Overview of Electric Power Supply Systems

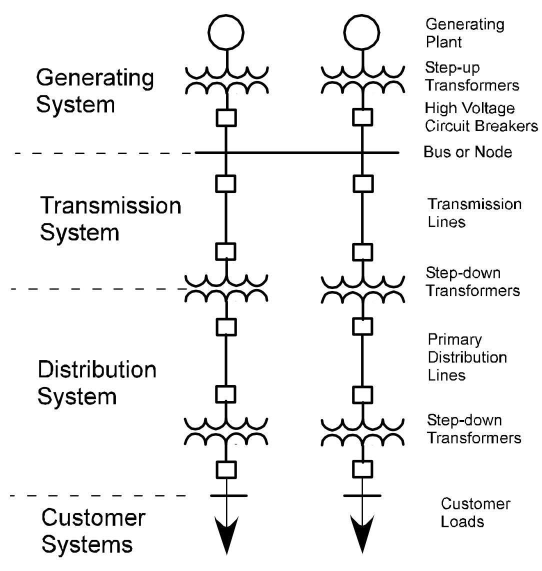
Why are electric power systems studied? What are the characteristics of power systems that justify spending a whole course on them? There are many answers to each of these questions; this course will touch on a few of them.

You will recall that ECE370 gave an overview of the circuit theory associated with electrical power and it is worth recalling that most power systems are three-phase and that when *balanced* systems are being analyzed these are usually drawn in terms of a one-line diagram, i.e. a single line is used to denote the three phases, which may or may not also have a neutral.

The US Electric Power System

The main aspects that describe power systems are: size, complexity and economic impact. Utility power systems cover vast territory, are subject to the whims of nature, are interconnected to each other, the quality of their commodity affects the ability of industry to produce effectively, and the price of their commodity has a significant impact on the economy of their service area.

Controlling power systems requires that electricity be supplied at the correct frequency, satisfactory voltage, with its phases balanced, have low harmonic content, and with all protection systems coordinated. The foregoing has to be achieved without overloading equipment and at the lowest cost to the consumer (after the utility makes a reasonable profit.) All this is complicated by the fact that demand for electricity changes throughout the day (and week, and season) and that electricity can not be readily stored in a practical manner. There are several conceptual levels of a power system, based on function and voltage level, as shown in the one-line form below:



The figure shows the conceptual levels of a power system as follows:

- generation systems where electricity is produced,
- transmission systems where electricity is moved in bulk,
- distribution systems where electricity is delivered to the customer, and
- customer systems where the electricity is consumed.

Some of the main components that make up the aforementioned systems are:

- *generating units* or generators that turn mechanical power into electrical power;
- *transformers* that step voltage up or down;
- *circuit breakers* that enable current to be interrupted, their operation is initiated by devices called *relays* (not shown in the figure) that sense when a circuit needs to be disconnected;
- transmission and distribution lines, these can be *overhead lines* that consist of bare conductors mounted on insulators, or *underground cables* that are buried.

CHAPTER 19
Industrial Power Systems

Once electrical power has been transmitted in bulk from the generating stations and distributed via feeders from substations, it is delivered to the customer. There are several different categories of customer and the most important ones are listed as follows:

- Industrial – these are typically manufacturing facilities where the bulk of the loads are motors, followed by lighting, HVAC etc. Light industrial facilities have a peak load in a typical range of 1 MVA to 10 MVA, while heavy industrial facilities are generally above 25 MVA. The vast majority of loads are three-phase.
- Commercial – these are typically offices, stores, hospitals, schools etc. Their loads are mainly lighting, HVAC, computers etc. Their peak loads typically range from a few tens of kVA to a few MVA. The majority of loads are three-phase, although much of this is single-phase banks that are balanced.
- Agricultural – these are obviously farms and the associated food processing facilities. There is a significant motor load along with lighting, HVAC etc. The peak loads are similar to commercial facilities. The loads are predominately three-phase, with a significant single-phase component.
- Residential – these are typically single-family homes and small apartment complexes; large apartment complexes usually being considered commercial loads. Their peak loads are typically a few tens of kVA, single-phase domestic appliances.

