10. Reduce Losses in the Transmission and Distribution System

1. Profile

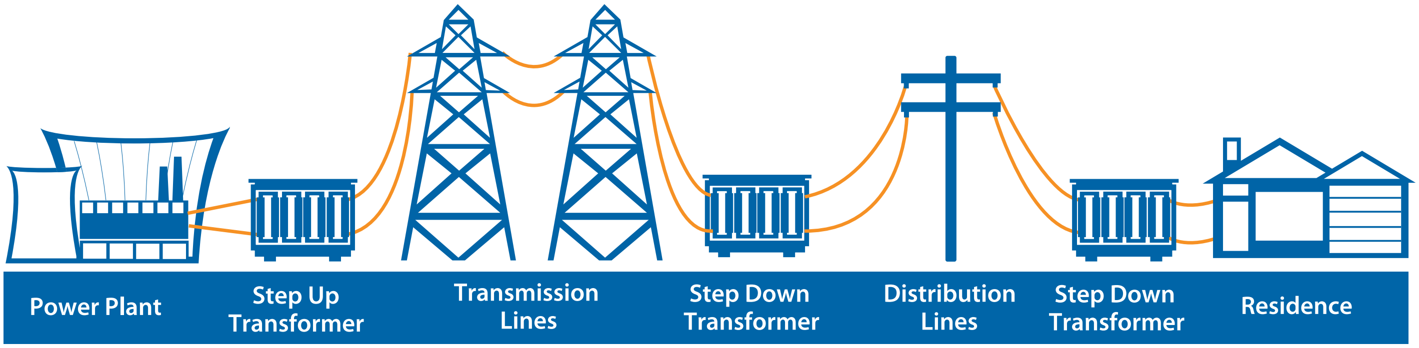
Electricity losses occur at each stage of the power distribution process,[1] beginning with the step-up transformers[2] that connect power plants to the transmission system, and ending with the customer wiring beyond the retail meter. The system consists of several key components: step-up transformers, transmission lines, substations, primary voltage distribution lines, line or step-down transformers, and secondary lines that connect to individual homes and businesses. Figure 10-1 shows a diagram of these system components. These electricity losses are often referred to generically as "line losses," even though the losses associated with the conductor lines themselves represent only one type of electricity loss that occurs during the process of transmitting and distributing electricity. System average line losses are in the range of six to ten percent on most US utility grids, but they increase exponentially as power lines become heavily loaded. Avoiding a small amount of electricity demand in the highest peak hours can reduce line losses by as much as 20 percent. At such levels of losses, disproportionately more generation resources need to be operated to deliver the same amount of electricity to end-users.

Each of the stages identified in Figure 10-1 is subject to losses, and therefore provides opportunity for efficiency improvements. The cumulative benefits can be very significant. This is because a one-kilowatt (kW) load reduction at the customer's end translates into more than a one-kW load reduction – sometimes very much more – moving "upstream" to the distribution, transmission, and generation levels because of losses compounding along the way.

Each component of the distribution system can be optimized to reduce line losses. This chapter discusses each component, and how equipment choices can affect efficiency

Figure 10-1

Simple Diagram of an Electric Transmission and Distribution System[3]



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[1] "Distribution" is, regrettably, an ambiguous term when discussing electric power. As used in this sentence, it reflects the overall process of delivering electricity from power plants (where it is generated) to end-users (where it is consumed by homes, businesses, and institutions). Distribution is also a technical term of art, however, which refers to the lower-voltage, later stages in the electricity delivery process, as illustrated in Figure 10-1. The reader should remain cognizant of the potential for the confusion this ambiguity creates.

[2] Transformers are used to increase voltage for more effective transportation of electricity and to decrease voltage back to levels suitable for industrial, commercial, and residential use.

[3] Adapted from: Cowlitz County (WA) Public Utility District. (Undated). *Electricity-Transmission (How Electricity Moves)*. Available at: http://www.cowlitzpud.org/pdf/electricity101/6%20Electricity%20-%20Transmission.pdf.

and, by extension, greenhouse gas (GHG) emissions.

In addition, line losses can be significantly affected by end-use energy efficiency policies (detailed in Chapters 11 through 15) and demand response programs (Chapter 23).

Engineering Fundamentals

Losses occur in both transmission and distribution lines and in transformers, the fundamental components of the electricity distribution system or "the grid." Some losses, called "core" or "no-load" losses, are incurred to energize transformers in substations and on the distribution system. A larger share is labeled "resistive" or "copper" losses; these losses reflect the resistance of the materials themselves to the flow of electricity.

