Electrical Transmission Grid

An Online Continuing Education Course for Engineers

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Electrical Transmission Grid

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Introduction

In the past 30 years electricity use has doubled as a percentage of the total energy usage in the United States. The electric power industry is vital to the efficient operation of the sophisticated information-based economy. It is one of the last major regulated industries and it is slowly moving toward becoming a competitive market.

There are over 3,000 utilities in the U.S. from very small municipal systems to large systems with several million customers. These utilities include investor-owned companies, cooperatively owned companies, and publicly owned systems. The electric power industry has traditionally been vertically integrated where, for the most part, the same company owned the generation, transmission, and distribution systems that served a given load center. The traditional view is that the electric power industry is a natural monopoly where the least costs are obtained by operating large centralized generating plants integrated with the transmission and distribution systems. Since the early 1990's the generation component of the industry has become more of a competitive market as independent power producers (IPP's) enter the market.

The purpose of the transmission system is to provide a path to transport power from the generating plants to the local distribution systems. With the advent of IPP's, who do not necessarily locate their plants near the intended load centers, the transmission system is facing new competitive pressures. Even with competitive generation and transmission becoming more competitive, the local distribution systems will likely continue as natural monopolies into the foreseeable future.

This course is an overview of the electric power industry. It includes a brief history of the industry, a description of the different participants in the market, a review of significant legislation affecting the industry, and a detailed description of how the electric transmission grid operates. We will begin with a look at the overall structure of the industry.

Chapter 1
Structure of the Electric Power Industry

The three major components of an electric power system: generation, transmission, and distribution are shown in Figure 1. Generation is the production of electrical energy from other energy sources. Transmission is the high-voltage transportation system to deliver power from the generators to communities. The distribution system converts the high-voltage transmission supply to lower voltages for distribution throughout communities and neighborhoods. The final portion of the distribution system further reduces the voltage to appropriate levels for use in a home or business. In this section we will take a brief look at each component in an electric power system.

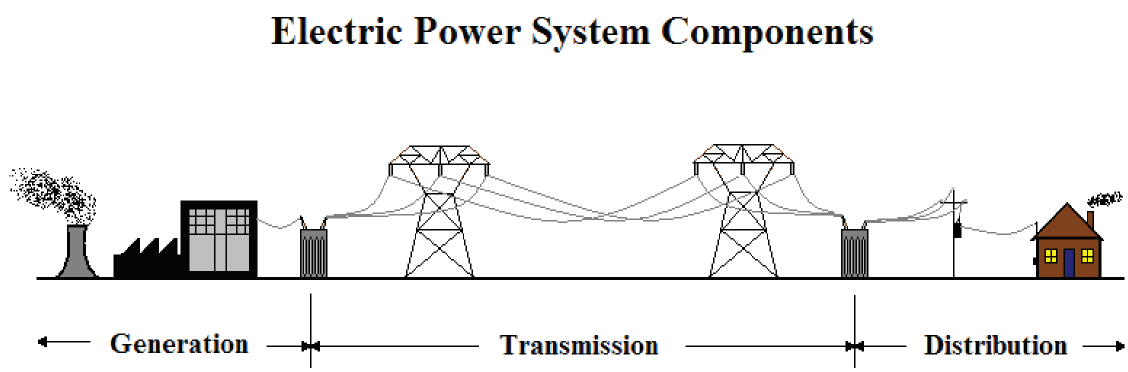


Figure 1

From a cost perspective, generation is the largest cost component of the industry followed by distribution, and transmission is actually a small component of the overall cost structure. See Figure 2 for a breakdown of the investment in the electric power industry.