The above categories are in roughly descending order, based on size of loads. In addition to being the largest loads, *industrial power systems* are the most important for all engineers to understand. Mechanical and chemical engineers are often called upon to operate the plants where they work; these so-called *plant engineers* are responsible for maintenance of equipment, expansion of facilities, co-ordination with utilities and minimization of utility costs, etc. Civil engineers have to layout buildings and the larger and more complicated the building, the larger and more complicated its electrical system. Not all companies employ electrical engineers for this work and so it is vital that non-electrical engineers understand the basic configuration of industrial power systems.

19.1 Objectives of an Industrial Power System

The main objectives of an industrial power system can be listed as follows:

- *Enabling Production*. This means that the system must meet the requirements of the load being served in terms of kVA demand, power factor, voltage level, and voltage regulation. Foreseeable load growth should be included.
- *Reliability*. Redundant feeds improve continuity of supply. Also, generally the higher supply voltages have higher reliability. The use of emergency generators and/or Uninterruptible Power Supplies (UPS) needs to be considered for critical loads.
- *Maintainability*. The design should facilitate the maintenance of the equipment. Redundancy is critical for maintenance as well as reliability. Accessibility and availability for inspection and repair are important considerations.
- *Protection*. Faults and overloads must be isolated and removed from the system in a prompt manner. Protection devices must be *selective* i.e. only trip faulted/overloaded equipment; since selection takes time, this means that protection becomes a trade-off between speed and accuracy.
- *Safety*. This is probably the most important consideration of any system design. Proper safeguards of persons during the installation, operation and maintenance of the system must be guaranteed.

The foregoing must also be achieved in a cost-effective manner, which usually leads to compromises between initial costs and operating costs that have to be resolved by applying discount rates to get a common cost base.

The cost of the industrial power system is usually small compared with the overall cost of the industrial installation; but the impact of a deficient power system is severe. Therefore cost is usually a secondary factor, with the above items being given higher priority.

19.2 Common Configurations of Industrial Power Systems

Some of the most common pieces of electrical equipment are shown in table 19.1, where the term *drawout* refers to a device that is mounted in a cabinet that requires it to be slid out, rather like a file cabinet drawer, when it is to be examined.

