ELECTRIC UTILITY SYSTEMS AND PRACTICES

A TEXT FOR A TRAINING PROGRAM IN ELECTRIC UTILITY ENGINEERING

ELECTRIC UTILITY ENGINEERING OPERATION
ELECTRIC UTILITY SALES DIVISION

GENERAL ELECTRIC

First printing - 1954
Second printing, revised - 1957
Third printing - 1959
Fourth printing - 1961
Fifth printing, revised - 1963
Second Edition - 1967
Second printing - 1968
Third printing - 1969

CHAPTER 2—THE POWER SYSTEM

INTRODUCTION

The present form of power system would be impossible without alternating current. The development of a practical transformer freed the utilities from the limitations imposed by the low voltage inherent in direct current. These limitations were beginning to be felt by the time the Edison direct-current systems were only three years old. After the advent of transformers much of the load was served by alternating instead of direct current. Then it became possible to generate power and transmit it to the load area at voltages appropriate for those functions, while continuing to serve the utilization devices at the low voltage considered safe for use in homes, offices, and factories. This arrangement freed generation from the necessity of being within 110 volts (volts, not kilovolts) transmission distance of the load. Power stations no longer had to be in the congested load areas; they could be built in locations that were better from many standpoints — accessibility of water and fuel, for example. Also, waterpower could be used to far better advantage. It was no longer necessary to locate the mill or factory right at the waterwheel. Now the wheel could be made to drive an electric generator and the power be sent electrically wherever it could be used advantageously.

The modern power system must recognize the public's dependence on electric service. Service reliability must be very high. Many years ago the operator of the village electric plant would shut down the village generator at nine or ten o'clock on a moonlight night. Today the electric clocks are expected to keep correct time throughout the year.

THE MODERN POWER SYSTEM

The basic elements of a modern power system are shown in Fig. 2-1. In this figure, for convenience, geographical separation is used to distinguish between bulk power supply and distribution. The generation, transmission, and primary substations are shown above the dashed line; the load (except the large industrial customer) and distribution below it. In most actual systems all the elements are more or less intermingled geographically, as will be seen later.

GENERATION

Five generating stations are shown. A small utility may have only five or even fewer; a large one may have a hundred or more. Again, the size of each plant may be anything from a hundred to many millions of kilowatts, or even more. Companies situated in an area where abundant hydro power was available developed power systems supplied only by hydro. As loads grew and exceeded the capacity of available hydro sites, thermal generation was necessary to deliver firm power. Firm power is the power or power producing capacity intended to be available at all times during the period covered by a commitment, even under adverse conditions. The Pacific Northwest, long a completely hydro electric system, is now reaching the stage where some thermal generation is more economical than additional hydro. Figures 2-2, 2-3, and 2-4 give an idea of the appearance of high-, medium-, and low-head hydroelectric stations. Steam stations are shown in Fig. 2-5 and 2-6.

Some utilities have no generation. They buy from other companies all the power they sell. For purposes of this discussion, however, we will assume that a utility normally generates its own power.

TRANSMISSION

Transmission is an indefinite term which usually designates the highest voltage or voltages used on a given system. The voltage may be anything from 115 kV up. Transmission voltages above 230 kV are usually referred to as "extra-high-voltage" (EHV). Power from the largest and from the most distant generating stations usually reaches the load area over the highest voltage circuits, and it is considered to be "transmitted." Interconnections from neighboring utilities, for the exchange of economy or emergency power, are quite likely to be made over "transmission" lines. Figure 2-7 shows a 500 kV transmission tower.

