Keys to Transmission and Distribution Reliability

A coordinated approach helps control costs.

Historically, transmission and distribution assets have been quiet utility stepchildren— generally ignored by both regulators and senior utility management while, their generating asset relations remained in the limelight. But as restructuring of the electric industry evolved in the 1990s, a looming competitive environment created strong pressures within utilities to reduce spending.

Many utility distribution engineers will tell you that underinvestment has been occurring since that time. Rate freezes, the removal of regulatory protections for generating assets, and management of transmission and distribution (T&D) assets by holding companies with significant unregulated operations also have contributed to pressures to reduce spending on T&D assets and infrastructure.

The problems created by reduced infrastructure spending are evident when one considers the highly capital-intensive cost structure of the T&D business. Electric utilities are roughly three to four times more capital-intensive than other capital intensive industries in the United States, requiring roughly four dollars of physical capital for every dollar of annual revenue The ratio of capital requirements per dollar of annual revenue indicates the value-added of the production process; it measures the willingness of the market to pay for capital recovery. Whereas companies like Intel can recover the cost of a multi-billion dollar investment in four or five years, the electric power industry requires 15 to 20 years to recover investments.

With 40 to 50 percent of total electric system investment historically allocated to the T&D sector, reductions in spending are bound to affect the performance of the system. This became very clear on Aug. 14, 2003, when a blackout affected millions of customers and caused perhaps billions of dollars in economic damages.[1] Belatedly, regulators are realizing that the once placid purview of utility engineers is an important arbiter of costs to customers, potentially more so than generating assets whose costs they have historically focused on.

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This new focus on T&D assets raises several critical questions for utilities and regulators alike. First, what does prudent management of a utility's T&D system require? A utility can defer routine maintenance and save money in the short run, but it risks unanticipated costs in the long run. Reducing budgets for tree trimming, for example, is a simple way to cut costs, at least until a power line sags onto a beckoning branch and causes a catastrophic outage.

On the other hand, replacing perfectly functioning assets simply because they have reached a given age can lead to unnecessary increases in costs. Of course, prudence should not require perfection: unanticipated events can and will happen, regardless of how extensive a utility plans for unexpected events. Moreover, attempting to reduce the likelihood of equipment failures to zero is simply uneconomic.

This raises a second question: What is an appropriate economic approach to manage T&D assets? How should a utility allocate scarce capital and expense dollars to maintain its T&D system in a way that correctly accounts for the trade-off between higher costs and better reliability? Too often, utilities (and regulators) have adopted simple rules-of-thumb or flawed analytical approaches that misallocate scarce resources, to the detriment of customers and utility shareholders alike.

These two questions are related. And both depend on a third, rarely addressed question: What is the best level of T&D system reliability for a utility? Some answers to these questions, and some of the pitfalls of using ill-conceived approaches to the dual questions of allocating scarce resources and addressing aging assets, are addressed below.

Common T&D Planning Problems

Before addressing the twin questions of how to definine prudent T&D system management and determine how to allocate T&D expenditures, it will help to briefly discuss some common T&D system planning problems. These include treating individual T&D assets as profit centers, relying on bang-for-the-buck measures to allocate expenditures, sweating T&D assets, underestimating the likelihood of catastrophic T&D failures, and failing to consider reliability tradeoffs adequately. Fortunately, as we will discuss, these problems can be avoided by clarifying T&D management objectives and applying more robust analytical methods.

How Profitable Is Your Substation?

Profitability is not a dirty word. Regulatory incentives that encourage utilities to increase profits while improving service quality benefit customers and shareholders alike. But in the T&D arena, profitability and, more insidiously, the profit-center concept, has sometimes been extended too far. Trying to define the profitability of individual substations and circuit breakers, for example, is at best fruitless, and, at worst, the type of calculation that can lead a utility to manage its T&D assets in a way that damages reliability and, ironically, hurts profits.

The profit-center fallacy stems from what economists refer to as the joint cost allocation problem. A typical textbook example is a steer that provides both meat and leather. It is straightforward enough to determine the total cost to raise the steer, but impossible to uniquely allocate that cost between meat and leather. The same sort of problem arises with a utility's T&D system. An individual substation, for example, has no value by itself. Instead, the substation's value arises because it is connected with an entire T&D system. If a utility allocates T&D expenditures based on the profitability of individual assets, however, the effects of the resulting decisions will be arbitrary. There is no guarantee that the resulting T&D system will be more reliable, or even more profitable as a whole.

Whiz-Bang Methods

In our experience, some utilities misallocate T&D expenditures because they use bang-for-the-buck measures to allocate budgets. While extracting the most value per dollar spent sounds perfectly reasonable, in practice such approaches have been implemented poorly for a number of reasons, including: (1) reliance only on benefit-cost ratios for spending alternatives; (2) allocating this year's budget based only on this year's costs and benefits, when many projects have implications far into the future; and (3) not considering all of the dimensions of project value. T&D projects are undertaken not only to improve reliability, but also to address safety, power quality and even environmental issues.