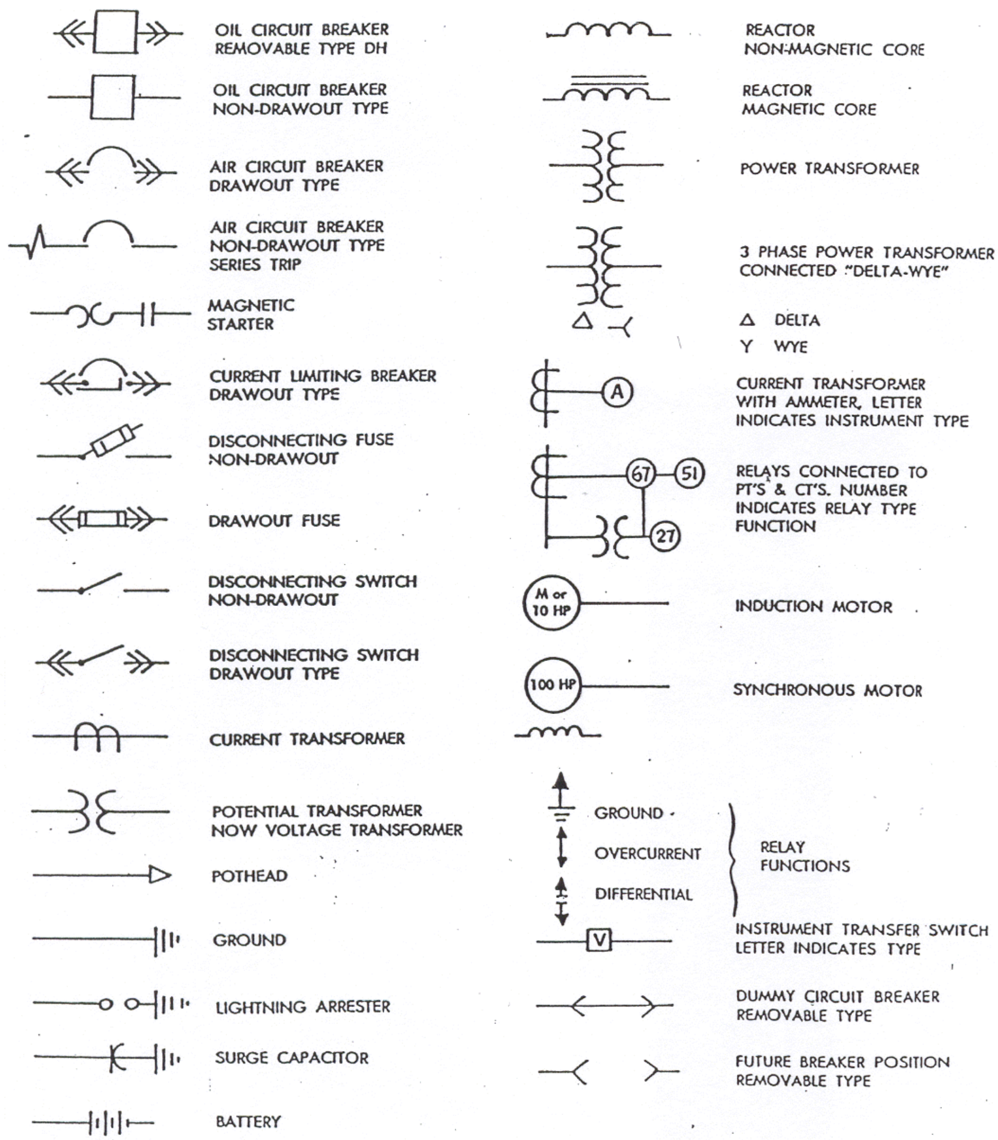


Table 19.1 – Common Electrical Symbols
Taken from IEEE Standard 141

Note that in circuit diagrams switches and circuit breakers are assumed to operate in the *closed* position although they are drawn with the switch arms *appearing to be open*. If a switch or circuit breaker has to operate in the normally open mode then the designation "NO" accompanies the device.

The various components are usually arranged in one of several standard configurations. The most common ones are shown as follows, starting with the simplest (which is also the cheapest) and progressing to more complex and expensive configurations.

19.2.1 Simple Radial System

The simple radial system is shown in figure 19.1; it consists of a single incoming main feeder that supplies all downstream feeders.