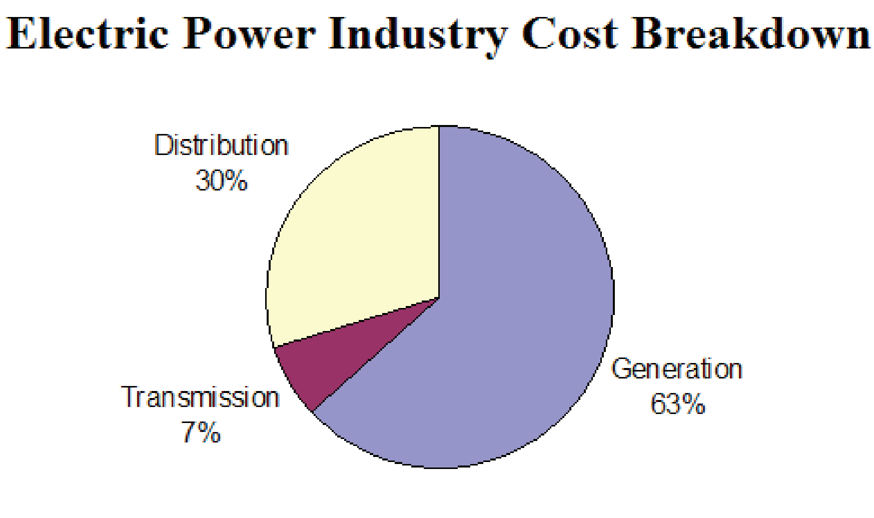


Figure 2

Generation

The generation fleet in the U.S. consists of over 10,000 power plants. They are classified by the type of prime mover, the fuel source, and the application. The prime mover is the machine that actually drives the generator and may be an internal combustion engine, turbine, or water wheel. The fuel source can be fossil fuels, such as diesel fuel, natural gas, propane, or nuclear fusion, water, wind, or even sunlight. The generator application is categorized into one of three load types: base, intermediate, and peaking. Base load units are generally very large units that generate electric energy relatively cheaply, such as nuclear or coal plants, and are designed to run continuously at a constant output. Peaking units use more expensive fuels such as natural gas and diesel fuel and are used to cover the short time peak load periods during a day. Hydroelectric plants are normally categorized as peaking plants due to the scarcity of water in many parts of the country. The output of peaking units can be varied relatively easily to meet the peak load. They are usually the cheapest units to build and can be put into service quickly. Intermediate plants cover the loads above the base load units and below the peaking units. Intermediate plants are predominately coal and natural gas combined cycle units.

The predominate fuel source in the U.S. is natural gas, followed by nuclear and coal. See the chart in Figure 3 for a breakdown of the fuel types.

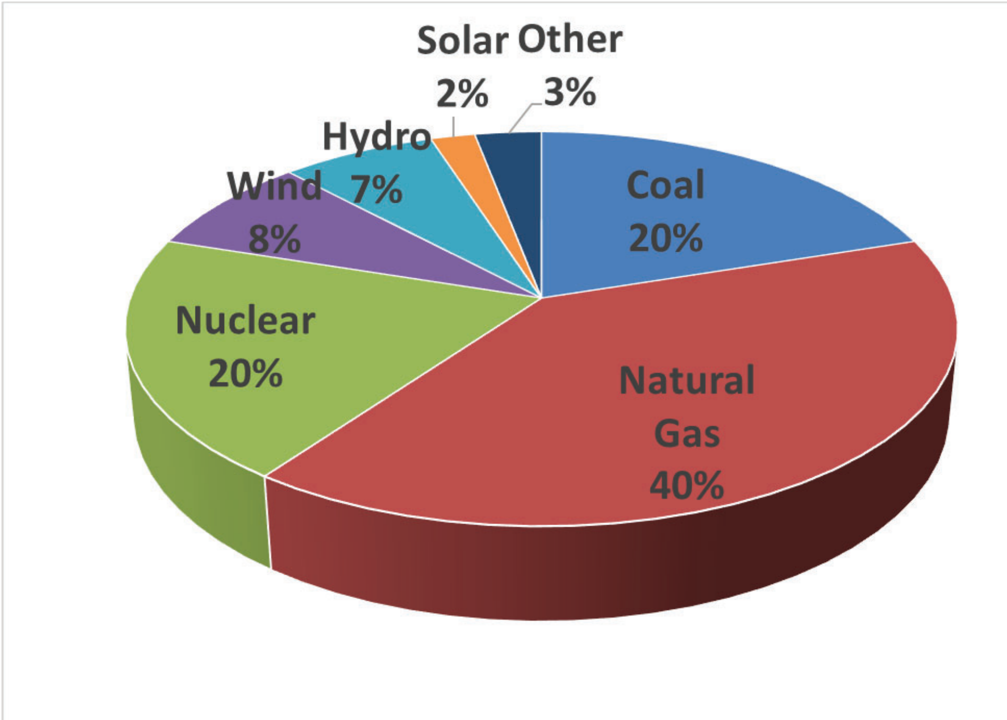


Figure 3

As you can see, natural gas makes up about 40% of the fuel mix, with nuclear and coal being about 20% respectively. Renewable fuels are about 17% of the mix. With the advent of fracking natural gas has become the predominate fuel source. With Coal's continuing decline as a fuel source, it is expected that nuclear will see a renaissance in the future to provide base-load generation. Renewable sources are expected to continue to make gains in market share.