Core losses are typically 25 to 30 percent of total distribution losses, and do not increase (or decrease) with changes in load. They are largely influenced by the characteristics of the steel laminations used to manufacture the core of transformers.

Resistive losses are analogous to friction losses in the lines and transformers. As loads increase, the wires (including those in the transformers) get hotter, the material becomes more resistive, and line losses increase. For this reason, resistive losses increase exponentially with the current on a line.[4]

At low-load periods, system losses are almost entirely core losses, and may be as low as three percent.[5] During peak electrical demand periods, however, resistive losses become dominant. At the highest load hours, average line losses increase into the 10- to 15-percent range, but marginal line losses (those that are avoided if load is reduced) may increase to 20 percent or more. This concept is analogous to a freeway at rush hour – even a small reduction in traffic volumes can produce very large reductions in "friction" and improve traffic flow. At peak extremes, it can take five power plants operating to provide the end-use electricity normally provided by four.

Therefore, line loss reduction is partly a function of system design and construction, but is also heavily affected by operation of the underlying electrical loads and by how well peak loads are managed. Chapters 11 through 15 and 23 address energy efficiency and peak load management, both of which are very important in reducing line losses.

Key Units for Measuring Electricity

This chapter necessarily involves technologies and terminology that may be foreign to air quality regulators, but are quite well understood by the utilities that they regulate. Several terms reflecting common units of electrical measurement – and their abbreviations – are defined below.

- **Amperes (A):** A measure of the current flow through lines and transformers. It is analogous to the flow of water through a pipe.
- **Kilovolts (kV):** Thousand volts, the unit of measure for generation, transmission, and distribution lines.
- **Kilowatt-hour (kWh):** A measure of energy or power consumed in one hour.
- **Volts (V):** Voltage is what drives current through lines and transformers to end-use appliances in homes and businesses. It is analogous to pressure in a water pipe. Voltage must be delivered within a narrow range of between 110 and 124 volts at all times for residential appliances and equipment to operate properly.
- **Watts (W):** A measure of the quantity of power or work (horsepower) that electricity can do at any moment. Watts is the product of amperes multiplied by volts. For example, 220 volts at 20 amps equals 4400 watts, about the amount that a typical residential electric water heater uses. A one-horsepower (1 hp) swimming pool pump motor uses 746 watts.

A later section will discuss additional terms, including power factor and reactive power, which slightly modify these units of measurements to reflect the character of electricity usage. Reactive power is measured by volt-amperes (VA) and by volt-ampere reactive (VAR).

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[4] This is reflected mathematically as I^2R, meaning the losses increase with the square of the current ("I" or amperage) multiplied by the resistance (R) of the transformer winding or line conductor.

[5] Because the current is low, the square of the current is also small.

Components of the System That Contribute to Losses

Each component of the utility transmission and distribution system contributes to losses, so a loss avoided at the customer's end-use or meter compounds, moving back up the system to the generation level. Table 10-1 below illustrates typical line losses at each stage below the transmission receipt point. Transmission system line losses generally involve two (or more) additional transformation stages and one (or more) additional set of lines. Depending on voltage and distance, transmission line losses range from two to five percent.

Table 10-1

Losses at Each Stage of Electricity Distribution[6]

Component	Estimated Loss as a Percentage of Energy Sold: Typical Urban	Estimated Loss as a Percentage of Energy Sold: Typical Rural
Subtransmission Lines	0.1	0.7
Power Transformers	0.1	0.7
Distribution Lines	0.9	2.5
Distribution Transformers No Load	1.2	1.7
Distribution Transformers Load	0.8	0.8
Secondary Lines	0.5	0.9
Total	**3.6**	**7.3**

The following section describes each segment of the transmission and distribution system, with an indication of how losses occur and how they can be mitigated.

Step-Up Transformers. These are the transformers located at generating facilities, which convert the power produced at generating plants to voltages suitable for transmission lines. Typical large generators produce power at 6600 volts, 13,800 volts, 18,000 volts, or even 22,000 volts, whereas typical transmission voltages in the United States are 115 kV, 138 kV, 230 kV, 345 kV, 500 kV, and 765 kV. Step-up transformers are typically sized to the generating units, with modest losses at normal operating levels. If, however, they carry more power than their original intended capacity, losses increase sharply. This can be a problem when generating units have been "uprated" to provide higher output without similar uprating of the step-up transformers. Also, if the generators are operating at a non-optimal power factor (explained below), the resulting increased reactive power output (also explained below) can increase system losses at every level.