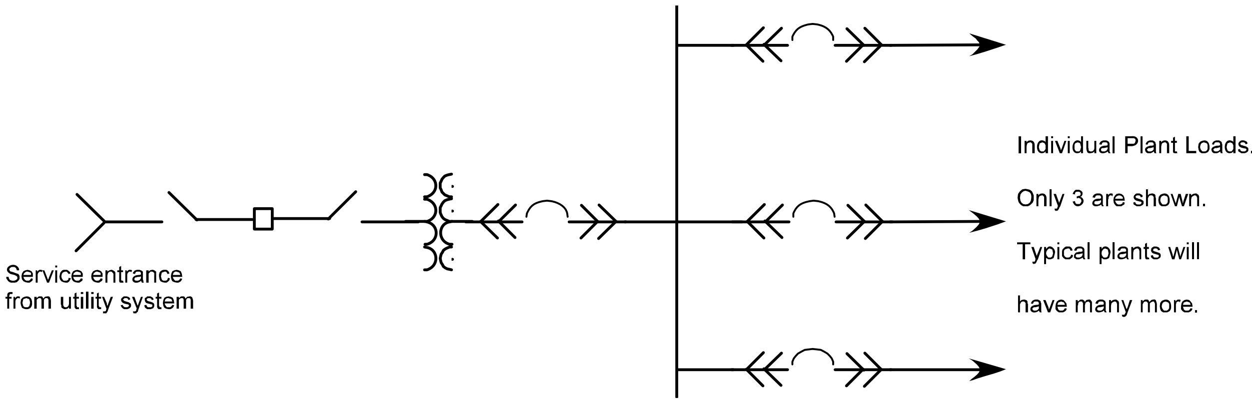


Figure 19.1 Simple Radial System

Load distribution occurs at the utilization voltage, i.e. there is only one transformer that supplies all feeders. Since there is no duplication of equipment, system investment is the lowest of all circuit arrangements. The outage of any piece of equipment will result in loss of load, therefore load must be disconnected in order to perform routine maintenance. Note that the low-voltage drawout circuit breakers can be replaced by fuses. This system is satisfactory for relatively small installations where the entire plant can be supplied by a single transformer.

19.2.2 Expanded Radial System

The advantages of the radial system can be applied to larger loads by adding additional transformers, as shown in figure 19.2.

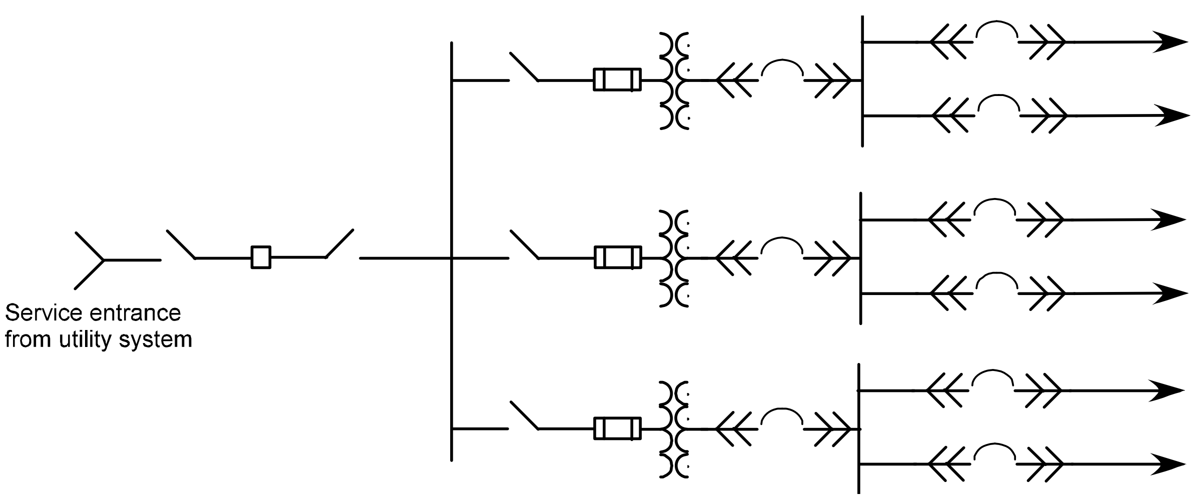


Figure 19.2 Expanded Radial System

The individual transformers are located near the center of the load they are supplying. A center of load can be calculated in a similar manner to a center of gravity, i.e. calculate the mean x and y ordinates from some datum point.

19.2.3 Primary Selective System

The primary selective system is shown in figure 19.3; it consists of two separate utility supplies to the load transformer.