Coal plants are known as *steam units* because the coal is burned in a boiler to generate steam that then drives a steam turbine. Nuclear plants are also steam units where nuclear fission generates heat to make steam to turn the turbine. These processes generate waste heat that must be cooled using cooling towers. Coal and other fossil fuel source plants require expensive pollution control equipment to capture sulfur dioxide (SO_2), nitrogen oxide (NO_X), and carbon dioxide (CO_2). Coal fired plants generate significantly more SO_2 than other fossil fuel sources. In fact, the amount of SO_2 in the coal varies depending on where the coal is mined. For instance, Eastern Appalachian coal has more SO_2 than Western coal.

Gas turbines and internal combustion engines are examples of *gas units*. Instead of steam, the units use hot gases from burning fossil fuels to drive the turbine. Gas units are cheaper to build than steam units, but they are less efficient. One form of gas unit is a *combined-cycle unit*. Combined-cycle units have a gas turbine to generate power, and then the waste heat from the unit is fed into a steam turbine to generate additional electric power. In the 1990's natural gas prices made these units economical for intermediate plants, but recent gas prices have made the economics of combined cycle gas units less attractive.

Cogeneration unit is a term used to describe a generator that is also used for another purpose. For instance, a sawmill may use waste wood chips to fire a boiler to generate steam to produce electricity. Furthermore, the waste heat from the generator may be used to provide space heating, etc. Cogeneration units are found in manufacturing plants and the term, cogeneration, comes from the fact that the steam used to fire the boiler is also being used for another application. There are two types of cogeneration units, bottom-cycling and top-cycling. With *bottom-cycling units*, the manufacturing plant generates high quality steam for its industrial process and the waste is then used to drive the turbine generator. With a *top-cycling unit*, the steam is first used to produce electricity and the waste steam is then used in the manufacturing process.

Kinetic energy units use water or wind to turn turbines to produce electricity. Most hydroelectric units are based on impounding large quantities of water. Since water is a scarce resource in many parts of the country, it is only feasible to run hydroelectric units for a few peak hours per day. There are some new, small, efficient, “run-of-the-river” hydroelectric units that do not require impoundments, but these units tend to be very small and not applicable to large scale generation. Wind turbines use an inexhaustible resource, wind, to generate electricity. These units are only feasible where significant wind sources are available, and community support is often difficult to obtain due to the impact the units have on the community’s “view shed”. Solar units are another renewable generating source that is gaining popularity. These units are best suited for small, end-use applications such as roof top units to serve a single dwelling. Both wind and solar units suffer from an intermittent fuel source.

The choice of a fuel source is largely dictated by the availability of natural resources in the area. The Pacific Northwest has a large base of hydroelectric plants because of the availability of water resources. The Eastern states are heavily dependent on coal because of the abundance of coal in the Appalachians. Oil-rich states such as Texas, Louisiana, and Oklahoma, use a lot of natural gas to generate power. Florida is a major natural gas user because of the expense of transporting coal to the State.

Transmission

There are over 150,000 miles of transmission lines in the U.S. that deliver power from the generators to the load centers. Not only are transmission lines used to deliver power to the load centers, but they are also used to provide interconnections with other utilities for reliability and economic load transfers.

Unlike the simple diagram in Figure 1 the transmission system is truly a “grid” where many power plants are connected to many transmission lines, which “pools” all generation resources into one common grid. The distribution system connects to this grid and draws power from that point on the grid. This interconnected grid concept results in an extremely reliable power system since the loss of any one power plant does not shut down the flow of power into the grid. See Figure 4 for a simple schematic view of the electric power grid.

As you can see in Figure 4 there are many paths from the generator to the load centers, and the loss of any one path from a generator, or loss of any one generator, would not cause a loss of power at the load center.