Transmission System Conductors. Long-distance transmission lines bring power from generators to the service territory of the distribution utility. In the western United States, these distances can exceed 1000 miles (for example, power from the Canadian border to Los Angeles). Although the conductors themselves have low resistance, the length of the lines and the sizing of the conductors affect losses. Losses along the line may be greatly reduced in direct current (DC) long-distance transmission systems, making DC transmission desirable for very long-distance transmission lines. However, additional losses of up to 1.5 percent occur in the converter stations at each end of a DC transmission line.

Distributing Stations. Many utilities have an intermediate step on their systems, with power taken from "distributing stations," which receive power at high voltage (230 kV and higher) and deliver that power to multiple distribution substations at 69 kV or 115 kV. Transformer losses that occur in substations are incurred twice – first in transforming power from high-voltage transmission to an intermediate voltage, then again at the substations transforming it down to primary voltage. The principal losses in distributing stations are transformer losses. The reason utilities use separate voltage levels is to isolate bulk power transfers from power that is serving load. This approach increases system reliability.

Substation Transformers. These take power from the transmission system, typically at 115 kV or higher, and convert it to the distribution voltage levels of 4 kV to 34 kV. Sized specifically for their maximum expected loads, they very seldom carry power near that limit in order to allow for load transfer between circuits, but there are two issues of concern. The first is core losses that may be too high when they are lightly loaded. The second is resistive losses that may be too high when they are heavily loaded.

Voltage Regulators. These are transformers with multiple taps installed along distribution circuits to enable increasing or decreasing voltage at various points. Historically these were installed along long rural distribution lines to enable a step-up of voltage at distant points, offsetting reduced voltage caused by resistance

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[6] Hydro One. *Distribution Line Loss Study.* Ontario Energy Board Docket. No. RP-2005-0020. Available at: http://www.ontarioenergyboard.ca/documents/edr-2006-rates/hydro_one_networks/eb-2005-0378/Exhibit%20A%20-%20Tab%2015%20-%20Schedule%202.pdf.

of the lines. Today there are additional functions for these devices. They enable acceptance of higher levels of distributed resources, such as residential solar, onto a circuit, by allowing the grid operator to ensure that "hot spots" do not result from the injection of power at mid-circuit. In addition, they enable more rigorous conservation voltage regulation along a distribution line, which can reduce total power consumption (see Chapter 5). Because they are transformers, they involve both core losses and resistive losses, and attention to both the materials and the sizing of these affects the level of line losses.

Primary Distribution Lines. Primary lines connect substations to circuits that bring power into business districts and neighborhoods. These typically run at 4 kV to 34 kV. The higher the voltage, the lower the current, and thus the lower the resistive losses on these lines. However, higher voltages require taller poles (or more expensive undergrounding technology), so there is a cost/efficiency tradeoff.

Line Transformers. These are the garbage-can-sized cylinders you see mounted on neighborhood power poles or in metal boxes mounted on concrete pads. They convert primary voltage distribution power to the voltages we use in our homes and businesses, typically 120 V, 208 V, 240 V, 277 V, and 480 V.

Secondary Distribution Lines. These connect line transformers to individual homes and businesses. They are typically very short, in part because at these lower voltages, the amperage needed to move power is significant, which requires larger (and thus more expensive) conductors. Losses can be quite high owing to the high current. This is especially true if the secondary load has grown beyond or faster than original projections.

Reducing Transformer Losses

Recall that transformer losses are caused in two different ways, core (no-load) losses and resistive (copper) losses.

Core losses are the losses incurred to energize the transformer. These vary with the size of the transformer and the materials used to construct the transformer. It is essential to "right-size" transformers to minimize core losses. In a situation in which, for example, a large industrial customer with heavy machinery and high power demand moves out of a large building and is replaced by a warehouse operation with only lights and a few office machines, and no accompanying modification is made to the transformers, core losses could exceed the annual power consumption of the new business.

Resistive losses are primarily a function of the current flowing through a transformer, heating it up. These losses are exponential with the current. For this reason it is important to not have too small a transformer, or it will "run hot" with high losses. One option is for utilities to install banks of three or more transformers at substations, de-energizing one or more during low-load periods (to avoid excessive core losses), but then switching them on during high-demand periods (to avoid excessive resistive losses). Again, there may be trade-offs resulting from increased circuit breaker maintenance costs and risk for decreased reliability.

Reducing Line (Conductor) Losses

All utility-grade conductors are made of very pure aluminum or copper, both of which have inherently low resistance to electrical current. There are three factors that contribute most significantly to conductor losses. The first is the quality of the connections at each end of the conductors (and any splices that may exist mid-line). The second is the size of the conductor relative to the amperage it carries. The third is the voltage at which the conductors operate.

