sensing/decision process typically requires between 0.5-3 cycles, and the entire operation, including breaker opening time, is typically around 2-8 cycles.

A relay is functionally a level-detector; they perform a switching action when the input voltage (or current) meets or exceeds a specific and adjustable value.

Relays are one of two basic types of construction: electromechanical or solid-state.

The electromechanical type relies on the development of electromagnetic forces on movable members which provide switching action by physically opening or closing contacts. An illustration of an electromechanical relay is provided in Fig. 2.

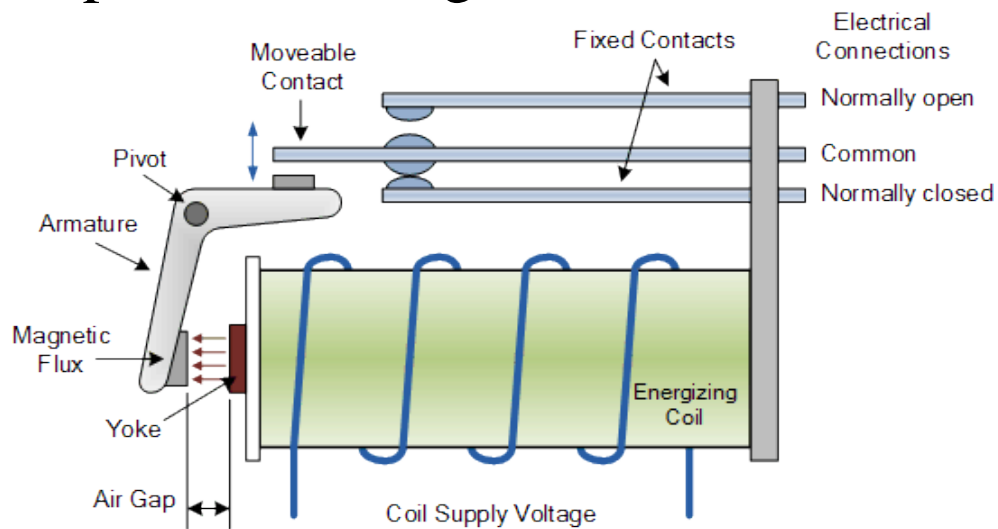


Fig. 2: Electromechanical relay

The solid-state type uses a signal to turn on a transistor which then energizes the trip coil of the circuit breaker. A solid-state relay is illustrated in Fig. 3, where the input circuit is isolated from the output circuit through opti-coupling to ensure protection of signal lines, power and ground bus and control circuits from switching noise and surges (which cannot pass through the optocoupler).

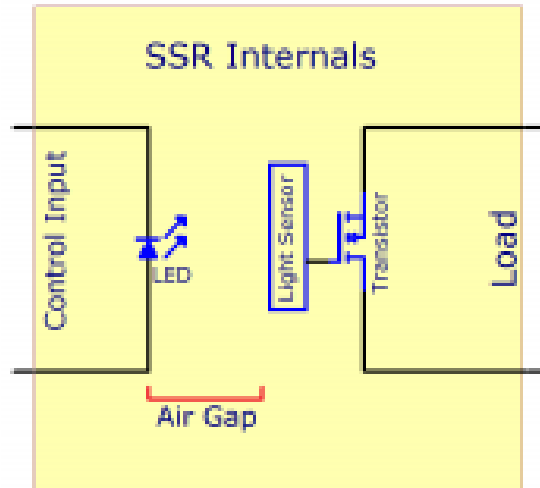


Fig. 3: Solid-state relay

Relay design and operation is, like circuit breakers, a deep subject that we do not have time to investigate further. Rather, we will study their relationship to the system in terms of learning how to perform relay settings.

3.0 Transducers

It is important to understand that, although breakers are high voltage, high current devices, relays are low current, low voltage devices, yet, the relays must sense changes in the voltages and currents experienced by the breakers.

Therefore, in addition to circuit breakers and relays, protective systems require transducers. These transducers may be one of two types:

- Potential (voltage) transformers (PTs or VTs)
- Current transducers (CTs)

Protective systems will typically employ at least one transducer per phase, and many will employ two per phase.