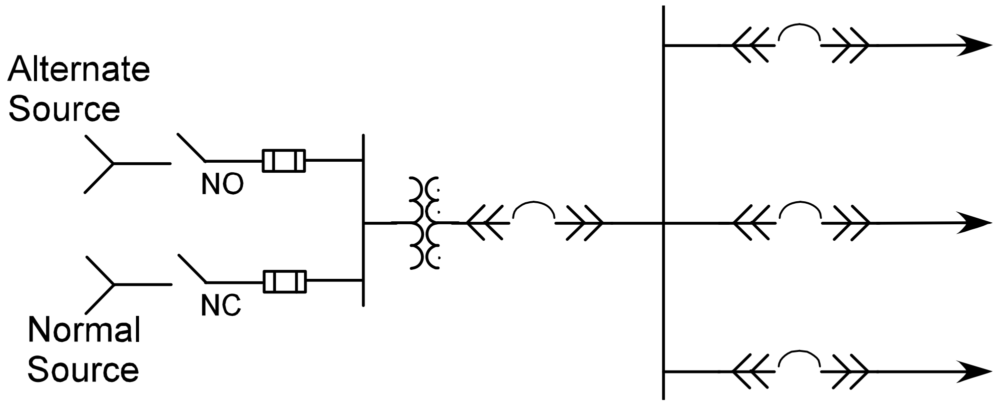


Figure 19.3 Primary Selective System

If the normal source fails, or is removed from service for maintenance, the transformer is switched to the alternate source. This switching operation can be either manual or automatic, but the load will be interrupted briefly. It is not usual to parallel the two sources as this causes circulating currents and would increase the fault level at the common bus.

19.2.4 Secondary Selective System

The secondary selective system is shown in figure 19.4; it consists of two load groups, each with its own transformer, connected through a normally open secondary tie circuit breaker.

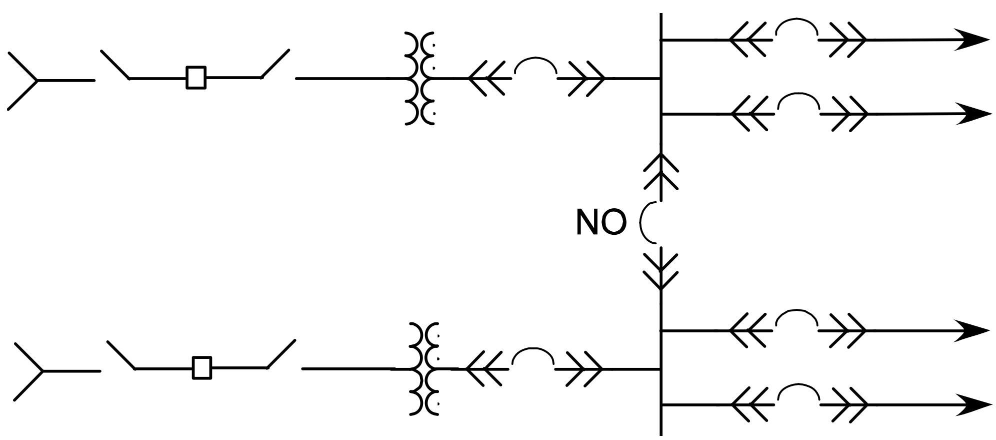


Figure 19.4 Secondary Selective System

If a primary feeder or the associated transformer fails, the circuit breaker on the secondary side is opened and the tie circuit breaker is closed, so that all load is supplied from the remaining transformer during the emergency period. To allow for this condition a combination of the following should be considered:

- Oversizing both transformers.
- Providing forced cooling so the transformer rating can be increased during the emergency period.
- Shedding non-essential load during the emergency period.

19.2.5 Sparing Transformer System

The amount of excess transformer capacity required for the secondary selective system shown in figure 19.4 can be reduced by adopting the sparing transformer arrangement shown in figure 19.5.