Connection quality is generally very good in the United States, but is a source of very significant line losses in less developed countries. Corroded connectors, or simple twisted wires, result in significant arcing of the electrical current, which wastes power in the form of heat.

Conductor size affects the resistance of the line to current passing through it.[7] Where high amperage is anticipated, larger conductors are required, just as a larger-gauge extension cord is needed to handle power tools and other high-usage appliances. Utilities sometimes change out the wires or "re-conductor" an existing distribution circuit (without changing its voltage) in order to increase the capacity and reduce losses on that circuit. This is expensive, but not as expensive as the full reconstruction necessary to increase voltage. And sometimes there is no other alternative, as when a single-family residential area gradually converts to multifamily or commercial development.

Voltage affects losses by reducing the amperage needed to deliver any given number of watts to customers. By increasing voltage on a line – which usually means that new transformers must also be installed – a utility can reduce the amperage in the line.[8] Higher-voltage lines

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[7] The radius of the conductor reflects the "R" portion of the I^2R formula noted previously.

[8] Thus reducing the "I" portion of the I^2R formula.

also generally require taller poles, however, and the costs involved in setting new poles may be prohibitive. The use of underground cable for higher-voltage lines is several times more expensive than overhead construction and is generally limited to relatively short distances and relatively flat terrain.

Encouraging the use of distributed generation such as solar photovoltaics and wind can also greatly reduce system losses if planned wisely. Distributed generation assists by providing a source of power closer to the receiving loads of the utility, thereby avoiding the need for power to be delivered from distant central power stations, suffering losses en route.

Power Factor and Reactive Power

These topics delve fairly deeply into electrical engineering, but they also represent very promising sources of increased electric grid capacity and reduced line losses. "Power factor" is a quantity that basically indicates how effectively a device utilizes electricity. It is measured as the ratio of "real power in kW" to "apparent power in kilovolt-ampere (kVA)" on a distribution circuit or end-use. The difference between the two reflects how efficiently real power is used. "Real power" is the portion of electricity that does useful work. "Reactive power" establishes the magnetic field required by motors and transformers to operate, but does not contribute to useful work.

Real power is produced only from generators – and distributed generation such as solar photovoltaics. Reactive power can be produced from both generators and capacitors. For maximum efficiency, a generator should operate at its rated power factor or higher. The same is true for motors and other end-use equipment.

Resistive loads (such as incandescent light bulbs) have a power factor of 1.00, meaning that they use only real power; so real power and apparent power are the same for such loads. However, motors, transformers, electronic equipment, and distribution lines consume both real and reactive power. So their power factor is less than 1.00 unless power factor correction technology is applied. In fact, some motors (such as those in refrigerators and especially older air conditioners) and electronic power supplies (such as those in personal computers, office equipment, and televisions) impose loads on the electric system that exceed the amount of power they actually use productively.[9]

While kilowatt hours (kWh) measure the amount of power used by an end-user, kilovolt-ampere hours measure the total amount of power that must be supplied by the utility. Modern metering can identify this difference, and can help enable consumers or utilities to take corrective action. This usually involves installing capacitors to supply reactive power at the customer's equipment instead of requiring the grid to supply all the reactive power needed.

Although utilities typically bill large customers in part for their peak demand level, including additional losses owing to poor power factor, most small business and residential consumers are not charged for peak demand. The primary reason for this is that the necessary metering equipment was historically fairly expensive, and residential consumers had few loads that created significant power factor issues. Today both of these factors have changed. Modern, inexpensive, smart meters can measure kilovolt-ampere hours as easily as they measure kWh, so utilities can bill customers for the actual power they require (kVA), not just the power they consume (kW). This in turn provides a real incentive for consumers to invest in power factor correction.

This is not a trivial matter. One of the most efficient home refrigerators sold, a Whirlpool 22-cubic-foot bottom-freezer model, has been measured to have a power factor below 40 percent, meaning that the kVA capacity required to serve it is 2.5 times the kW the unit actually consumes.[10] This drives up the current on the home circuit, the secondary distribution line, the line transformer, and so on up the distribution circuit if capacitors are not installed somewhere on the circuit to address and correct this power factor problem. Because conductors, transformers, and power generators are actually rated in kVA not kW, if this power factor is not corrected, it increases the cost of the entire electrical system. And, if left uncorrected, the resulting higher amperage imposed on lines and transformers also drives up resistive losses. Utilities – and their ratepayers – must then spend more money sooner to replace grid equipment that becomes unnecessarily overloaded. Circuit and station upgrades and even generation additions can be reduced or even postponed if power factor is corrected.