SWITCHING STATIONS

Switching stations are for the purpose of sectionalizing the system. There are two principal reasons for sectionalizing. The first is to disconnect the system from trouble (e.g., faults or short-circuits). Few short-circuits are self-clearing. When a circuit or piece of apparatus becomes faulted, it is usually necessary to de-energize it to clear the trouble. To avoid shutting down the whole system every time there is a short-circuit anywhere, nearly all circuits are connected to the system through circuit breakers, which are tripped open automatically. The second reason for sectionalizing is to facilitate maintenance or new construction. However, when it is necessary to de-energize a circuit, it is desirable to keep in operation as much of the system as possible: circuit breakers are used, therefore, to

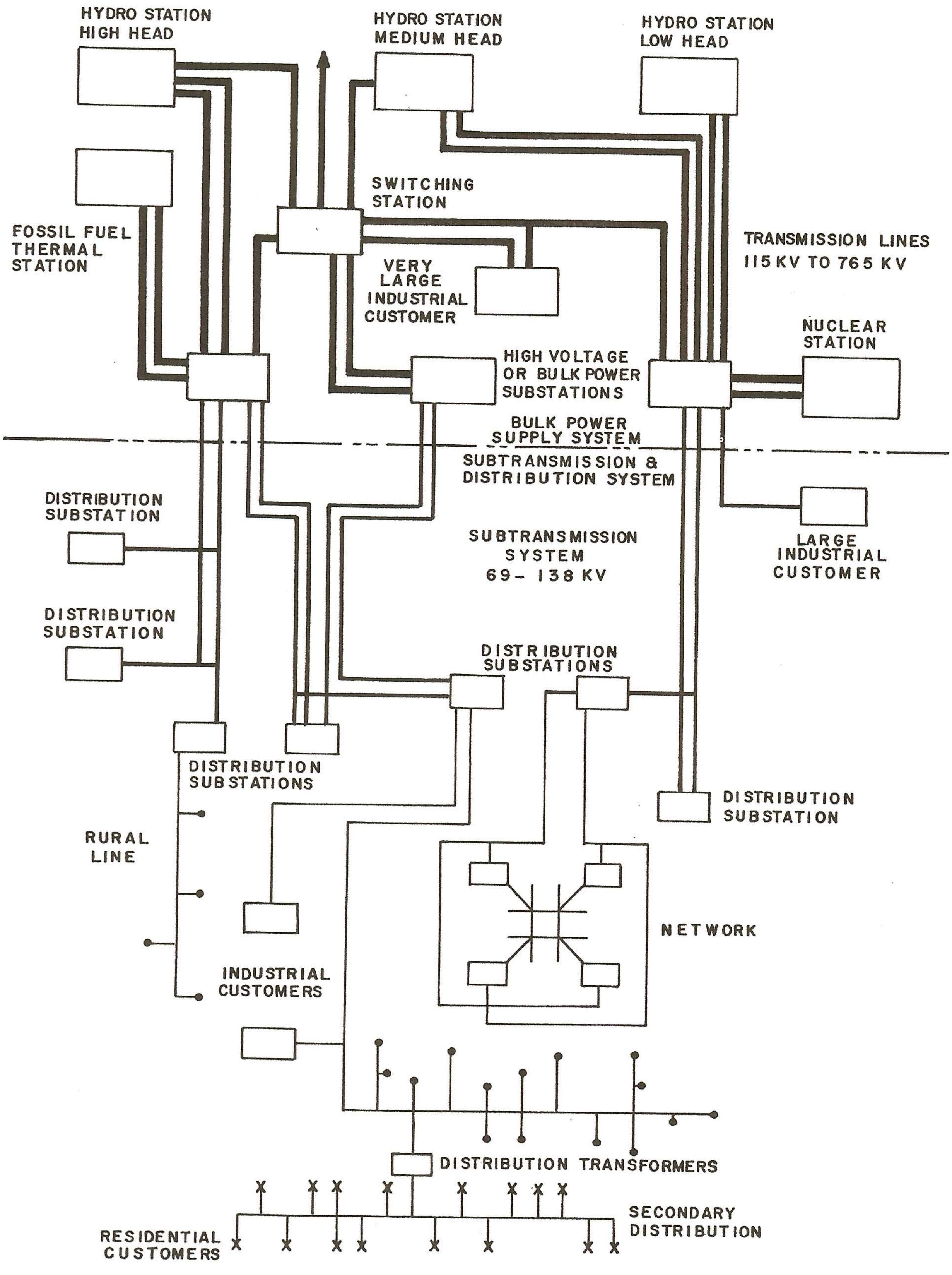

Fig. 2-1 Basic elements of a modern power system

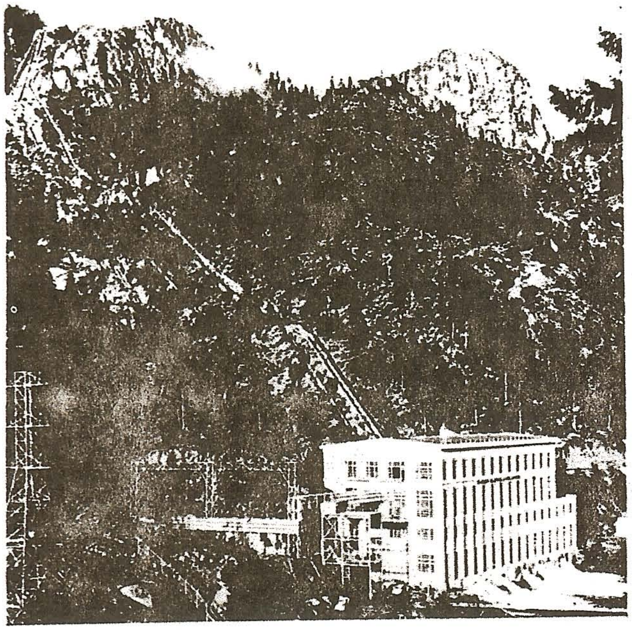

Fig. 2-2 High-head (2131 ft), hydroelectric generating station

cut off only the selected circuit. Switching stations are thus substations whose sole function is switching circuits in and out of service. They are usually necessary only on long transmission lines. Figure 2-8 shows a switching station.

PRIMARY SUBSTATIONS

It is not good policy, and usually it is not possible, to run the high-voltage transmission lines into the load area. They are terminated some distance away in substations, which are variously called "high-voltage substations," "transmission substations," "bulk power substations," "major substations," or "primary substations." At the primary substations the voltage is stepped down to a value more suitable for the next part of the journey toward the load.

The equipment found in a primary substation would include power and instrument transformers, lightning arresters, circuit breakers, disconnect switches, capacitor banks, bus work and a control house in which are located the station control equipment, protective relays, etc. Some primary substations might include even more equipment and some less, depending upon the functions they are

