

# THE MASTER HANDBOOK OF ELECTRICAL WIRING



The do-it-yourselfer's bible to  
every phase of electrical wiring.

BY ART MARGOLIS

THE MASTER  
HANDBOOK OF  
ELECTRICAL WIRING

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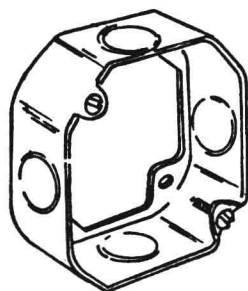
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## Preface

Some mechanically inclined people are disposed to view the subject of electrical wiring as a simple one. The notion is far from true. Although a certain amount of brawn is often involved in a wiring project, the elements of skill, thought and care are required in far greater degree. A safe and proper electrical installation demands a level of expertise that none can deprecate.

The material within these covers is designed to meet the desires for information and instruction of a multiple audience. The book addresses both the non-professional and the professional. Some readers will be interested in pursuing the career of an electrician, in qualifying for Apprentice, Journeyman or Master status, in earning a living through the installation of electrical systems. Furthermore, the material will prove extremely useful to the electronic technician and add a full new dimension to his repertoire.

The preponderance of the readership, however, is likely to consist of do-it-yourselfers and amateur electricians. Some members of this category will be novices who wish to learn how to add a switch, receptacle or simple circuit to their households. Others among the group will be looking for guidance in planning—even hooking up (in accordance with official inspection)—the entire electrical system in a new home or in revamping an outmoded system in an old home.

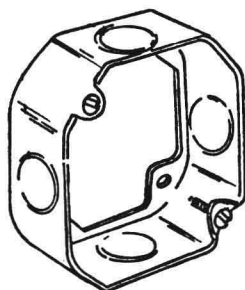
Whenever instruction, advice and recommendations are directed to the professional, the author intends for the non-

professional to attend the message closely. As in all do-it-yourself activity the amateur becomes proficient by study and imitation of the professional. The more the amateur learns about the professional electrician's field the better he will be equipped to carry out his own projects.

This book has been written simply but is complete enough to be of considerable value to each segment of its readership. It discusses tools, elementary theory and hardware in Chapters 1 through 8. Chapters 9 through 12 delve into circuit considerations. Chapters 13 through 17 put to work all the material in the first 12 chapters: residential, farming and commercial wiring jobs are calculated and the installations discussed.

The 1978 National Electrical Code is being printed as this book is being completed. The material here has been keyed to conform with the new Code as closely as possible. If you read these pages from beginning to end, you will have covered the same general areas that are taught in vocational schools and professional-type classes throughout the country.

Art Margolis



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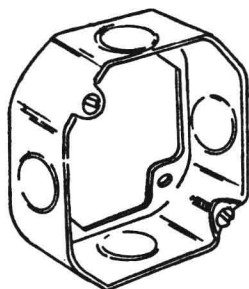
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## **INTRODUCTION**

The wireman who installs and repairs electrical systems in residences, farms, shops and factories deals with the last link in a long chain. The electric utility company delivers three or four wires to him. The wires are loaded with electrical energy. The wireman adapts these wires to supply the electrical system he has installed or repaired.

### **The Overall Electric System**

This book discusses the electrical wiring systems (Fig. 1) the wireman works with. These systems begin with what is called the service. The service is attached to the wires of the utility company. The service is the last link between the utility company and the realm of the wireman.

Before beginning a study of the electrical systems needed in home and business, it is desirable to have a picture in your mind of the general electrical network from the utility company's generating plant to the home or business service. This introduction presents an overall view of the major components in the network, showing how electricity is generated, transmitted, changed around for various uses, delivered to different distribution systems and conveyed to the service the wireman installs.

### **BASIC PARTS OF THE SYSTEM**

The typical energy producing and delivery system is composed of the following major parts. First of all there are the generating