As residential loads have moved from resistive loads (e.g., incandescent light bulbs, electric ranges, electric dryers, and electric water heaters) to more electronic and

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[9] The increased current on the distribution system therefore affects the "I" component of the I^2R formula. This means that losses will increase by the square of the current.

[10] Measured by RAP Senior Advisor Jim Lazar, using a Kill-A-Watt meter, on August 10, 2014.

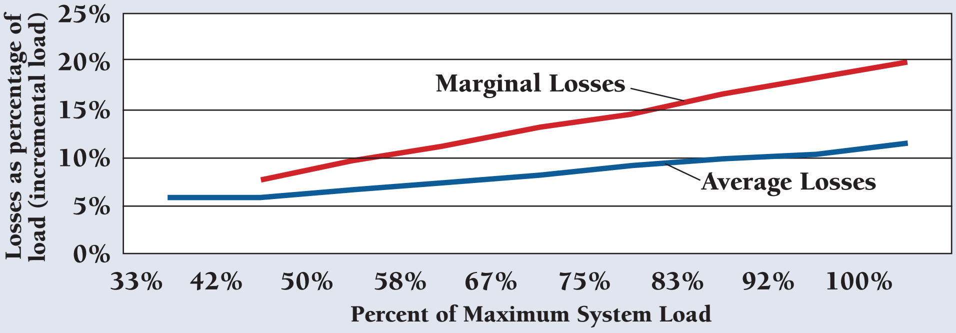
motor loads (e.g., air conditioning compressors), residential power factor has become a promising source of significant capacity reduction, making power factor correction increasingly important in improving system efficiency.

Power factor correction is most effective when done close to the loads involved, so that the higher current does not affect wiring upstream from the end-use. Federal appliance standards could require high power factor along with high measured kWh energy efficiency, but until this is in place and the existing appliance stock has been upgraded, utilities may be able to achieve significant capacity benefits and reductions in line losses by addressing commercial and residential power factor issues with carefully placed capacitor installations on distribution circuits.

Figure 10-2

Average and Marginal Line Losses Increase With Load[13]

Assumes 7% average losses; 25% No-load, 75% I^2R



Benefits of Demand Response Programs on Line Losses

Demand response (DR) programs reduce loads during the highest demand hours on a system. These are the hours when line losses are highest, because the amperage on conductors is highest.

Because line losses are exponential, reducing load a little bit at peak hours results in an exponential reduction in line losses.[11] Figure 10-2 shows how marginal losses increase with load twice as rapidly as average losses on a utility distribution system.[12] As the figure shows, peak hour line losses on a distribution circuit may exceed 20 percent.

Conversely, off-peak marginal losses may be as little as five percent. Thus, shifting an electric water heater load from on-peak to off-peak may save 15 percent of the power shifted, a savings that would dwarf the standby loss that would occur from holding that hot water in a well-insulated tank.

Ice storage or chilled-water storage for air conditioning can provide similar benefits, reducing on-peak losses dramatically, while increasing off-peak losses only moderately. And there is another benefit of making ice at night: the outside air is cooler, allowing the chiller equipment to work more efficiently because heat is more readily released (i.e., the "heat rejection" of the equipment is improved).

The capacity value of DR needs to be measured in a manner that includes the avoided line losses, because the amount of generation avoided is a function not only of the end-use load that is reduced, but also the losses incurred between the generation system and the load. As noted earlier, this can range from 5 to 20 percent more than the load.

Other forms of DR (addressed more comprehensively in Chapter 23) not only provide peak load relief, but also reduce line losses by shrinking on-peak losses, thereby avoiding not only the fuel used to generate wasted electricity (and the associated emissions), but also over time at least some of the capital investment in generation, transmission, and distribution facilities necessary to supply that wasted electricity.

2. Regulatory Backdrop

The technical standards of the electric distribution system are defined and largely self-regulated by the industry in the United States, notably by the Institute of Electrical and Electronics Engineers, the American National Standards Institute, and the National Electrical Manufacturers Association.

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[11] In mathematical terms, the first derivative of the I^2R function is 2IR, meaning that the marginal resistive losses at every hour are two times the average resistive losses.

[12] Assumes an illustrative hypothetical system with 25-percent core (no-load) losses and 75-percent resistive (copper) losses.

[13] Lazar, J., & Baldwin, X. (2011, August). *Valuing the Contribution of Energy Efficiency to Avoided Marginal Line Losses and Reserve Requirements.* Montpelier, VT: The Regulatory Assistance Project. Available at: http://www.raponline.org/document/download/id/4537.