Bang-for-the-buck methods generally work as follows. First, a utility decides how much money will be available for maintenance and capital improvements on its T&D system. The utility then ranks potential expenditures in terms of their benefit-cost ratios and selects the actions with the highest ratios, until the total expenditure has been allocated. These calculations are either performed on a strictly deterministic basis or, in some cases, with the addition of rudimentary uncertainties, such as the likelihood of equipment failure. In all cases, however, the dollar allocations are problematic: they fail to account for the interconnected nature of the T&D system and they incorrectly compare decisions that may have different value dimensions.

'No-Sweat' Solutions

Another common fallacy is to equate efficient T&D asset management with maximum utilization. The logic of this so-called "sweating" assets approach equates unused capacity, such as a distribution circuit that is not fully loaded at all times, with "wastefulness" and lost margin. There are several basic problems with this approach. First, T&D assets that are operated at or near their rated capacities can wear out more quickly or be more prone to catastrophic failures, both of which increase costs. Second, such an approach fails to consider the cost of adding new capacity, which may be much lower. Moreover, this approach fails to account for a basic economic principle: sunk costs are sunk. Once a T&D asset is purchased and installed, the only costs that matter are those going forward, whether replacement equipment or maintenance.

'Oops' Is Not Enough

T&D system engineers frequently use contingency analysis to determine the need for system investments. Such "N-contingency" planning examines layers of events that adversely affect system reliability and capacity. For example, the loss of a major high voltage transmission line can be called a first contingency, or "N-1" event. Subsequent loss of a second high voltage line would be a second contingency, or "N-2," event, and so forth. Generally, high voltage transmission systems are planned so as to provide reliable service under N-2 conditions.

A fundamental problem arises when the contingencies are treated as independent events when they are, in fact, dependent. Electric systems are highly interdependent, some more so than others. This interdependence creates the potential for dependence among multiple contingencies. If this dependence is not taken into account, the likelihood of catastrophic events can be severely underestimated—depending on the degree of interdependence, the underestimates can be off by as much as several orders of magnitude.[2]

Reliable Sources

Utilities have different customers and face markedly different reliability problems. Rural utilities tend to have higher outage rates and longer outages than urban utilities. High-tech industries need better power quality than grocery stores. Rapidly growing areas are more likely to suffer from too little capacity than slow-growing ones. Simply defining "reliability" can be problematic, and problems that aren't well-defined cannot be solved, or at least solved well. Add to this complexity the issues of competing utility objectives to reduce costs, meet short-term financial goals, or even respond to outside political and regulatory pressures that have nothing whatsoever to do with T&D system management, and you create a recipe for failure. This is why prudent T&D asset management must be well-defined. It must incorporate reasonable standards that define overall system objectives, recognize the multiple facets of reliability, and address sound economic and decision analysis techniques that recognize the uncertainties that affect T&D systems.

Prudent T&D Asset Management

As a regulatory concept, prudence has focused primarily on generating assets. In part, this is because generation accounts for one-half to two-thirds of electric utilities' total costs. Looking only at capital expenditures, however, T&D spending accounts for 40 to 50 percent of costs. Thus, T&D asset decisions should not be ignored or made as an afterthought to generation assets decisions.

Of course, gauging the prudence of a generating asset investment decision also is relatively straightforward, since the most common outputs, electric energy and capacity, are easily measured.[3] This is not to say that decisions regarding the prudence of generation asset investments have not been controversial; they have. But most of those controversies have focused on measurable issues: Does future load growth justify an acquisition? Are the costs too high relative to other alternatives? Has there been malfeasance or fraud involved?

