Electric Transmission and Distribution Efficiency

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The electricity transmission and distribution (T&D) system serves to collect electrical power and energy from generating plant and delivers it to customers. The T&D system is a part of a just-in-time system – power is produced, transmitted and received in an amount equal to the 'demand' of the customer. This power system is in the midst of unprecedented changes. Public policy, the electric utility industry and market innovations are determined to transform the grid into an 'energy delivery system'.

This presentation is a summary of one aspect of the transformation, namely, the efficiency of the T&D as a delivery system. Relative to other innovations with spectacular impact on the nature of energy production, delivery and utilization, improved T&D efficiency will provide gains that are modest but not insignificant.

Efficiency Defined

In general, efficiency is defined as output divided by input, expressed in percent. For electric transmission and distribution systems – the 'wires' part of the grid- the input is the amount of electricity, Megawatts(MW), that enters from power generating stations and the output is the electricity in MW delivered to customers. The difference is lost, consumed primarily in heat due to wire resistance and in the iron cores of transformers, with a smaller amount serving the electricity requirements of ancillary equipment. A higher efficiency implies lower loss. Efficiency is a useful number but it is the loss value that is important because loss can be monetized and compared. To belabor the point, a transformer has a fixed component of loss that depends on voltage. When the transformer serves a demand approaching its capacity the efficiency is high. But at lower demand the efficiency will appear to be low.

How efficient is Transmission and Distribution?

Myths abound – Hodge states "50-60% of the electricity is lost in transmission due to faulty lines and obsolete infrastructure"[1].. It is true that, if we take the input to be the calories in coal and the output to be the light (lumens) from an incandescent bulb, the efficiency is indeed dismal! However such statements, referring perhaps to overall efficiency and not T&D efficiency, are often quoted and re-quoted until they become fact.

Losses in the Transmission and Distribution infrastructure are not so large – ranging from 7% to perhaps 15% (in legacy systems).

- In a recent presentation Minervini[2] notes a 1995 estimate of T&D losses of 7.5 % as well as a 2005 US Energy Information Administration estimate of 9 %.
- The International Electrotechnical Commission (IEC) suggests losses of 3-5% in transmission and 8-15% for the complete T&D system.

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[1] http://www.greenchipstocks.com/articles/efficiency-emergers-as-strongest-cleantech-sector/1026
[2] www.**pppl**.gov/**colloq**uia_pres/WC13MAY09_J**Minervini**2.pdf

Relative Significance of T&D Inefficiency

Take the net demand of New Mexico to be 2000 MWe. A 90% efficiency for T&D implies 10% or 200 MW of Loss. A 10 % reduction in this loss implies a 20MW reduction in demand to the generation system. With a 70% demand factor and $0.03/kWH avoided cost the annual savings approach $4 million. Certainly, the incentive to improve efficiency is there, but the benefits must be balanced against the cost of technology needed to achieve this level of savings. As we learn to recognize, model and monetize long-term impacts such as carbon issues, the emphasis on even small improvements in efficiency will surely grow.

It is also necessary to consider all parts of the energy production, delivery (T&D) and utilization infrastructure. Production efficiencies continue to improve[3] and there is broad consensus that as much as 30% demand reduction will be achieved through end-use efficiency improvement, and perhaps even more through distributed generation. These sectors dwarf what can be achieved through T&D efficiency improvement.

That said, there is also consensus that T&D efficiency improvements should not be ignored.

Sources of T&D Inefficiency

The first primary source of losses in T&D involves resistance of wires. As electric energy moves through the T&D system, some energy is required to overcome resistance and appears as heat in the wires. A second, more esoteric, loss is associated with transformers which are used to move from one voltage level to another. Transformers use Iron to create magnetic fields and there is a loss, core loss or 'iron' loss, that is inherent in this process.

[3] http://www02.abb.com/global/seitp/seitp202.nsf/c71c66c1f02e6575c125711f004660e6/64cee3203250d1b7c12572c8003b2b48/$FILE/Energy+efficiency+in+the+power+grid.pdf

The amount of power transported through T&D is related to the product of voltage and current. Moving larger and larger blocks of power through T&D at a set voltage requires more and more current. The power lost to resistance grows as the square of the current – thus T&D is less efficient at higher power levels, i.e., in periods of high demand.

On the other hand, increasing the voltage for a given power level results in lower current thus rapidly reducing loss. This observation explains the use of Extra-High-Voltage transmission (765 kV). It also explains the utility practice of running T&D at the higher end of allowable voltage for the class of technology used.

