United States Environmental Protection Agency

Roadmap for Incorporating Energy Efficiency/Renewable Energy Policies and Programs into State and Tribal Implementation Plans

Appendix B: Overview of the U.S. Electric System

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Contents

FIGURES

SECTION B.1: INTRODUCTION

Generating electricity from fossil fuels is the single largest source of anthropogenic carbon dioxide (CO_2) emissions in the United States, representing 40 percent of CO_2 emissions in 2009.[1] It is also the largest source of criteria air pollutants that affect air quality and human health. For these and other reasons there has been growing interest in understanding the impacts of state-level energy efficiency and renewable energy (EE/RE) policies on emissions from power generation. Much of this interest has come from state environmental regulators interested in including emission reductions from EE/RE policies in their plans for improving and maintaining air quality.

Many air agencies are already familiar with the electric system, and the roles and responsibilities of energy agencies in their state. For those who want more information on the topic, it is provided here in this appendix as a convenience. For these stakeholders and others working to analyze the effects of clean energy on air pollution emissions, there is a need to:

- Understand the electric system
- Understand how the system is likely to respond to the introduction of clean energy resources
- Conduct analyses that credibly and accurately represent this interaction and estimates reductions in air pollution

Appendix B is intended to address these needs, in addition to other resources.[2] It highlights the basic workings of the electric system and addresses important issues that arise in energy and emissions planning; most notably quantification of emission benefits for incorporation in State Implementation Plans (SIP)/Tribal Implementation Plan (TIP) (see Appendix I for details on quantification methods). A key take-away from this Appendix is that the operation of regional power systems is complex and dynamic, so predicting how these systems will react to new resources – including EE/RE – is likewise a complex undertaking.

SECTION B.2: ABOUT THE U.S. ELECTRIC SYSTEM

The most common way to generate electricity is to burn fossil fuels to convert water into steam, and to use the steam to spin a turbine that is connected to an electric generator. Generators can also be turned by water – as is the case with hydroelectric power plants – or by wind turbines. In all cases, the electricity generated at these facilities flows across the transmission and distribution system to where it is needed to meet customer demand in cities and rural areas.

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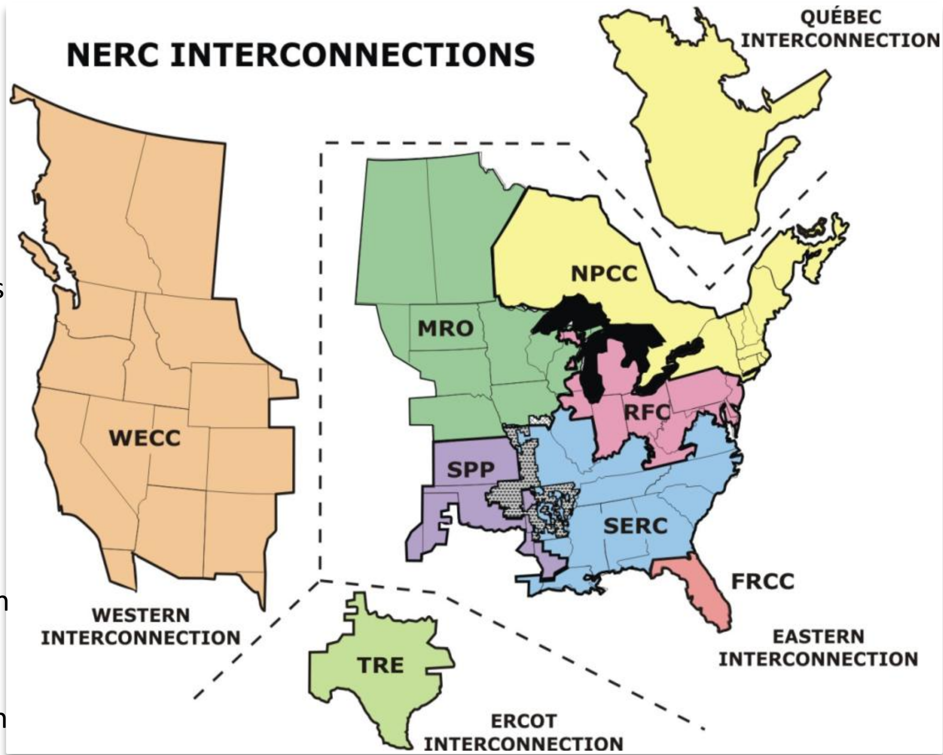
[1] EPA (2011).
[2] EPA (2010).