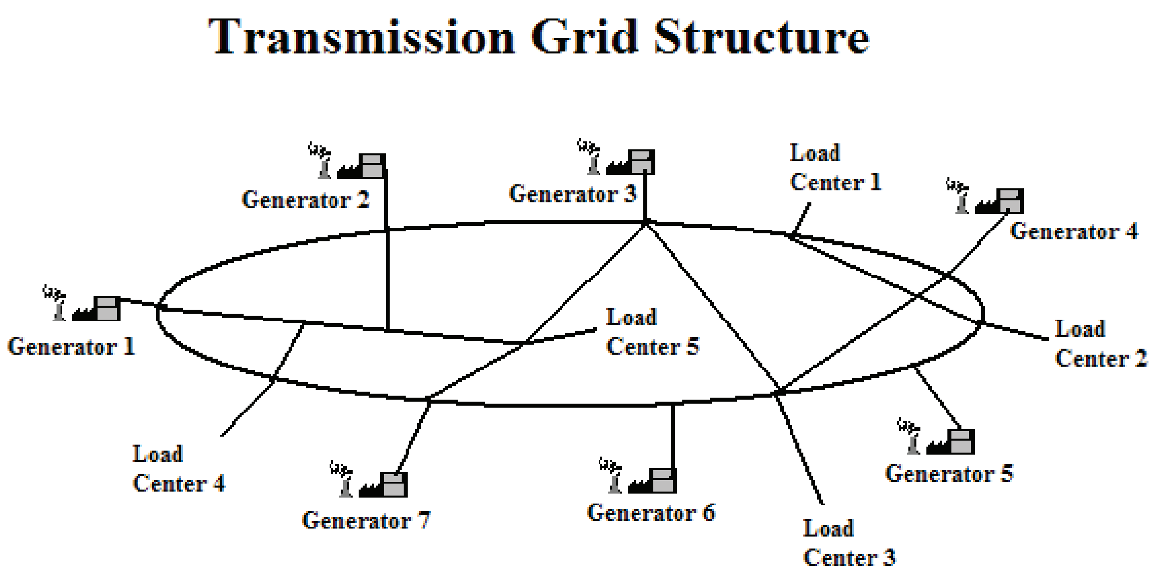
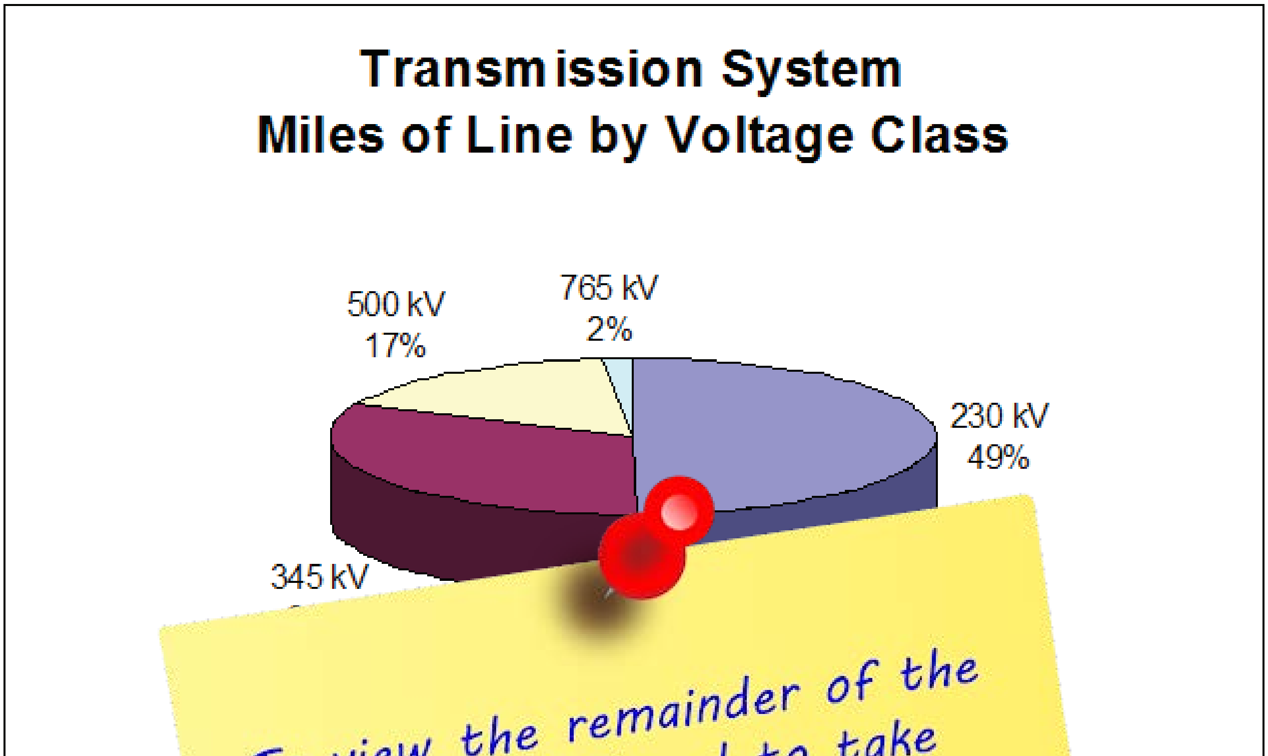
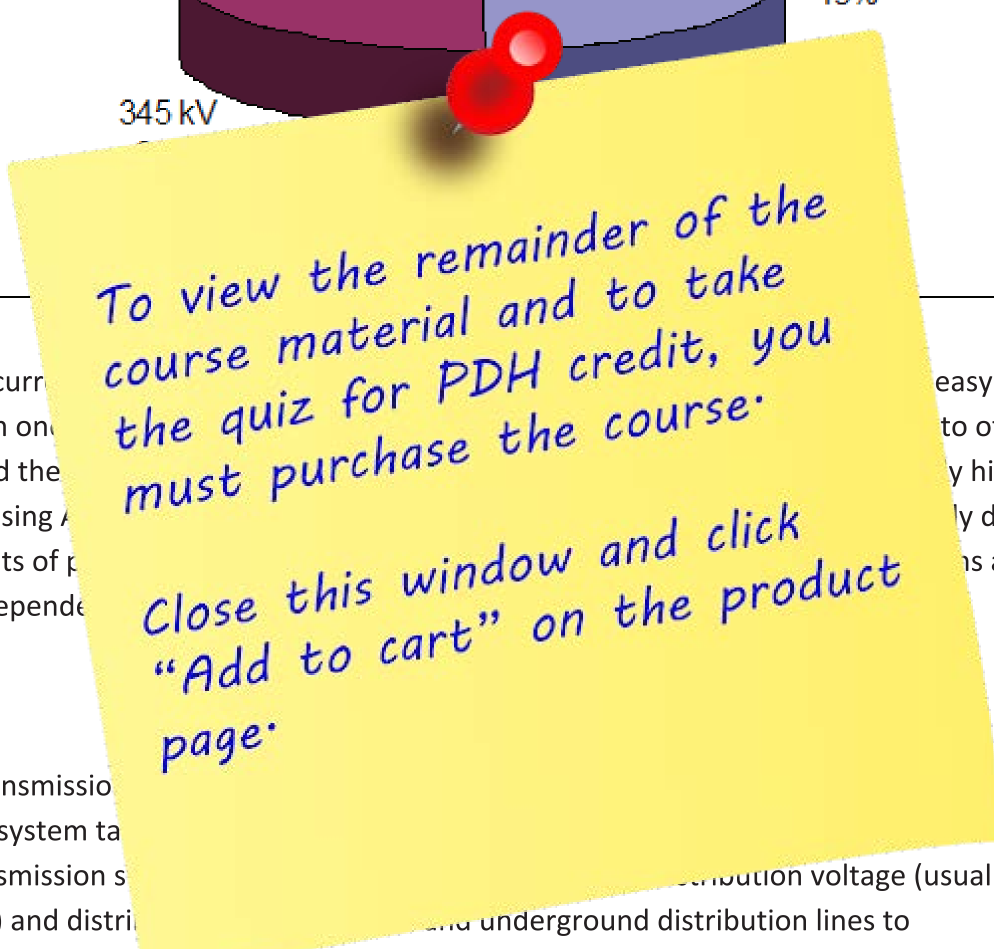


Figure 4

Transmission systems utilize high voltage, alternating current (AC) systems to promote the transportation of large amounts of power and to reduce the I^2R, or heat losses, due to the resistance in the power lines. Although there is not an exact definition of transmission voltages, it is generally assumed that anything over 138 kV is transmission. Another class of transmission, called sub-transmission, is in the range of 46 kV to 115 kV and is used to deliver power in a community to different distribution substation sites. There is a small amount, less than 3%, of the transmission system that operates on direct current (DC).

See Figure 5 for a breakdown of miles of transmission by voltage class. The 230 kV voltage class represents 49% of the market. Next is 345 kV, which has 32% of the market. 765 kV has the smallest share at only 2% of the market.





Alternating curr … easy to convert from on… to other voltages, and the … y higher than when using … ly deliver large amounts of … ns are not frequency depend…

Distribution

Once the transmissio … distribution system ta … igh voltage transmission s … ribution voltage (usually 15, 25, or 35 kV) and distri … underground distribution lines to neighborhoods. At the … user, the voltage must again be stepped down to an end user level (120/240-volts for a residential application).