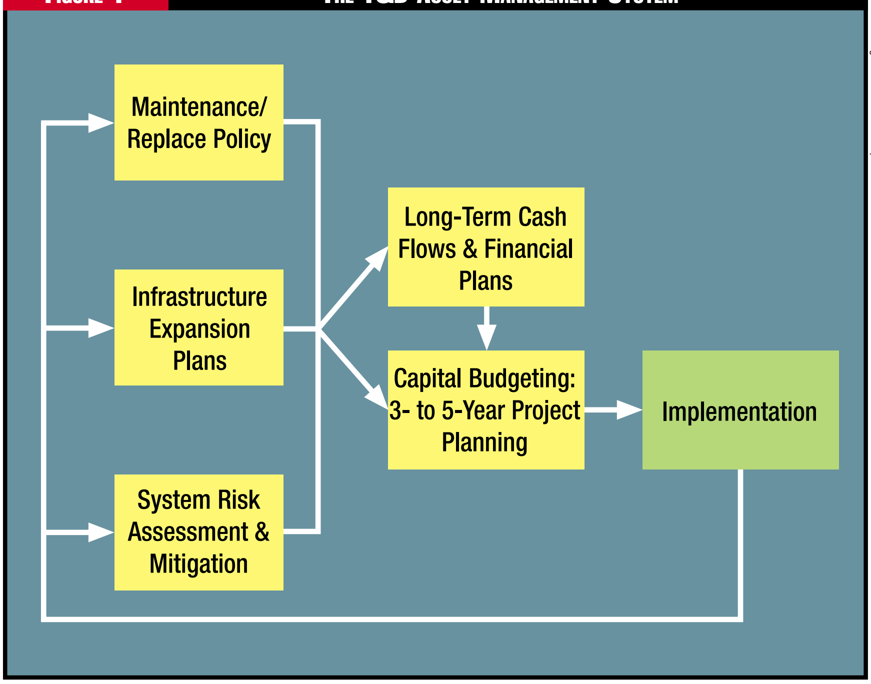
Determining the prudence of T&D asset management decisions is more difficult. Utilities invest in T&D assets to ensure a reliable power supply for their customers. But unlike generation, a reliable T&D system behaves much more like a public good because changes in reliability tend to affect all customers; it is usually difficult to provide individual customers with customized reliability levels, except in very specialized circumstances.

If one doesn't consider the value of reliable service to customers, then the prudent strategy, from a least-expected cost basis, would be to do nothing to improve, or even maintain, reliability levels. Of course, this is not the case; customers clearly do value reliable power service and, as was amply demonstrated in the Aug. 14, 2003, blackout, an unreliable T&D system can impose staggering economic costs. However, different customers can value the attributes that define reliability very differently.

Since no utility's T&D system can ever be perfectly reliable, prudence should focus on several critical issues. First, utilities should manage T&D assets so as to reduce the likelihood of extreme events, rare and otherwise. And, utilities must be able to determine which events are rare and which are not by recognizing and addressing the interconnected nature of some multiple contingency events. Reducing the likelihood of catastrophic events may include more maintenance and tree trimming expenditures, accelerated replacement of aging assets, or lower utilization levels for key equipment.

How low a likelihood of a catastrophic event is reasonable and prudent? Although a zero likelihood is clearly unreasonable, there is no unique answer. Therefore, utilities and regulators, both state and federal, first need to establish clear reliability standards, including a definition of catastrophic events. Moreover, standards should also encompass maintaining general system reliability so as to minimize nuisance events to reasonable levels, and prevent nuisances from becoming catastrophes. Prudence also must recognize differences among utility systems. Requiring a utility whose customers are primarily rural to meet the same nuisance standards as a utility whose customers are primarily urban is unreasonable.

FIGURE 1 THE T&D ASSET MANAGEMENT SYSTEM



Source: New England Economics Group

Second, working together regulators and utilities should establish clear planning methodology guidelines. These guidelines should require sound decision-making approaches that minimize expected T&D costs over much longer planning horizons, much as least-cost planning requirements often address generating resources. These decision-making approaches should incorporate uncertainty robustly, recognizing the interactions between reliability decisions. Regulators also must recognize the difference between good decisions and good outcomes, since the unexpected will always occur, regardless of how comprehensive a utility plans for unlikely outcomes.

Third, regulators must ensure that utilities have sufficient access to capital markets. Utilities cannot be expected to provide high-quality service if regulators do not provide sufficient returns and rates that recover T&D capital and maintenance expenses. At the same time, utilities must demonstrate to regulators that their T&D asset management programs are well-reasoned, neither spending too much nor too little. Utilities should be able to demonstrate they are taking a long-term view to make their capital budgeting decisions.

A New Approach

Ideally, a T&D asset management strategy will address the following questions: (1) how best to maintain and replace existing assets; (2) how best to expand the system to meet future needs; (3) how best to provide system performance from the perspective of customers (which requires that reliability, among other system attributes, be measured and valued); and (4) how best to specify and allocate capital budgets over time, given the utility's long-term financial planning goals and requirements. The relationship between these four questions is shown in Figure 1.

Repair or Replace?