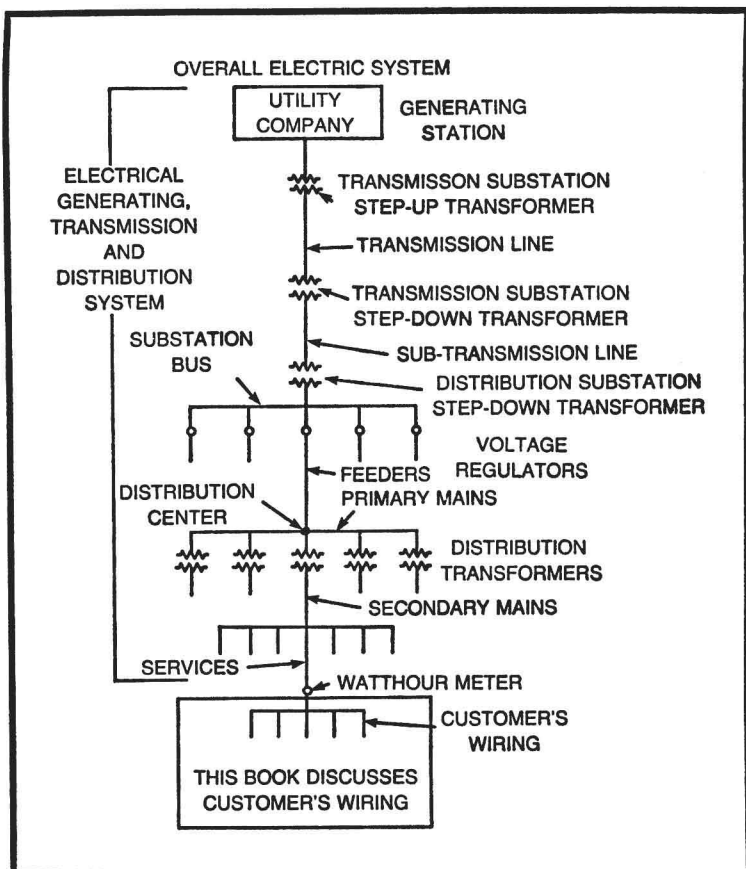


Fig. 1. Most electricians work on customer's wiring. This book is concerned mostly with this area.

stations. These are the gigantic, space age appearing installations throughout the nation. They contain engine or turbine generators that are powered by steam. The steam is produced in furnaces fueled by oil, coal, natural gas or atomic energy.

Once the turbines generate electricity, the voltage is attached to transmission lines. The transmission lines connect to substations. Out of the substations come feeder lines containing the electrical energy. The feeders go to what are called the primary mains. At the end of the mains are distribution transformers. Secondary mains emanate from the transformers. The secondary mains run up and down the streets and alleys near homes and business places. These mains are tapped for the service to individual buildings.

This is a general description. The actual electrical networks can be quite complex. There can be a number of generating stations and tens of substations. The system can be large or small, depending on the number of customers.

## **ELECTRIC GENERATORS**

The generators at the utility company's plant are able to transform the energy of coal, oil, atom or moving water into electricity. For the generator to produce electricity, its turbine or water wheel must be driven. (The steam engine generators of past years have now all but disappeared from the scene.)

The modern turbine generator is usually driven by steam. The steam is produced from heat. The heat is created by burning coal, oil or gas, or by harnessing the energy released in atomic fission. Once the steam is made, it is used to turn the blades of the turbine.

Most steam plants have high smoke stacks which discharge sulphur dioxide and particulate wastes into the atmosphere and are a source of pollution. The nuclear power plant is an exception, since it produces no fossil fuel residues. However, nuclear plants present other hazards, such as radiation. The generation of electrical energy has its problems and the conversion of fuel to electricity is a major international worry.

About one fifth of the nation's electric generators are hydroelectric. They are located at waterfalls. The descending stream of water turns water wheels of sophisticated design and the need for fuel is eliminated. The hydroelectric plant has a lot of advantages which are the result of its not needing fuel. However, dams must be built and land flooded and the overall expense is high. More importantly, there are not enough suitable sites to generate the power that the consumers demand.

Besides the large generator stations, there are many small ones. For example, a large industrial plant might find it feasible to build its own on-site electric generator. The generator would make the plant independent of the utility company.

Although most smaller plants use fossil fuel or water wheels to generate electricity, some use internal combustion engines. These engines are usually powered by diesel fuel, but sometimes by gasoline.

Most generating plants produce three-phase alternating current at a precise frequency of 60 hertz. Sixty hertz is easy to transmit over the extensive distances between plant and users. In

foreign countries nearly all electric power is produced at 50 hertz. This presents some conversion problems on occasion.

The only exception to 60 hertz production in this country is the output of hydroelectric plants. Often these plants are located at great distances from the consumer, the reason being that the plants must be built by the side of a waterfall. The city where the power will be consumed might be 100 miles or more from the plant. A large voltage drop loss could occur between plant and city, even at the low 60 hertz frequency. To prevent this, the transmission frequency would be lowered well below 60 hertz and then transformed back to 60 hertz at the city.

## TRANSMISSION SYSTEM

The voltage produced at the generator might be of the order of 13,800. This seems like a high voltage, but if it were transmitted over the wires for any significant distance, a large voltage drop would take place, resulting in a great loss of power.