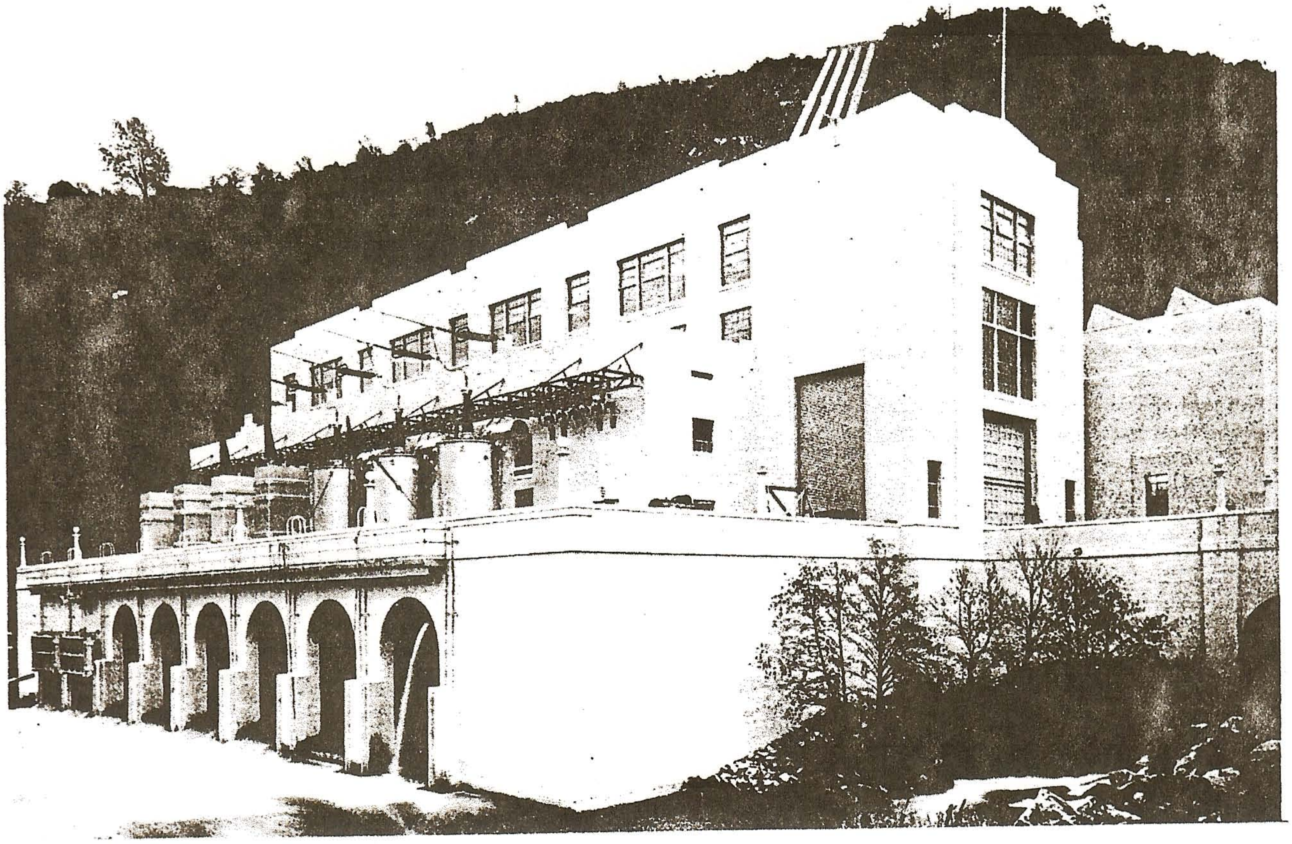

Fig. 2-3 Medium-head (830 ft), hydroelectric generating station

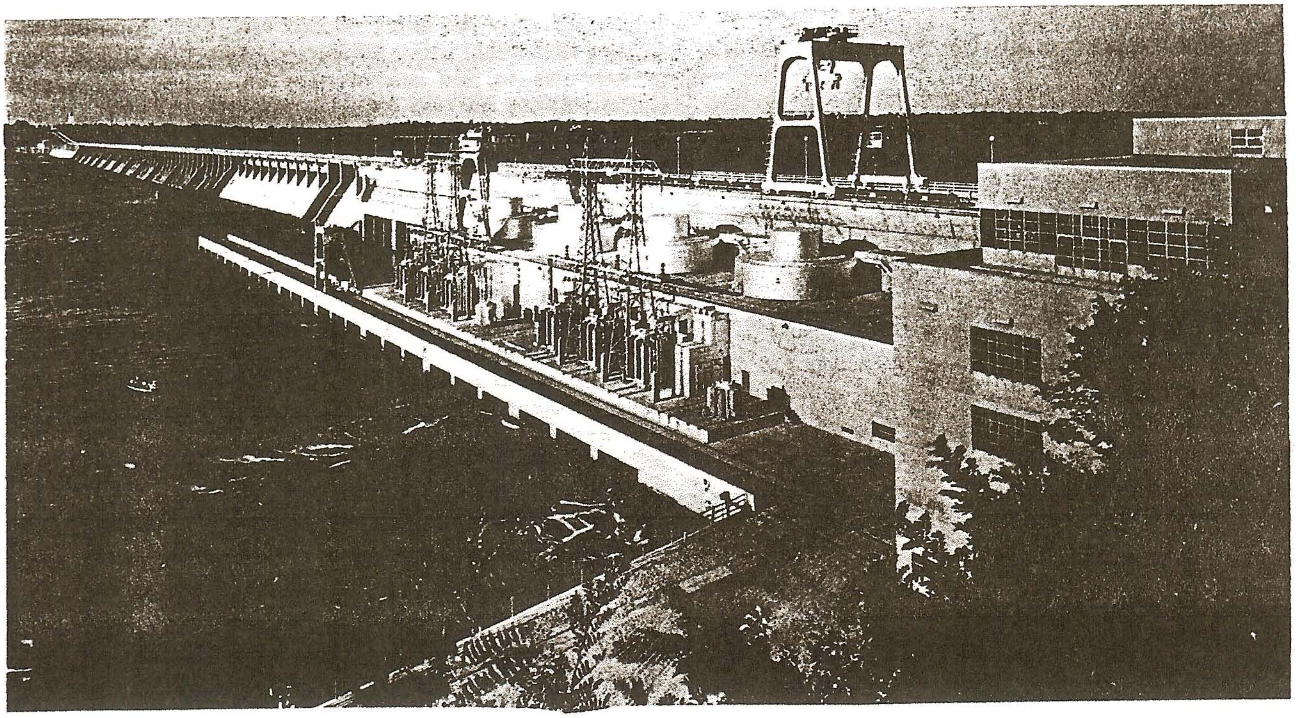

Fig. 2-4 Low-head, hydroelectric generating station

intended to perform. Some stations are manually operated and others are completely automated. Fig. 2-9 shows a primary substation in which no control house is visible.

SUBTRANSMISSION

Subtransmission usually designates that part of the system between the transmission and the distribution systems. If a generating plant is located in or close to the load, there may be no transmission lines from that plant. It will then feed directly into the subtransmission or distribution system.

The voltage of the subtransmission system is intermediate between the transmission and the distribution voltages. Some systems have only one subtransmission voltage. Frequently there are more than one. If there are, the reason may be historical. Several subtransmission voltages in one system may be an inheritance from the past, each voltage, in turn, having formerly been a transmission voltage until it became inadequate for that function. Then it was relegated to the role of subtransmission as higher-voltage transmission circuits became necessary.

On the other hand, economics may justify the use of two subtransmission voltages in series, even without any influence of the past. If the length and loading of the circuits point to a higher voltage than can safely be taken all the way to the distribution system, it may be cheaper to use two voltage levels, even though that necessitates the investment and losses of an extra transformation in the intermediate substations. Circuits which take off across country and serve a number of small villages and crossroads communities might well need a voltage different from any used to serve the higher load density areas.

Figures 2-10, 2-11, and 2-12 show types of lines used for subtransmission.

DISTRIBUTION SUBSTATIONS

The distribution system is fed through distribution substations. Prior to the development of a successful automatic reclosing relay, these substations had to be attended. They were of large capacity and supplied power to a large area through many feeders. Modern distribution substations are unattended; many are close to the load and small, and control only a few feeders — sometimes only one (for example, a single-circuit unit substation). A distribution substation is shown in Fig. 2-13.

PRIMARY DISTRIBUTION

Primary distribution takes the power from the distribution substations to the final stepdown operation, which, in residential areas, may be a distribution transformer as shown in Fig. 2-14. Primary voltages are usually between 4 kV and 34.5 kV.

