

# Notes 1: Introduction to Distribution Systems

## 1.0 Introduction

Power systems are comprised of 3 basic electrical subsystems.

- Generation subsystem
- Transmission subsystem
- Distribution subsystem

The subtransmission system is also sometimes designated to indicate the portion of the overall system that interconnects the EHV and HV transmission system to the distribution system.

We distinguish between these various portions of the power system by voltage levels as follows:

- Generation: 1kV-30 kV
- EHV Transmission: 500kV-765kV
- HV Transmission: 230kV-345kV

- Subtransmission system: 69kV-169kV
- Distribution system: 120V-35kV

Our focus in this course is on the distribution system. About 40% of power system investment is in the distribution system equipment (40% in generation, 20% in transmission).

The distribution system may also be divided into three distinct subsystems.

- Distribution substation
- Primary distribution system
- Secondary distribution system

The remainder of this introduction will focus on each of these three subsystems.

## **1.1 Distribution substations**

The distribution substation receives power from one or more transmission or subtransmission lines at the corresponding

transmission or subtransmission voltage level and provides that power to one or more distribution feeders that originate in the substation and comprise the primary network. Most feeders emanate radially from the substation to supply the load.

There are five main functions of the distribution substation:

1. Voltage transformation: One or more transformers will always be located within the substation to step down the voltage to the primary distribution voltage level. These transformers will always be three-phase banks, or they will be three single-phase banks connected in a three-phase configuration. The standard primary distribution voltage levels include 4.16kV, 7.2kV, 12.47kV, 13.2kV, 14.4kV, 23.9kV, and 34.5kV.

- 2.Switching and protection: Different kinds of switchgear will be located at the substation, including the following:
- a.Switches: devices that can carry and interrupt normal load current and thus disconnect portions of the network.
  - b.Circuit breakers: devices that can carry and interrupt normal load current, like switches; in addition, they interrupt short-circuit (fault) current. Circuit breakers are always paired with a relay which senses short-circuit condition using potential transformers (PTs) and current transformers (CTs).
  - c.Reclosers: devices similar in function to circuit breakers, except they also have the ability to reclose after opening, open again, and reclose again, repeating this cycle a predetermined number of times until they lockout.
  - d.Fuses: devices that can carry a defined load current without deterioration and interrupt a defined short-circuit current.

Circuit breakers, reclosers, and fuses are *protection devices*. Often, switches are used on the high side of the transformer, and protection devices are used on the low side, but substations supplying large amounts of load may have protection devices on both sides of the transformer. Special substation designs to achieve high reliability may utilize multiple circuit breakers, as shown in Fig. 1. Less expensive designs may use protection only in series with the feeders, as shown in Fig. 2. In these figures, switches and circuit breakers are normally closed unless there is a “N.O.” (normally open) indicated beside it. The Fig. 1 design provides that all feeders can remain supplied for a transformer outage (caused by maintenance or fault) or a subtransmission line outage. The low voltage breaker scheme of Fig. 1 is called “breaker and a half” because it requires 3 breakers to protect 2 feeders.