Functional operation of a PT is very similar to a step-down power transformer where we connect the primary winding in shunt with the circuit we are transducing.

Functional operation of a CT is different from a step-down power transformer in that the primary winding is in series with circuit we are transducing.

Fig. 4 illustrates.

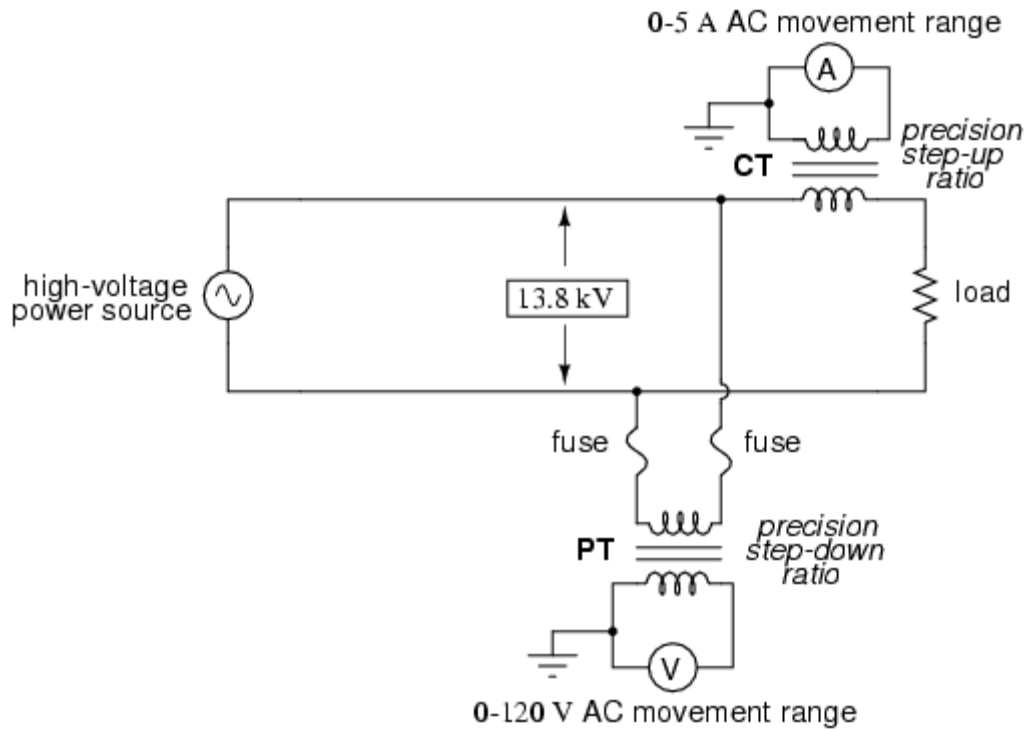


Fig. 4: PT and CT

4.0 Local vs. system-wide protection

We will study only local protection in this class. By “local protection,” we mean protective systems used to clear faults from components. Such equipment is quite common in power systems these days.

However, you should be aware of a more complex type of protective system called system protection schemes (SPS). These are protection

systems that do more than simply clear a fault; in addition, they initiate other actions such as

- Generator tripping
- Fast insertion of additional components such as
 - Series capacitors
 - Shunt capacitors
 - brakes
- Controlled islanding
- Load shedding

SPS are more heavily used today as compared to the past because of the difficulty and expense associated with building new transmission, i.e., it is a more economic way to obtain additional capacity.

All of what we will do from this point addresses local protection systems.

5.0 Protection criteria

The basic criteria of protection design is to protect against faults in a way that is:

- Selective
- Secure
- Dependable

5.1 Selectivity

This refers to the overall design of protective strategy wherein the minimum number of components are disconnected, or the minimum load is interrupted, in order to clear a fault. It is both an operational issue as well as a design issue.

In regards to being an operational issue, selectivity means that only those protective devices closest to a fault will operate to remove the fault. This is a problem because there are multiple protective devices in the network, and without *coordination*, any of them could potentially operate for a given fault. We will discuss further the coordination issue later.

In regards to being a design issue, your textbook, Fig. Ex. 1, pg. 497, gives an excellent example.