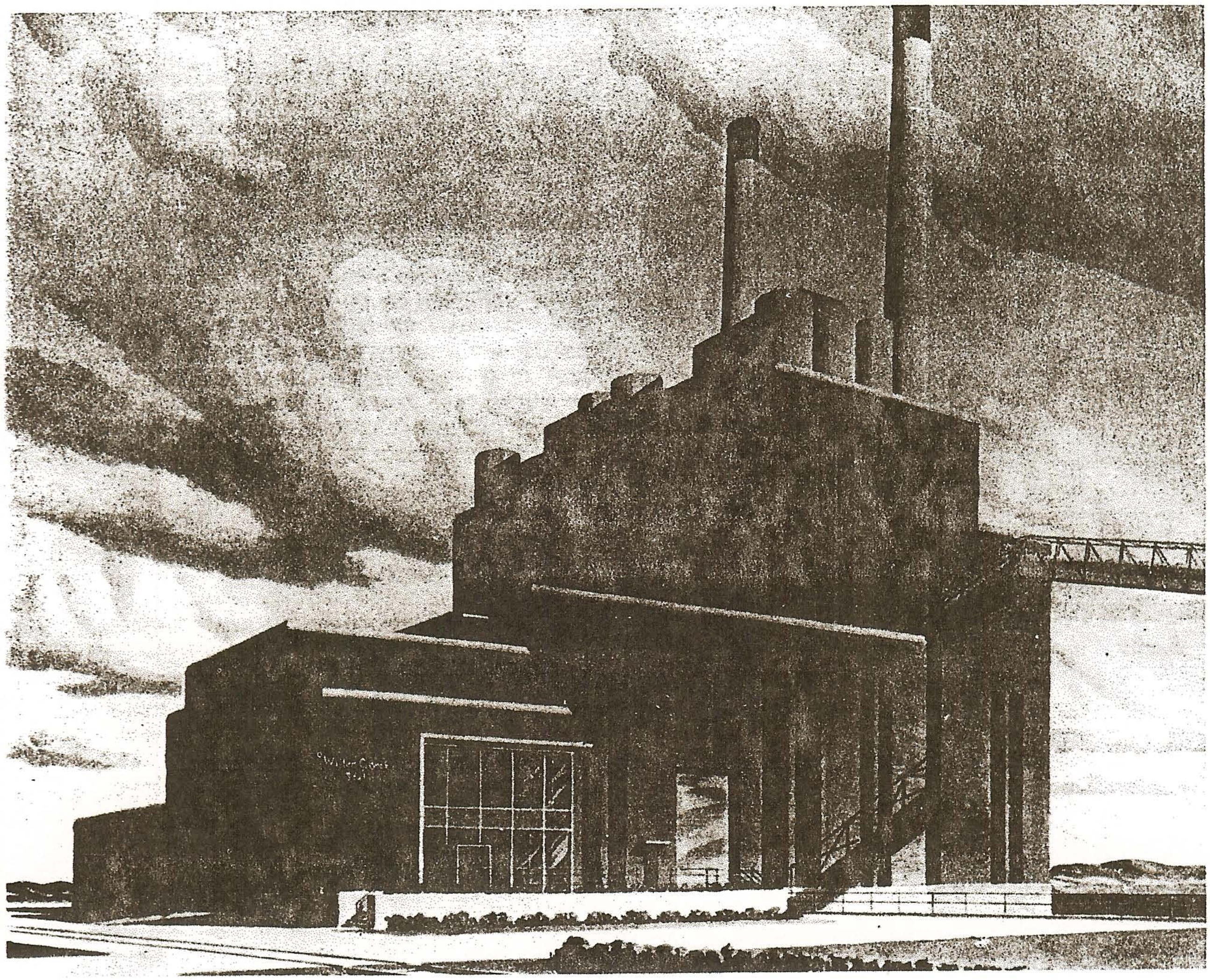

Fig. 2-5 Example of a steam generating station

Fig. 2-6 Example of a nuclear generating station

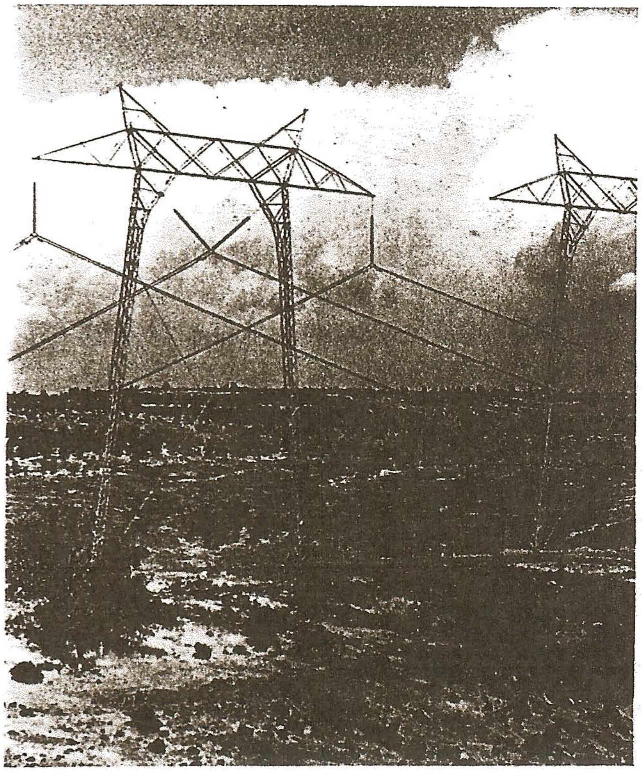

Fig. 2-7 500 kV transmission line showing two ground wires, two-conductor bundle and guyed towers. Second line under construction.

