Applications Guide: Distribution Capacity Planning with Distributed Resources

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Applications Guide: Distribution Capacity Planning with Distributed Resources

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Outline

- Introduction
- Summary of early studies
- New focus: DR as a strategy
- New planning methodology
- An Example

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This talk presents a new approach to DR economic analysis and planning. The new approach is based on the Area Investment Strategy Model.

The talk answers the following questions:

1. What is the Area Investment Strategy Model?
2. Why should one use the model to answer DR investment questions?
3. How are other methods deficient? How is the Area Investment Strategy Model a superior method?
4. How does the model work?
5. How is the behavior of the model illustrated?

We focus on the Area Investment Model because it provides the only state-of-the-art approach to answering the DR question.

Introduction

Overview of benefits

- Customer site
- Distribution systems

Statement of problem

- An engineering & economic problem
- Develop least-cost expansion strategies that explicitly include DR options
- Uncertain future infrastructure needs and costs
- System problem

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1. DR provides two kinds of benefits.

At a customer site, DR can supply back up generation and many even reduce or replace dependence on the local electric utility.

In the distribution system, DR can be integrated into the electric power delivery system to provide capacity and, in the case of generation and storage technologies, energy.

2. The problem of distributed resources planning is to determine how best to integrate distributed resources into the capacity expansion plan for a local planning area. The analytic problem is to determine whether the least cost expansion plan for an area includes distributed resources.

Important characteristics of the problem include:

-both engineering--what it does--and economic--how much it costs--aspects

-needs (peak load and energy) and costs are uncertain

-DR must be integrated into an existing system

Summary of early studies

Deferring T&D plans

PG&E's area and time specific costs

The Delta model / methodology

Wisconsin electric study

What has changed

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These studies provide a context for the Area Investment Strategy Model: why it was built and what it does.

These studies develop methodologies for DR analysis that are each flawed in different ways. We learned from the shortcomings o f these models. Nor do we have the last word. The Area Investment Strategy Model can surely be improved and we are working on improvements. But it is far superior to anything available at present.

Early studies

T&D deferral

- Time value of money
- Asset utilization

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•Two arguments are often made for deferring large capital investments with small capital investments: time value of money and asset utilization. Because DR investments tend to be smaller and have lower total cost than traditional T&D investments, a benefit is achieved, based on the opportunity cost of deferred capital expense, when the small investment is used to defer the large investment. Money is saved when expenditures are delayed, all other things equal. Thus, if the objective is to minimize costs, deferral has legitimate cost saving benefits.

•In contrast, while it may be appealing to maximize asset utilization as an investment goal, using such an objective is not necessarily cost reducing. It is easy to show that using the small investment to increase utilization can, in many cases, result in higher present value of the total costs.

•In practice, the deferral methodology has not been used to find investment solutions with minimum total costs. In most cases, the solution found tends to maximize deferral as long as deferral is cost effective. This has an interesting effect: maximum deferral results in delaying T&D investments until the cost of deferral equals the benefit. This means that the two solutions, the original policy and the policy deferred by DR investments, will tend to have equal cost (Lesser (1999)).

Early studies

PG&E's area & time specific costs

- Motivated by rapid urban growth
- Document differences in area cost of service
- Delta study
- Methodology perspective
- Key contribution

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•In the late 1980s the PG&E rate department developed an area and time specific (ATS) costing methodology to support the costing study. The objective of the methodology was to allocate investment cost to the customers and peak hours that are responsible for the capacity needs. The motivating event was rapid urban growth and the resulting costly investments in infrastructure. All customers experienced cost increases, including those in non-growth areas. This generated customer complaints.

•The ATS costing methods were used to allocate the investment costs necessary for meeting new incremental load to the specific hours and customers responsible for the needed capacity expansion. It was found that when the expansion costs were allocated to a few hours of peak or nearly peak load, the cost of serving that load could be quite high

•The Delta study applied ATS costs to justify targeted DSM to avoid capital investments. This appears to be the first case of such a strategy.