The North American electric system is an interconnected network for generating, transmitting, and delivering electricity to consumers. Over the past 100 years, the system developed around a "central station" model that distributes power from large generating stations (often located near a fuel source) to customers located in load centers that are hundreds of miles away. The current electricity delivery system was designed and built in the 1950s to move large quantities of power from generators to consumers at low cost. Despite a recent trend towards more "distributed" power in which small generation facilities such as combined heat and power systems are located near loads, most electric power in the U.S. continues to be generated at central-station facilities powered by coal, natural gas, nuclear, and hydropower.

Figure 1: NERC Interconnections



Source: http://www.nerc.com/fileUploads/File/AboutNERC/maps/NERC_Interconnections_color.jpg

The North American electric system is divided into four distinct North American Electric Reliability Corporation (NERC) interconnection grids in the continental United States and Canada: eastern grid, western grid, Quebec grid and the Electric Reliability Council of Texas (ERCOT) (see Figure 1). The generators, power lines, substations, and power distribution system are the responsibility of various utility companies working together under regional oversight to keep each grid operational. Each grid has only limited connections to the other three, but within them electricity is imported and exported continuously among numerous smaller power control areas (PCA).

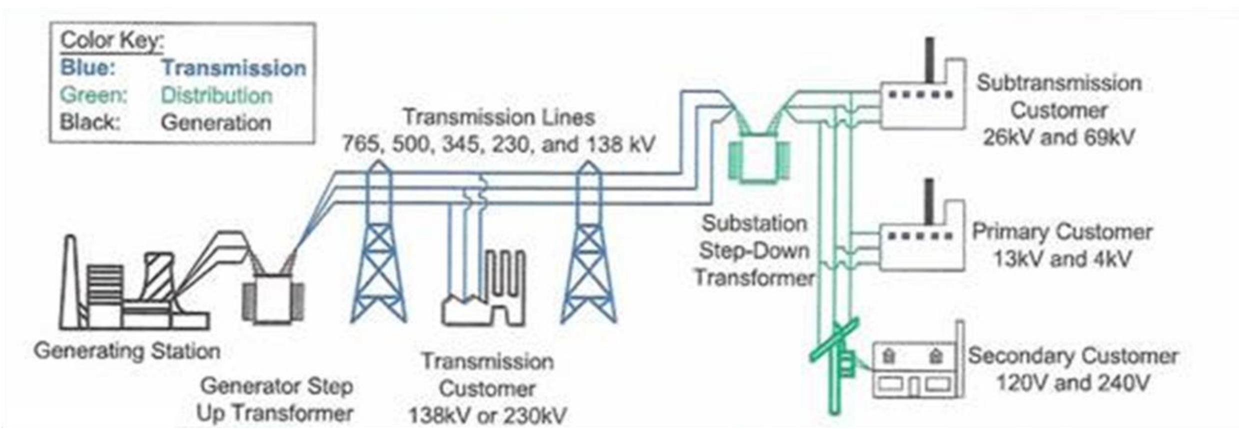
PCAs are managed by system operators, or transmission organizations, whose main function is to maintain the reliability of the system in their areas (e.g., New England, New York, California). They do this by balancing the electricity supplied by the power plants with that demanded by customers. This happens in real-time, every day of the year. In other words, energy is simultaneously being generated and consumed on each grid in the same quantity. There is very little ability to store electricity, and it is difficult for the grid to accommodate large, rapid changes in use and generation.

SECTION B.3: HOW THE ELECTRIC SYSTEM WORKS

Figure 2 depicts the flow of power from the generating station, or power plant, to the transformer and transmission lines through a substation transformer (that reduces voltage) to the distribution lines. It then flows through the pole transformer to the consumer's service box. Electricity *transmission* typically refers to power flow between the generating station and a substation, and electricity *distribution* most often refers to delivery from the substation to consumers. The flow of electricity occurs in accordance with the laws of physics—along paths of least resistance — in much the same way that water flows through a network of canals.

Over time in a given location, the consumer demand for power fluctuates significantly. For instance, residential electricity demand typically peaks in the morning and evening when residents are home and operating electricity-consuming products. In contrast, commercial electricity demand typically peaks during the middle of the day while industrial demand varies by individual firm and type of industry. System planners have to account for these variations as well as other factors, such as weather and the availability of individual power plants, all while keeping the system in balance. Fortunately, the aggregate demand of the many jurisdictions across a single grid behaves in a relatively predictable manner.