Managing existing T&D assets, including underground cables, transformers, poles and breakers, requires identifying the lowest life-cycle cost repair/replace policies. To do that, a utility must be able to forecast asset performance, which will usually depend on factors such as age and past behavior. In some cases, the analysis must take into account the information provided by equipment diagnostics and testing.[4]

Local Distribution Investment Planning

In developing asset strategies for expanding the electric infrastructure of local distribution areas, the most critical issues will be the volatility and uncertainty of local load growth, the area customers' reliability and power quality requirements, and the impacts of alternative system expansion options—including emerging technologies such as local generation—on overall system reliability

Reliability Planning

Reliability planning actually encompasses two distinct reliability issues. The first concerns normal or expected variations in reliability and how these variations impact customer satisfaction. Design, maintenance, and investment decisions affect average reliability and power quality. Thus, what is really needed is to determine how alternate levels of expected or average reliability affect customer satisfaction. This will depend on local customer needs and the nature of the local infrastructure. System-wide averages do not provide a sound basis for reliability planning.[5]

Second, how do we evaluate the likelihood and appropriate design or operational responses to low probability but catastrophic failures?[6] The results of this type of strategic risk analysis will differ for every utility. However, such analyses will share the same components: identify and assess the potential for catastrophic events; describe the consequences of those events; and develop strategies for mitigating the risk of catastrophic events.[7]

The Bottom Line: Capital Budgeting and Project Prioritization

Implementing repair-replace policies, expanding local area distribution capacity, and creating a T&D system that provides the best level of reliability (least-cost as defined by utility and customer costs over and appropriate planning horizon) will ultimately be limited by the utility's financial condition. Today, most electric utilities operate in a world of greater perceived financial risks, which can limit their access to capital. Gold-plating a T&D system is unlikely in today's financial markets. More likely is the utility that adopts a penny-wise but pound-foolish capital budgeting approach, so restricting spending as to create significant additional financial and system performance risks in the long run.

The realities of financial constraints mean that capital budgeting for T&D asset management has become increasingly important. This capital budgeting problem has two overall components. The first is project analysis—determining the priority of different projects. That priority will depend on the utility's overall corporate objectives, including improved reliability, maintaining or improving safety standards, better environmental performance, and so forth. This requires that different objectives, including risk, be traded off of one another in a consistent manner.

The second component of capital budgeting is portfolio development. The utility must decide which projects will be undertaken over the next budget period and which projects will be deferred. Deferral saves money, and increases system performance risks. One way to solve the problem is to maximize the present value of the timed portfolio of projects selected and to assess and measure the risk of deferral associated with that portfolio. The planner is then able to choose among efficient portfolios, each with different risk and value levels.[8]

It is critical to examine multi-year portfolios of projects, rather than focusing solely on this year's budget cycle. Just as it's better to plan for retirement by evaluating financial asset strategies over many years, rather than planning one year at a time, a multi-year capital budgeting approach allows utilities to reduce their costs. The reason is that investments today affect system performance and the future cost of ensuring acceptable performance levels tomorrow.

As the Aug. 14, 2003, blackout starkly demonstrated, managing T&D assets can be a life-or-death matter. The management system we have discussed here is a comprehensive and, more importantly, coordinated approach that can help utilities provide the reliability their customers require, while controlling costs and achieving important financial performance targets.

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Endnotes

1. Earlier events in Chicago and New York City raised similar questions about the prudence of reduced infrastructure spending.
2. The magnitude of this underestimation problem has been demonstrated in recent work by Peter Morris Charles Feinstein and Stephen Chapel. See, Strategic Reliability Analysis, Presentation at EUCI, "Using Analytical Tools To Improve Asset Management For T&D," October 2003. Copies of this briefing can be obtained from the authors.
3. We recognize that many generation units also can provide reactive power for system support and voltage stability. However, we are aware of few regulatory decisions where the prudence of a generating asset investment was decided primarily on reactive power.
4. This is not the same as an increasingly popular approach called reliability centered maintenance (RCM). The objective of RCM is to maintain functionality and extend the life of a particular kind of equipment. While potentially important , RCM neither identifies strategies for replacing equipment nor directly addresses the question of minimizing lifecycle costs. Therefore, RCM does not provide a least-cost solution to the repair-replace problem. We are indebted to Charles Feinstein and Peter Morris for pointing out the limitations of the RCM method.
5. See Chaper 7, "Moving Beyond Traditional Reliability Analysis," Customer Needs for Electric Power Reliability and Power Quality: EPRI White Paper, October 2000.
6. With dependent contingencies, "low" probability events may not be so "low" probability after all.
7. These steps are suggested by Feinstein, Morris, and Chapel in their briefing, Strategic Reliability Analysis, op. cit.
8. The methodology for solving the multi-attribute, multi-year capital budgeting problem is well-developed and available in the public domain. The recognized expert in multi-attribute decision theory is R. Keeney (see R. Keeney, Value Focused Thinking: A Path to Creative Decisionmaking). Applications of the methodology to electric utility capital budgeting are becoming more common. See, e.g., L. Merkhofer on Priority Systems. Lee Merkhofer, 2003, and S. Chapel, et al., Project Prioritization System: Methodology Summary, EPRI 2001. Both papers can be downloaded from the publications page of www.s-chapel.com.