The US Department of Energy (DOE) has regulated the efficiency of distribution line transformers since 2007, but because of their 40-plus-year lifespan, millions of older, less-efficient transformers remain in service. States that have adopted energy efficiency resources standards may allow utilities to meet a portion of their obligation through distribution system efficiency improvements such as transformer replacement, conductor replacement, or voltage upgrades.[14] The DOE's standards for distribution transformers adopted in 2013 are expected to save 350 billion kWh over the next 30 years, compared with the typical transformers being built. This equates to a savings of about 30 percent in losses.[15] Further refinements to these standards could increase these savings by an additional one-third, although there is also a cost trade-off involved owing to the more costly materials used.

It is important to note that capital projects to install new, or to improve existing, transmission and distribution systems or components are typically regulated by public utility commissions and require commission approval above certain expenditure levels. Public utility commissions strive to ensure that such capital expenditures are "prudent" and "used and useful" to avoid undue burden to ratepayers. As such, improvements in these systems may also be required to demonstrate reliability gains and/or cost reductions to ratepayers before they are approved.

3. State and Local Implementation Experiences

Aside from initial siting issues, improvements to electricity transmission and distribution systems rarely come before air quality regulators. They do often appear in public utility regulatory dockets, typically for prudency review and cost recovery purposes.

Almost every electric utility has undertaken specific programs for distribution system improvement, and they generally consider line loss reduction as one of the resulting benefit streams. Comparatively few utilities, however, have undertaken specific programs directed solely toward line loss reduction.

Burbank Water and Power, a small municipal utility in Burbank, California, is an exception. It has given specific attention to line loss reduction in the following ways. It has:

- Increased some distribution circuits from 4 kV to 13 kV and 34 kV;
- Installed gas-cooled substations with high-efficiency station transformers;
- Re-conductored some residential circuits with larger conductors to reduce resistive losses;
- Installed smart meters that enable the system controllers to measure voltage at thousands of points in order to facilitate a conservation voltage regulation program;
- Identified substations where one of three station transformers can be de-energized during the winter period to reduce core losses;
- Extended power factor (kVA) rates to medium-sized commercial customers to create an incentive for these customers to install power factor correction;
- Installed capacitor banks at strategic points on the distribution system to improve power factor; and
- Identified customers occupying premises with oversized (or undersized) line transformers to optimize or "right-size" the transformers and thereby reduce losses.

The multiple-transformer approach described in an earlier section is used by many utilities at the substation level, but there are also opportunities to do it at the customer level where loads vary seasonally. For example, a program to de-energize transformers serving only irrigation pumping loads during the non-irrigation season has been examined by the Northwest Power and Conservation Council's Regional Technical Forum.[16] Installing the necessary switching would, of course, require additional capital investment in the distribution system.

4. Greenhouse Gas Emissions Reductions

Distribution system efficiency improvements can readily avoid two to four percent of total energy required at the generation level. Air quality regulators could nominally anticipate a corresponding reduction in GHG emissions from reduced generation. However, depending on which

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[14] Energy efficiency resources standards policies are discussed in Chapter 11.

[15] American Council for an Energy-Efficient Economy. (2013, April). *New Department of Energy Transformer Standards Are a Mixed Bag.* Available at: http://aceee.org/press/2013/04/new-department-energy-transformer-st.

[16] Refer to: Podell-Eberhardt, Z.,Travis, R., Phillips, C., & Koski, S. (2012). *Draft Presentation of Five Standard Protocols.* Cascade Energy, Inc. Available at: http://rtf.nwcouncil.org/meetings/2012/10/Draft%20Protocol%20Presentation%20for%20Oct%2023.pptx.

generation sources are dispatched to serve the reduced load, the impact on GHG emissions can be greater or less than the percentage of energy savings. If older steam generating units are curtailed or retired, GHG savings are likely to significantly exceed the percentage of energy savings; if newer gas turbines are curtailed instead, the GHG savings are likely to be less than the energy savings percentage.

5. Co-Benefits

Addressing line losses reduces both capacity and energy requirements on the electricity system. In addition, by reducing electricity generated, the societal benefits of reduced emissions – of all emitted GHG, criteria, and toxic pollutants – are realized. Numerous co-benefits, including energy-related and non-energy benefits, also occur with reduced generation, as noted in Table 10-2.