•PG&E's area and time specific costing approach allocated capital costs to peak load hours and across years. These allocations are necessarily arbitrary. They are based on accrual accounting methods and do not reflect actual cash flows. As a result, this costing approach is flawed.

•The interesting implication of the PG&E costing methodology is not that T&D deferral is a good idea (although the method has been used to promote investment deferral). Instead, the key contribution is the insight that the best plan for meeting load increases is at least partially driven by local conditions. These conditions includes local load growth and shape, the cost of adding the necessary local T&D infrastructure, and the needs and willingness-to-pay of local customers .

Early studies

Delta methodology

- Magnitude & timing of area peak loads
- Effect of DR on peak load at bulk & local levels
- Area & time specific avoided costs
- Effect of DR on expansion plan

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•This model builds upon the PG&E area and time specific costing methodology and is a capacity expansion tool (Orans (1991), Horii (1996)). The Delta methodology addresses four questions:

> •What are the magnitude and timing of peak loads in a distribution area?
>
> •How will local resources (DSM and local generation) affect peak load at both bulk and local levels?
>
> •What are the area- and time-specific costs (transmission and distribution avoided costs)?
>
> •How will DR affect the planning area's expansion plan?

•The objective of the Delta methodology is to find the least cost mix of DR and local T&D over some planning period, say 20 years. For each year of the plan, the model produces the least cost amount of DR and investment in T&D capacity. The model makes two key assumptions: (1) load is predictable and thus the capacity plan is based on a foreseeable load path, and (2) a given local T&D plan exists and the optimal strategy is found by deferring this plan using DR.

Early studies

Wisconsin study

- Delta methodology
- Two methodology observations
  - » Considering DR would change the T&D plan - not just deferral
  - » Uncertainty is an important planning consideration

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•Initially the Delta methodology was used by Wisconsin Electric to explore whether local generators and DSM could be used to defer T&D planned investments. In retrospect, this study produced two important methodology-related observations made by distribution engineers and planners at WE. After observing the Delta model result, the WE planners argued that when they developed their T&D plan, they had not considered DR, and if they had they would have come up with a different plan. *That is, consideration of DR would have changed the T&D plan and not just deferred the plan.* The WE engineers also argued that load uncertainty was an important planning consideration and that the Delta model and other existing approaches assume that future load, among other variables such as siting uncertainty and technology costs, is known with certainty. WE staff encouraged EPRI to proceed with the development of a methodology that would jointly determine the least-cost mix of T&D and DR options, and that would explicitly incorporate load growth and other important uncertainties.

Early studies

What has changed

- Initial idea: DR used to defer T&D investments
- Now: DR promoted as an investment strategy
- Need "strategy" focused methodology

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•The initial discussions of DR were focused on the deferral benefits of single installations. DR is now being considered and promoted as an investment strategy. This creates a need for a new "strategy focused methodology."

•The purpose of the methodology should be to determine whether DR makes sense as a broad strategy, rather than which specific DR technologies should be dispatched during any particular hour or year. Current EPRI-supported modeling efforts are directed toward the strategic analysis. This refined purpose requires a change in focus with respect to the structure of models and the data required to use them.

•The EPRI Area Investment Strategy Model is the result of: (1) applications of the PG&E time- and area-specific costing, (2) applications of the Delta model at several companies including WE, and (3) encouragement from WE engineers and others to develop a better planning tool.