Figure 2: Flow of Electric Power

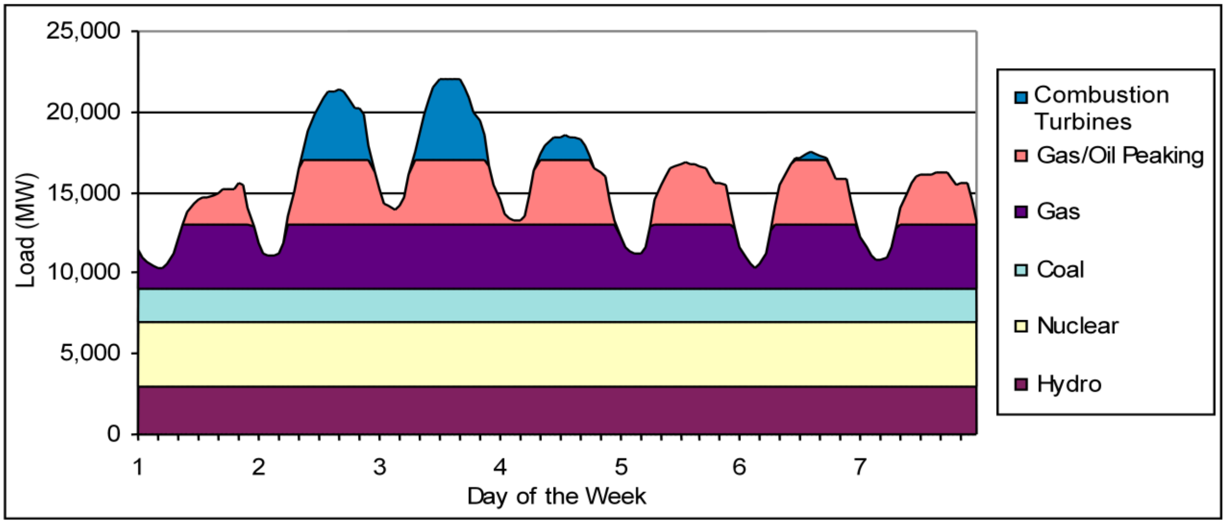


Source: https://reports.energy.gov/BlackoutFinal-Web.pdf

To meet consumer demand, the grid operators rely on a fleet of power plants with different operational characteristics, fuels, and cost structures. Base load plants, such as nuclear and most coal plants, operate 24 hours a day and do not readily cycle up and down. They are meant to start up and keep running until maintenance is needed. Base load units are also characterized by relatively high capital costs, low operating costs, and a ramp-up process that is typically slow, expensive, and results in wear on the generating units. As power demand increases over the course of a day, intermediate and peaking plants come on line. These plants have the physical capability to quickly ramp up power production to meet increasing demand

and to rapidly cycle down once that demand dissipates. These plants are often engines or turbines that are fueled by oil or natural gas (see Figure 3).

Figure 3: Unit Dispatch in a Power System



Source: http://www.synapse-energy.com/Downloads/SynapseReport.2005-07.PQA-EPA.Displaced-Emissions-Renewables-and-Efficiency-EPA.04-55.pdf

The decision of which power plants to dispatch and in what order is based in principle on economics, with the lowest-cost resources dispatched first and the highest cost resources used last. The last resources to be called upon are referred to as the marginal units, which are typically the most expensive units to run. In some cases in certain parts of the country, these plants can also be among the dirtiest and least efficient of the power plant fleet.

Renewable energy and EE can affect the dispatch in different ways, though both cause marginal units to run less frequently and result in fewer air emissions. In the case of efficiency, energy savings occur at the point of consumption resulting in a reduction in demand on the electric system and a corresponding reduction in emissions from the power plant fleet.

In contrast, RE sources reduce the output from the marginal unit by producing electricity for the power. Thus, a wind farm producing electricity displaces the need for electricity that would have

Marginal Units

- ✓ The highest-cost unit dispatched at any point in time is said to be “on the margin” and is known as the “marginal unit.”
- ✓ At peak times, for example, high-cost combustion turbines and gas/oil peaking units are frequently on the margin.
- ✓ During off-peak times, plants with lower operating costs (e.g., combined cycle gas turbines and coal-fired steam units) can be on the margin.
- ✓ In some regions, the cost used to determine merit order for dispatch is the variable cost of running each plant (mainly fuel cost), but in other regions the criterion for dispatch is a bid price submitted by the owners of the generators.

otherwise been produced by that marginal unit. Since wind power results in zero emissions, overall emissions from the power plant fleet are reduced (absent a cap on emissions that determines overall pollution levels).