Where losses are reduced by improving power factor at the customer's end-use, the amount of heat released within the customer premises can also be reduced, avoiding some air conditioning load in air conditioned buildings. Refrigerator motors that run cooler after power factor correction also reduce the amount of cooling that is required for the refrigerator to keep food cool. These can provide additional participant benefits, which are not mentioned in the table at right, in comfort and operations and maintenance costs.

Figure 10-3 illustrates that the benefits of line loss reduction spread across the spectrum of direct and indirect economic benefits associated with energy efficiency.

Table 10-2

Types of Co-Benefits Potentially Associated With Reducing Line Losses

Type of Co-Benefit	Provided by This Policy or Technology?
Benefits to Society	
Non-GHG Air Quality Impacts	Criteria and toxic pollutants emitted by generating units are also reduced
Nitrogen Oxides	Yes
Sulfur Dioxide	Yes
Particulate Matter	Yes
Mercury	Yes
Other	Yes
Water Quantity and Quality Impacts	Maybe
Coal Ash Ponds and Coal Combustion Residuals	Maybe
Employment Impacts	No
Economic Development	No
Other Economic Considerations	Maybe
Societal Risk and Energy Security	Maybe
Reduction of Effects of Termination of Service	No
Avoidance of Uncollectible Bills for Utilities	No
Benefits to the Utility System	
Avoided Production Capacity Costs	Maybe
Avoided Production Energy Costs	Yes
Avoided Costs of Existing Environmental Regulations	Maybe
Avoided Costs of Future Environmental Regulations	Maybe
Avoided Transmission Capacity Costs	Maybe
Avoided Distribution Capacity Costs	Maybe
Avoided Line Losses	Yes
Avoided Reserves	Yes
Avoided Risk	Yes
Increased Reliability	Yes
Displacement of Renewable Resource Obligation	No
Reduced Credit and Collection Costs	No
Demand-Response-Induced Price Effect	No
Other	

6. Costs and Cost-Effectiveness

Line loss reduction investments at the time of system upgrades are almost always highly cost-effective. That is, when a transformer, conductor, or electric motor is being replaced, it is essential that the replacement be a high-efficiency and high power-factor unit. Retrofit costs associated with replacing an in-service, operational unit are dramatically higher than the incremental capital costs of selecting a more efficient component at the time of installation.

For example, the economic analysis associated with the DOE transformer standards referenced previously estimated a payback period of as little as 2.4 years for some sizes. For all sizes of transformers, however, the payback period was well within the useful life of a utility-grade distribution system transformer.[17]

Power factor correction is one of the most cost-effective measures both utilities and customers can take to improve efficiency and reduce losses. Making their customers aware of potential power factor savings should be an important

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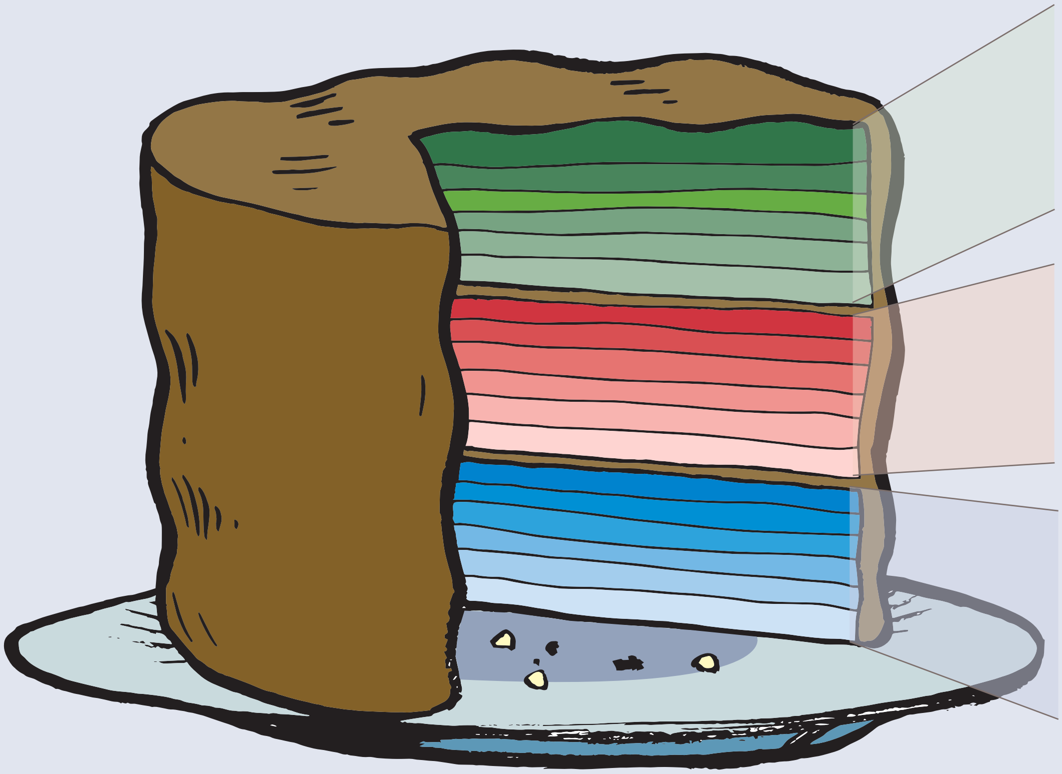
[17] US DOE. (2007, October). Federal Register, Vol. 72, No. 197, Page 58219.