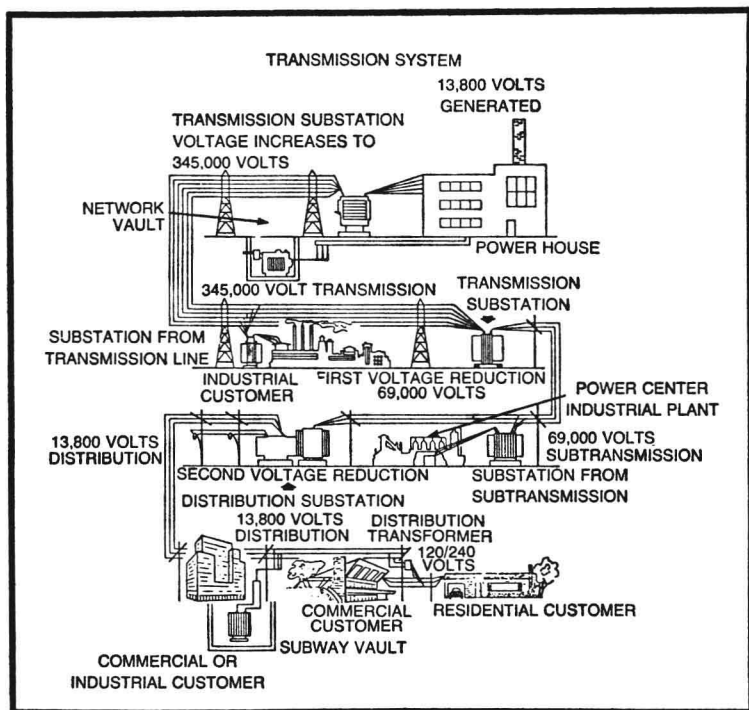


Fig. 2. The typical electrical transmission system has a number of step up and step down transformer substations between the power house and the customer.

Therefore, these 13,800 volts are passed through a transmission transformer before heading out across the transmission lines. The transformer substation steps up the 13,800 volts to 345,000. Then the voltage is sent out over the transmission lines.

The transmission lines are copper conductors and they are strung from pole to pole across the open spaces of our country. The poles and lofty towers are a familiar sight throughout the nation. The conductors are pressured with 345,000 volts. If you look up at the poles, you'll observe strings of porcelain disk insulators. The insulators hold the lines away from the pole's superstructure. At the top of the superstructure small static wires are attached. These wires are bare and connect from the metal on the pole to ground. They are lightning shields and arrestors.

Large cities do not permit the high transmission voltage to be strung overhead. There is too much of a possibility of wire breakage. High voltage lines falling onto city streets could cause great damage and death. All of the high voltage lines in cities must be run underground. The lines pass through underground tunnels. The lines look like pipes. They are actually pipes containing three well insulated and shielded cables. They transport large quantities of three-phase power throughout the city (Fig. 2).

## **SUBSTATIONS IN GENERAL**

A substation is essentially a large transformer system. The transmission lines, whether overhead or underground, terminate at substations. Some large industrial customers of a utility might have their own substations. These customers will receive the high voltage and use the substation to convert the voltage for their particular needs. Normally, though, it is the utility company's substation which does the transforming, whether the customer be industrial or residential.

A substation's purpose is, first of all, to step down the high voltage in accordance with the needs of the consumer. For instance, the 345,000 volts can be stepped down to 69,000 volts at the transmission substation; then the voltage can be sent to small industrial plants which can utilize the 69,000 volts.

A second substation can step down the remainder of the voltage from 69,000 to 13,800. The voltage can then be distributed to an even greater number of customers who are able to utilize the 13,800 volts. A third transformer can step down the voltage even more, all the way down to 240 volts to suit the needs of a residence.



In addition, substations can have the capability of changing the frequency. For example, the voltage as mentioned could be transmitted at a lower frequency than 60 hertz. The substation could have the capability of changing that lower frequency back to the desired 60 hertz. There are other functions a substation can perform, including switching the circuits on and off.

## **SUBSTATION TYPES**

There are three general types of substation, as sketchily described in the last section. There are transmission substations, subtransmission substations, and distribution substations.

The substations are differentiated by the function of their transformers. The most important of their functions is to change the generated voltage from one level to another. The transformer is able to either step up or step down the voltage, according to its design.

The transmission substation is a step up voltage type. It is located near the generator. The generator in a large plant typically produces 13,800 volts. The transmission substation steps up the 13,800 to the six-figure range, usually between 115,000 and 765,000 volts. The higher the voltage the easier it is transmitted over long distances.

The subtransmission substation is located somewhere along the route of the transmission. It is a step down station. It steps down the voltage to an intermediate voltage. Typical voltage levels at this stage are 23,000, 34,500 and 69,000 volts. These intermediate substations act as a distribution source for the local distribution substations.

Distribution substations are located near the consumers. These substations step down the voltage even further. The output of these substations is usually 4,160 volts. This voltage is distributed to the street wiring. It is the voltage that travels to the pots on the poles behind your house or beneath the ground to the concrete pads holding the small backyard distributor transformers. (Street Wiring is discussed in Chapter 18.) The pots and backyard transformers convert the 4,160 volts to the 240/120 volts needed in homes.

## **SUBSTATION TRANSFORMERS**

The substation transformers are power transformers. They can handle prescribed amounts of energy. The energy is measured in kilovolt amps called kVA. This measurement resembles kilowattage, called kW. Both kVA and kW are measures of electrical