New focus: DR as a strategy

Reformulate distribution and DR planning

The analytical problem

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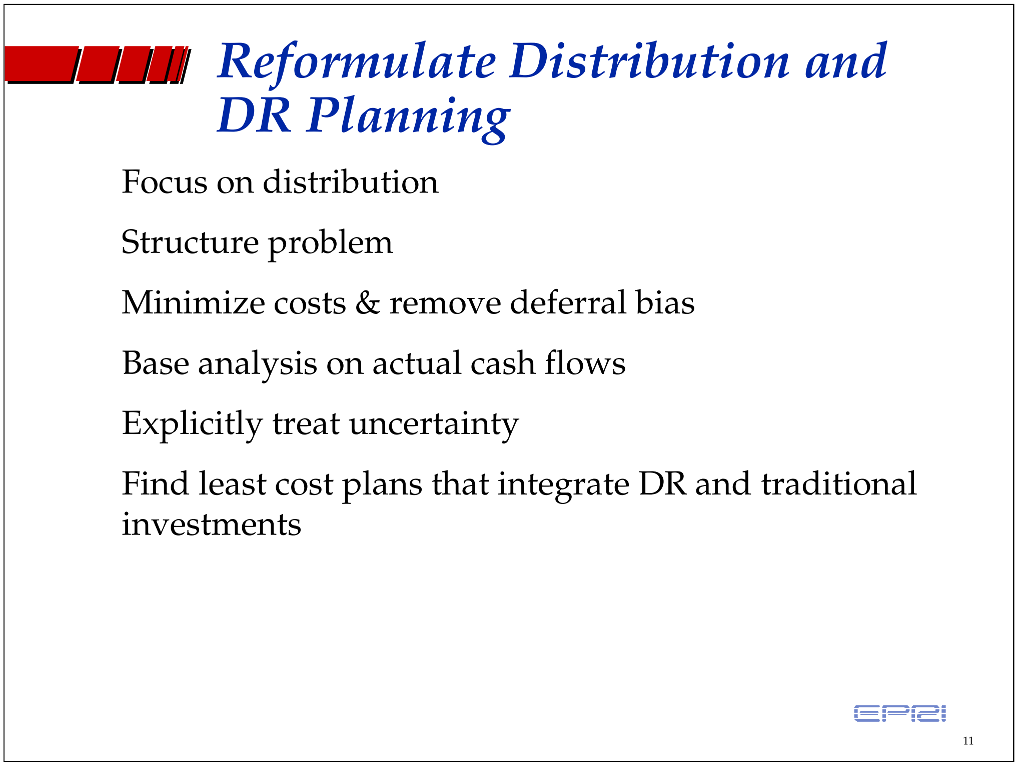
•In order to focus on DR as a strategy, the investment strategy problem must be reconsidered. The formulation followed in the early studies has been shown to be flawed.

•The new approach to investment planning reformulates the objective and the analysis methods, and focuses on the distribution system.

•The reformulation is based upon a set of fundamental economic valuation principles that apply to the problem and a set of analytical questions that must be addressed when solving the investment strategy problem.

•We begin with the reformulation of the problem (next slide).



•In the initial excitement over the DR concept it was believed that DR investments could possibly be substituted for investments in central generation, bulk transmission, and local (sub-) transmission and distribution. It now appears that the main effect of DR investments will be at the distribution and the local transmission levels.

•Because electric distribution systems are composed of interconnected components, identifying alternatives for increasing capacity and expanding the systems over time requires identifying specific load-growth locations and the bottlenecks in the system that limit capacity.

•The EPRI approach to DR planning is designed to remove the deferral bias that is present in the current view of distributed resources. Instead of selecting DR investments to defer planned capacity installations, the new approach selects DR investments to minimize the total cost of service.

•A change in economic analysis from most earlier methods is that the actual cash flows, capital plus operating, are used. One should eliminate the use of arbitrary marginal avoided costs wherever possible.

•The primary uncertainty in DR applications in local distribution planning areas is whether anticipated load growth will occur. For distribution planning, a key issue is at what point in the future will load growth result in new capacity requirements. A complete description of potential load trajectories over time is required in order to specify the probability distribution on the time that new capacity is required.

Analytical problem

Valuation principles

Economies of scale

Limitation of scope

Uncertainty

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•The economic valuation principles that apply to the investment strategy problem are discussed below (next slide). (These describe how we evaluate alternatives.)