Figure 10-3

“Layer Cake” of Benefits Associated With Line Loss Reduction[18]



Utility System Benefits

- Power Supply
- T&D Capacity
- Environmental
- Losses and Reserves
- Risk
- Credit and Collection

Participant Benefits

- Other Fuels
- Water, Sewer
- Operations & Maintenance Costs
- Health Impacts
- Employee Productivity
- Comfort

Societal Benefits

- Air Quality
- Water
- Solid Waste
- Energy Security
- Economic Development
- Health Impacts

part of every utility’s conservation program. Utility rules and regulations should specify a minimum power factor requirement as a condition of service. Overall power factor of 95 to 98 percent should be the norm.[19]

7. Other Considerations

Reducing line losses makes it less likely that system loads will exceed system capacity, thus enhancing reliability by avoiding brownouts and blackouts that can occur under such circumstances.

In addition, improving the power factor of end-use motors extends the lifetime of those motors owing to reduced heating, thereby providing end-use reliability improvements for businesses and consumers.

More fundamentally, the electric power industry is undergoing unprecedented change at this time. The associated uncertainty should foster enhancements to the transmission and distribution system as a way to secure greater yield from existing generation resources (which compares favorably to the risks involved in constructing new supply resources). At the same time, however, declining electrical growth in many areas, coupled with increasingly competitive distributed generation alternatives, may make the financing of new, more efficient grid infrastructure challenging.

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[18] Adapted from: Lazar, J., & Colburn, K. (2013, September). *Recognizing the Full Value of Energy Efficiency (What’s Under the Feel-Good Frosting of the World’s Most Valuable Layer Cake of Benefits).* Montpelier, VT: The Regulatory Assistance Project. Available at www.raponline.org/document/download/id/6739.

[19] Power factor for individual induction motors may be limited (e.g., to 93 percent) to avoid harmonic issues, depending on the motor’s design.

8. For More Information

Interested readers may wish to consult the following reference documents for more information on line losses in electricity transmission and distribution systems.

- Lazar, J., & Baldwin, X. (2011, August). *Valuing the Contribution of Energy Efficiency to Avoided Marginal Line Losses and Reserve Requirements.* Montpelier, VT: The Regulatory Assistance Project. Available at: http://www.raponline.org/document/download/id/4537.
- Lazar, J., & Colburn, K. (2013, September). *Recognizing the Full Value of Energy Efficiency (What's Under the Feel-Good Frosting of the World's Most Valuable Layer Cake of Benefits)*. Montpelier, VT: The Regulatory Assistance Project. Available at http://www.raponline.org/document/download/id/6739.
- Rozenblat, L. (2013). *What is Power Factor?* Available at: http://powerfactor.us/whatis.html.
- Schneider Electric. (2008). *Electrical Installation Guide, Chapter K: Energy Efficiency in Electrical Distribution.* Available at: http://www.schneider-electric.com.au/documents/electrical-distribution/en/local/electrical-installation-guide/EIG-K-energy-efficiency.pdf.

9. Summary

Reducing line losses in the electrical transmission and distribution system is a readily available option to enhance electrical efficiency and reduce generation-related emissions. Advances in technology and understanding have made possible significant efficiency gains through investments in improved grid components and, on the demand side, in load management at peak levels. As with several other options, the primary limitation on this strategy is economic, not technical. It is essential that new system builds take advantage of more efficient components. Upgrade and/or replacement of the broad electrical distribution infrastructure now in place, however, will remain a significant obstacle. Changes in the electric power industry, declining electrical demand in many areas, and increasingly competitive distributed generation alternatives, may make the financing of new, more efficient grid infrastructure challenging. The advent of mandatory CO_2 emissions reduction requirements will improve the payback of such improvements, but it will simultaneously motivate more efficient end-use equipment and clean distributed generation as well.