In contrast, lowering the voltage towards the bottom of the allowable range of 114-126V at the customer end, can reduce losses in transformers and motors and also may result in a lower demand[4]. This process has been called 'Conservation Voltage Reduction (CVR)'.

CVR can be implemented at the customer level or at the utility level[5] (from the T&D side). The latter is now called "Voltage Optimization" and is clearly a T&D issue. Customer side CVR is likely better considered an end-use efficiency issue.

Additional losses in T&D come from reactive power. The operation of power lines, transformers, motors rely on electromagnetic fields. Reactive power is a back-and-forth flow of energy necessary to maintain these fields. There is no net energy consumption involved. However, resistance must be overcome to move this energy back and forth resulting in losses. Ideally, power systems are operated so that reactive power flow is held to a minimum. This is accomplished both by adding equipment, capacitors and reactors, and by carefully controlling voltages.

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[4] www.pcsutilidata.com/userfiles/file/IEEE_2004_Rural_Paper.pdf

[5] http://www.currentgroup.com/system_optimization.php

Towards Improving T&D efficiency

Improving T&D efficiency has been the subject of extensive research. It is generally accepted that the following options are available to improve T&D efficiency:

- Using higher efficiency transfomers /lower resistance conductors:

  Transformer/Conductor selection has traditionally been based on cost-benefit analysis, trading off the cost of losses over the life of the asset against capital cost. In recent times the pressure to manage capital expenditures may have worked against efficiency considerations. Resistance can be reduced by using larger conductor which drives up capital cost.

  A closely related option is re-conductoring transmission lines. Often driven by the need for additional capacity, emphasizing efficiency can be a synergistic consideration[6]. New types of conductors that are larger in size but retain strength will have a major impact in this area, as will new transformer designs and advanced materials.

  Super-conducting transmission, with a wire loss of zero, will also contribute; however the justification will come from other benefits such as increased load carrying capability and system security.

- Demand reduction:

  Any technology that reduces demand or reduces peak demand (better 'utilization factor') produces efficiency benefits throughout the T&D system. Thus demand response programs, distributed energy resources and CVR all have the added benefit of improving transmission efficiency. In fact, the perceived decrease in T&D efficiency are directly attributed to the fact that demand increases in the absence of T&D additions has increased both the peak demand and lowered the utilization factor in T&D.

[6] www.southwire.com/transmission/powerDemandsOHC.htm

- Voltage Optimization

At the transmission level utilities and Regional Transmission Operators (RTO) have made extensive investments in real-time and near-real time tools to minimize losses in transmission networks. It is noted that there is extensive metering/ monitoring at the transmission level. As indicate earlier, Reactive Power also contributes to loss; under normal circumstances it is unusual to see significant reactive power flow on transmission lines.

Distribution systems are poorly monitored. Thus operational efficiency improvements are achieved by pre planning and through technologies such as controlled capacitor banks. Voltage Optimization is an analysis and control tool addresses minimizing losses in the distribution system but can also be used to implement CVR from the utility side. The application of the voltage optimization concept has been hindered by the lack of metering in the distribution system. The key issue is that it is critical for any utility side solution to know that customers at the tail end of the system continue to receive adequate voltage. The ongoing smart-meter implementations as well as new technologies that are applied at the service transformer level will allow distribution companies to implement comprehensive voltage optimization and CVR programs

Policy, Incentives and Regulatory Issues

The benefits of end use efficiency are very well recognized and significant federal and state incentives are available in New Mexico. Sections of HR 2454 refer to efficiency initiatives[7]. Thus, significant awareness exists of overall efficiency issues. With regard to T&D efficiency, and given that efficiency investments would be made by electric utilities, little regulatory guidance exists as to whether such investments will be approved and rate-based.

[7] http://thomas.loc.gov/cgi-bin/query/z?c111:H.R.2454:

Conclusions:

Improvements in T&D efficiency will provide sizable benefits. The savings are not as significant as those from end use efficiency improvements and conversion efficiency improvements. However, efforts to improve T&D efficiency can have synergistic benefits in improving other aspects of performance. Many efficiency improvements will be created by technologies that address demand response and distributed generation. Efficiency improvements will also be enabled by smart grid technologies that provide more comprehensive information for use in tools such as voltage optimization. Utility level efforts for improving efficiency will be enabled through public policy that properly provides incentives for capital expenditure.