Exercise 1. We are given the two alternative arrangements of circuit breakers shown in Figure Ex 1. Which breaker scheme is preferable from the point of view of minimizing the loss of load in the event of faults on buses and/or lines? *Note:* Three breakers are employed in either case.

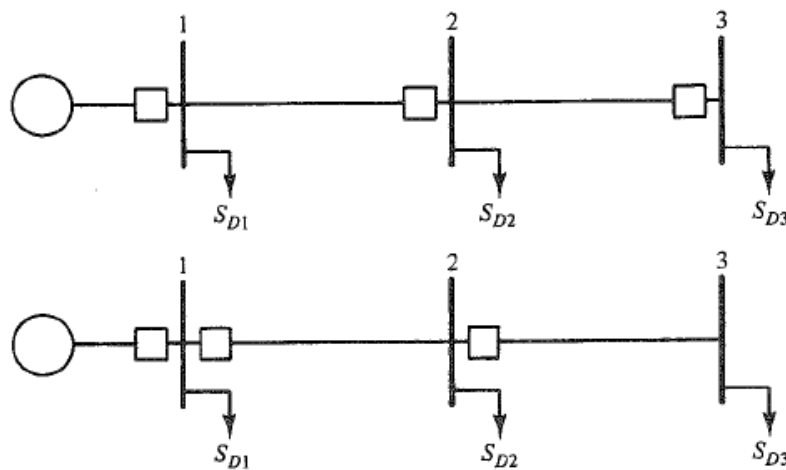


Figure Ex 1

5.2 Security

The word security has multiple meanings, e.g., there is personal security, financial security, information security.

Even within power system engineering, it has at least three meanings.

Cyber security is a relatively new one.

Transmission security is the ability of the transmission system to withstand disturbances.

Protective system security is the ability of a device to refrain from unnecessary operations.

A protective system unnecessary operation is also commonly referred to as an inadvertent operation.

Inadvertent operations can occur as a result of, for example, improper relay settings.

5.3 Dependability

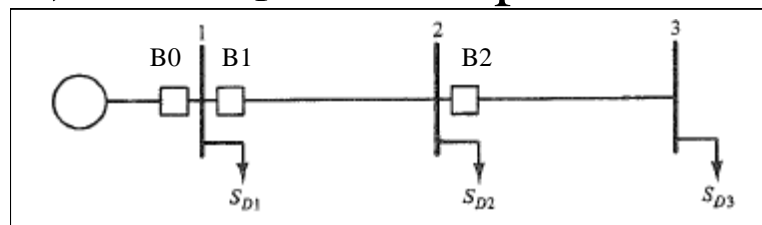
A protective system is dependable if it operates when it is supposed to operate so that any

faulted power system component is removed from the system in a requisite amount of time.

A key ingredient for high dependability is *backup protection*, which brings along with it the notion of *primary protection*.

The idea here is that any protection device may fail to operate (and so the device may be undependable), requiring the operation of a backup device (so that the overall protection system is dependable).

This notion is easy to understand in terms of the below figure (same as Fig. 13.2 in text) where we see that B_1 would be an appropriate backup for B_2 , that is, if B_2 failed to operate for a fault on line 2-3, then B_1 would open.



However, this leaves us with a selectivity issue. If we design both B_1 and B_2 to open for a fault

on line 2-3, then how do we ensure that when B_2 does NOT fail to open, that B_1 does NOT open!

This is a coordination problem, and we will address it in the next class.

[1] <https://www.youtube.com/watch?v=PKXPeTvmVQg>

[2] <http://www.energy.siemens.com/includes/root/apps/pmapi/siemens-energy-power-transmission-Interrupter-Unit-3095020975001.mp4>

[3] <http://www.energy.siemens.com/includes/root/apps/pmapi/siemens-energy-power-transmission-spring-drive-mechanism-3094928709001.mp4>

[4] “Power Circuit Breaker Theory and Design,” Edited by C. Flurschein, Peter Peregrinus Ltd., London, 1985.

[5] C. Flurschein, “Power circuit breaker theory and design,” Peter Peregrinus Ltd., 1982.