SECONDARY DISTRIBUTION

This is the part of the system through which the power finally reaches a large proportion of the customers — practically all, in fact, except the industrials and other large-use consumers.

SECONDARY NETWORK

The downtown commercial district of a city or a large shopping center is an area of high load density. Because of the nature of the loads, it is very desirable to avoid interruptions to service. This part of the city is usually served by a secondary network which feeds all the customers in its area. Usually the network, the network unit which feeds it, and all connections to and from it are underground.

INDUSTRIAL CUSTOMERS

Small Industrial Customers are served directly by the primary feeders, or possibly from the subtransmission system. Large Industrial Customers are fed directly from the subtransmission system. and Very Large Industrial Customers may be served from the transmission system. Figure 2-16 shows a "customer substation" which might be used to serve a large industrial customer.

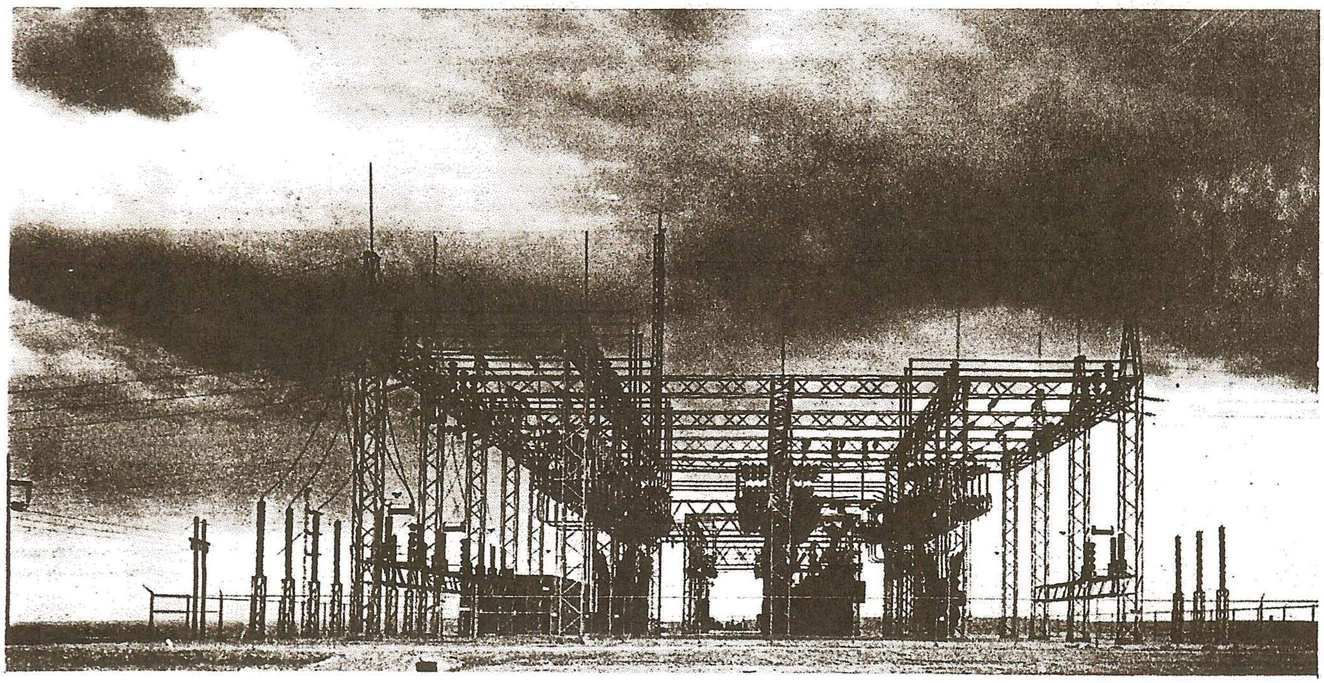

Fig. 2-8 Switching station (115 kv)