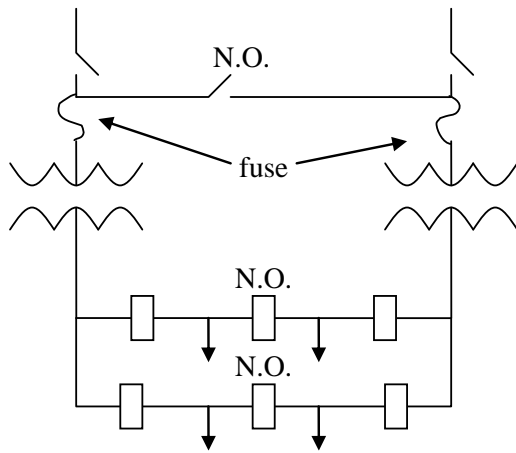


Fig. 1: A high-reliability design

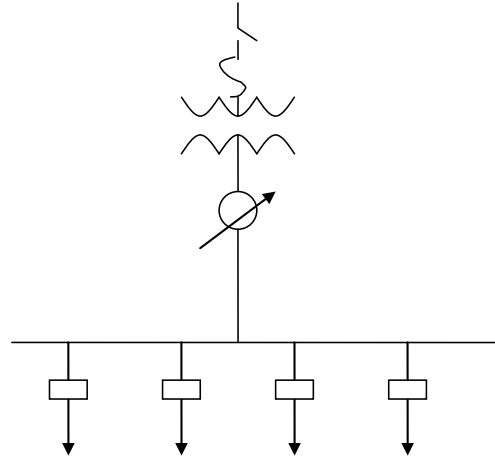


Fig. 2: A lower-reliability design

3. Voltage regulation: Because current  $I$  flows from source to load along the length of the feeder, and because the feeder has some amount of impedance per unit length  $Z$ , the feeder will cause a voltage drop  $IZ$  volts per unit length. Thus, loads connected along the length of the feeder will see different voltage levels with the load at the far-end of the feeder seeing the lowest voltage of all. This is illustrated by the solid line in Fig. 3. Note that this line indicates the voltage at the substation end of the feeder is 1.02pu. However, the voltage at feeder far-end is about 0.97pu (residential customers would be seeing

about 116 volts instead of 120). If the load were to increase, the far-end voltage would drop to an even lower value. As a result, we must regulate the voltage along the feeder as the load varies. Ways to do this include substation load tap-changing transformers (LTCs), substation feeder or bus voltage regulators (employed in Fig. 3), line voltage regulators, and fixed or switched shunt capacitors.

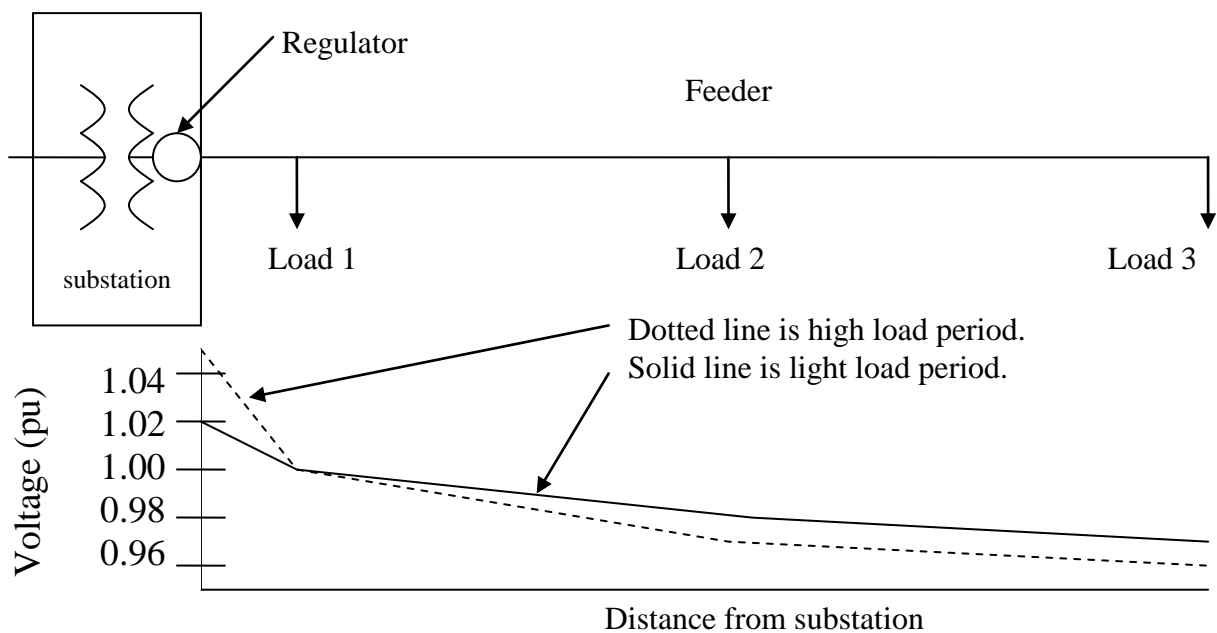


Fig. 3: Illustration of feeder load variation

4. Metering: Most substations do have some sort of metering device that records, at a minimum, existing current and current max and min that have occurred in the last time period (e.g., 1 hour). Digital recording is also heavily used and capable of recording a large amount of substation operational information.

Most distribution substations carry between 5 and 60 MVA.