This theory of "economic dispatch" predicts that any new resource will shift upward all resources above it in the dispatch order, thereby reducing demand on the marginal unit (the most expensive unit needed to meet demand). Actual plant dispatch, however, is frequently more complicated than the representation in Figure 3 for three main reasons:

- Transmission constraints may require system operators to dispatch certain units that are more expensive than other available units.
- It is time consuming to start and stop many types of large generating units. Limitations on unit "ramp-up rates" also force system operators to keep some units running during periods when they are not needed (in order to have the units available when they are needed). These are referred to as load following, or intermediate units, and are often running at a lower and less efficient rate while not producing any power for input into the grid.
- System operators do not treat generating units as single entities in the dispatch process. Instead, plant owners in competitive markets typically bid the power from an individual generating unit into a smaller number of "blocks" that are instead bid into the grid.

Because actual unit dispatch often looks very different from the ideal shown in Figure 3, environmental regulators and others should be aware of how these electric-system realities are represented in control-measure estimates of emission reductions.

SECTION B.4: ROLES AND RESPONSIBILITIES

In the electric system, four entities have key roles and responsibilities:

- State energy offices
- Public utility offices or service commissions
- Vertically integrated utility companies
- Regional transmission organizations and independent system operators

State energy offices perform a number of functions:

- Assist in achieving state energy-related environmental goals
- Ensure that the needs and issues of industry, business, and residential energy consumers are considered during energy policy and program development
- Aid businesses in using energy effectively, modernizing industry, and retaining and creating jobs
- Help residential and other low-level energy consumers meet their energy needs through cost-effective and energy efficient solutions

- Demonstrate the application of cost-effective advanced EE/RE and other clean energy technologies
- With other state agencies, deploy technologies to reduce energy consumption and meet energy-related environmental goals

Public utility or service commissions act as governing bodies that:

- Regulate the rates and services of a public utility that provide essential services, including energy
- Oversee and evaluate EE/RE policies
- Ensure reliable utility service at fair, just, and reasonable rates
- Ensure that the facilities necessary to meet future growth can be financed on reasonable and fair terms
- Encourage harmony between utility companies and their customers
- Foster planned growth of public utility services
- Coordinate energy supply facilities with the state's development
- Cooperate with other states and the federal government in providing interstate and intrastate public utility service and reliability of energy supply

Vertically integrated utility companies:

- Oversee the entire chain of power delivery
- Produce electricity through the operation of power plants
- Deliver power to residential, commercial, and institutional customers

Regional transmission operators and independent system operators provide several services:

- Serve as grid operators, coordinating the power grid to ensure reliable delivery of two-thirds of the electricity used in the United States to two-thirds of its population
- Match generation to load instantaneously to keep supply and demand for electricity in balance
- Provide non-discriminatory transmission access, and facilitate competition among wholesale suppliers to improve transmission service and provide fair electricity prices
- Schedule the use of transmission lines
- Manage the interconnection of new generation and monitor the markets to ensure fairness and neutrality for all participants

SECTION B.5: LOCATION OF EMISSION REDUCTIONS RELATIVE TO THE SITING OF CLEAN ENERGY RESOURCES

The goal of clean energy policies in the SIP planning context is typically to reduce emissions within the jurisdiction where the policies are implemented. To achieve this goal, all (or a portion of) the emission reductions from EE/RE must occur in a location that affects air quality in the implementing jurisdiction. The environmental regulator can take steps to ensure that the analysis supporting such a policy accounts for the interconnected and dynamic nature of the power system, and that it examines the possibility that the benefits of clean energy policies may not be completely realized within the jurisdiction of interest.

This can be illustrated by the example of a state with a renewable portfolio standard requiring utilities to buy a fixed percentage of their electricity from renewable energy facilities. If a local utility signs an energy-purchase contract with the nearest renewable facility, the state may find it difficult to correlate wind power produced by that wind farm to a corresponding reduction in electric output and emissions from specific fossil-fuel generators. The implementing state needs to ensure that the emission reductions occur at an upwind or nearby facility, which affects the implementing state's air quality. For this reason, it is critically important to understand and accurately predict how the regional power grid is likely to behave when assessing the emission benefits from clean energy resources.

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