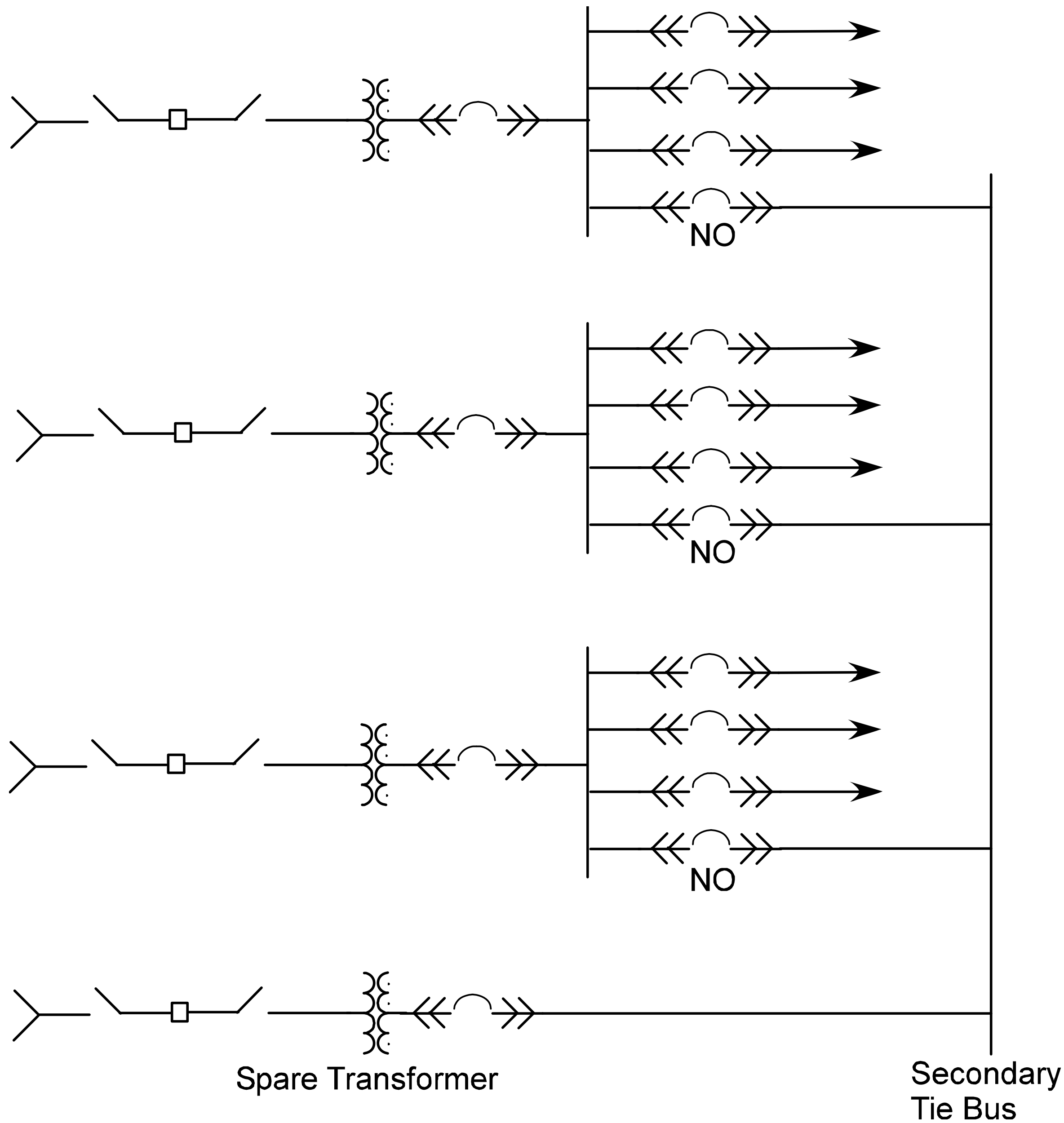


Figure 19.5 Sparing Transformer System

Now if a primary feeder or the associated transformer fails or is shut down for maintenance, the circuit breaker on the secondary side is opened and the associated "NO" circuit breaker is closed, so that its load is supplied from the sparing transformer during the emergency period. In this case, the total capacity is equal to (n - 1) times the capacity of one transformer.