## **1.2 Primary Distribution**

The primary distribution system consists of the feeders emanating from the substation and supplying power to 1 or more secondary distribution systems. Such feeders are usually 3-phase circuits.

Feeders are almost always radial from substation to loads (i.e., one way flow of power) in rural areas, usually radial in



residential neighborhoods, and they are often radial even in urban areas. In densely populated urban areas, particularly commercial and business districts where reliability is critical, feeders may be looped. The prices to pay for such a reliability benefit are as follows:

- Protection is more costly since a given fault on the loop will require at least two protective devices to operate, and to obtain the reliability benefits, multiple switching devices must be installed along the feeder.
- The fault currents tend to be lower, closer to normal load currents, and therefore there is less margin between breaker trip current and normal load current.
- Voltage control is complex since there are 2 control points.

One way to obtain the reliability benefit of a looped configuration while avoiding some of the above difficulties is to operate a looped configuration in open-loop, i.e., employ a normally open switch mid-way in

the loop. Then when the loop is faulted, the normally open switch can be closed while a switch just downstream of the fault can be opened, and all of the de-energized loop up to the downstream switch can be supplied. This is illustrated in Fig. 4.

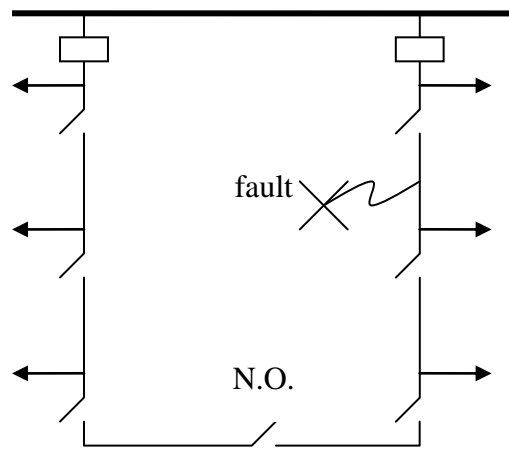


Fig. 4: Normally open looped system

As indicated previously, the standard primary distribution voltage levels include 4.16kV, 7.2kV, 12.47kV, 13.2kV, 14.4kV, 23.9kV, and 34.5kV.

However, equipment is specified in terms of voltage class. Equipment of one voltage

class may be utilized in at any operating voltage assigned to that class. For example, an insulator of voltage class 15 kV may utilized in a 12.47kV, 13.2kV, and 13.8kV system. There are four major distribution-level voltage classes: 5kV, 15kV, 25kV, and 35kV. The 15kV voltage class is the most prevalent.

North American utilities have been gradually increasing the percentage of distribution primaries at the higher voltage range, mainly because it allows for greater power carrying capability using less current. In addition to the increased capacity, higher voltage also results in

- Less voltage drop
- Decreased losses
- Ability to operate over greater distances, thus decreasing the number of substations required to serve a given area.

One disadvantage of the greater reach is that it tends to result in more customer

interruptions due to the greater number of customers per protected circuit.

Typical feeder mains are between 1-15 miles in length.

### **1.3 Secondary Distribution**

Branching from the main feeder are laterals, also referred to in the industry as taps or branches. The laterals may be three-phase, two-phase (two phases of the three-phase feeder with a neutral), or single-phase (one phase from the single phase feeder and a neutral). The laterals are usually protected with fuses so that faulted laterals do not cause interruption at the feeder level.

Standard secondary voltage levels are

- 120/240 single phase
- 120/208 3 phase
- 277/480 3 phase

The 120/240 configuration is obtained from the low-side of a HV/240 volt transformer, where HV is the rated voltage on the high voltage side, and the 240 is the rated voltage on the low voltage side. Then a center tap is connected to the low voltage winding and grounded along with the low side of the primary winding. This provides three wires on the low voltage side. One is +120V, one is -120V, and one (the center tap) is 0. Thus, two are “hot,” one is ground (neutral). The 240V connection is obtained by connecting across the two hot wires. The 120V connection is obtained by connecting from either hot wire to the neutral wire.

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## **1.4 Some other essential equipment**

Some other essential equipment not yet mentioned includes:

- Lightning arrestors

- Insulators
- Wood poles