Chapter 1 Power Distribution

Power distribution systems connect the end users of electric energy to the generation and transmission systems through an extensive network. The design and operation of this network influences the reliability and quality of user service. Service must meet certain performance criteria in the most economical manner. These criteria include supplying, on an individual level, voltage service which is regulated and undistorted, and on the system level, adequate power capacity to supply all customers simultaneously. Effective system planning, therefore, requires the investigation of voltage regulation at various locations in the system, line power flows, system losses and capacity, and harmonic distortion of the supply.

This chapter addresses some of the problems faced in system planning and provides methods for their solution. The methods in this chapter are applicable to both transmission and distribution systems. This chapter includes the following sections:

Power systems calculations are done using a normalizing scheme called the Per Unit system. The complexities introduced by transformers in circuit calculations are eliminated by judiciously selecting the base values of voltage and power in a system. These considerations and techniques are addressed in Section 1.1.

Once a system has been cast in an appropriate per unit notation, an equivalent circuit can be devised which will make the system easier to solve. Using this type of model, power losses and voltage drop calculations for radial transmission and distribution lines are done by concentrating the distributed loads on the lines and then computing the voltage drop and power losses in the equivalent system. Section 1.2 of this chapter describes this technique. This method is well suited to distribution system analysis, and will allow a fairly accurate prediction of system behavior.

The solution to the load flow problem gives the losses associated with the transmission and distribution lines in a power system. Power losses are due to the resistance inherent in all electrical conductors. The solution to the load flow problem also gives the amount of real and reactive power flowing in each line segment in the power system and the voltage at the substation buses. Section 1.3 includes a demonstration of the Newton-Raphson algorithm as applied to this problem, using the equivalent circuits developed in Section 1.2.

The largest sources of losses in a power system are the transformers. Resistance in the windings and hysteresis effects in the iron core dissipate significant amounts of real power. These power losses add to the cost of owning and operating the transformer. Section 1.4 investigates the sizing and efficiency of a transformer for the most economical operation.

The extensive use of sophisticated and sensitive power electronic equipment makes the issue of power quality important. Section 1.5 discusses harmonic sources and their effect on the supply quality. A method is provided for predicting the impact of harmonic sources on systems, and, by extension, the level of regulated, undistorted voltage available to the end user.

Load flow and voltage drop calculations require the impedances of the lines and transformers as input data. Section 1.6b includes the electrical characteristics of conductors used commonly in distribution and transmission systems. This section gives the formulae to compute the resistive, inductive, and capacitive effects of conductors in overhead lines. Modeling the electrical characteristics of the conductors during unbalanced conditions is possible with the formulae provided in this section.

The methods demonstrated in this chapter are commonly used in power engineering practice. The user can review the methods and extend them to larger systems including complex modeling. However, given the limitations of personal computers, the documents in this chapter are not intended to replace specialized software for studying large-scale systems. The user may refer to these documents as a tutorial or for a preliminary investigation of a problem.