•The analytical questions that must be addressed when solving the investment strategy problem are the following, and are described in the three slides following the next one.

•The analytical issues are: (1) scale economies of the investment alternatives, (2) limited scope for modular investments (distributed resources and load control programs), (3) uncertain future load and costs, and (4) the need to include load control programs as part of the portfolio of investment alternatives. (These describe what is important to consider in the investment strategy problem.)

Investment Planning First Principles

Deferral has direct economic value - opportunity cost of $

- the higher the cost of $ the greater the value of deferral
- lumpy investments OK if used some day

There is a tradeoff between economy of scale and flexibility

- big resources are generally cheaper but provide no flexibility
- small investments defer big investments and provide option to revisit big decision
- option to delay allows learning before deciding

The value of being able to revisit depends on nature of uncertainty

- EV, VAR, CORR, Type of Event
- no uncertainty, no value

Independent of uncertainty, modularity has value

- easier siting
- tracks load better

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•Deferral of capital projects has direct economic value. This is the result of the opportunity cost of financial capital; that cost is measured by the discount rate when doing net present value calculations. The higher the cost of financial capital the greater the value of deferral. Large investments providing over-capacity in the near term can be good investments if the capacity is likely to be eventually needed.

•There is a tradeoff between economy of scale and flexibility. Large capacity resources are generally cheaper per unit capacity but provide limited future decision flexibility. Small investments defer large investments and provide the option to revisit the large decision. This option to delay allows for learning before deciding.

•The value of being able to revisit a large investment decision depends on the nature of load uncertainty. If there is no uncertainty, there is no potential for learning and no value associated with revisiting the decision. Even with uncertainty, if the uncertainty is not reduced over time, there is no value associated with delaying to revisit the decision.

•Independent of uncertainty, modularity has value. Small increments of capacity track load more closely and can be easier to site.

Economy of Scale - The Two-edged Sword

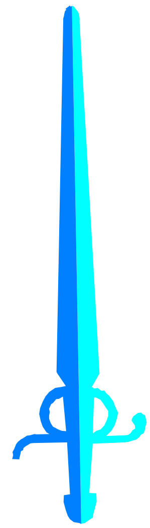
When to invest in the big stuff?

Type I Error: convict the innocent

- avoid investment because first cost is too large
- this ignores benefits of economies of scale

Type II Error: release the guilty

- make investment because the $/kW is small
- but what if load growth is small or very uncertain?
- if so, large capital cost for unused capacity for a long time



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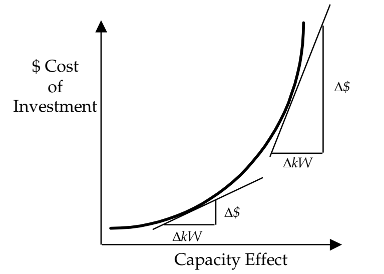
•In most cases, there are scale economies associated with larger capacity investments. Scale economies suggest that it may make sense to invest in a large increase in delivery capacity if that capacity will eventually be needed.

•Two kinds of errors can result from an incorrect analysis of the benefits of economies of scale. The first error is to avoid a large investment because the first cost is large but, in fact, the large investment is the least cost strategy over time. The second error occurs if a large investment is made because the unit cost is relatively small but that investment, when correctly evaluated, is not the least cost choice.

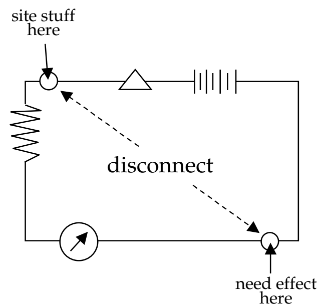
Limitation of Scope - Cost Versus Capacity Effect

Part I: For DSM & modular investments, increasing costs for a fixed capacity effect



Part II: Can the modular & DSM investments be located where the capacity needs exist?

– Yes, but the effect saturates
– No, so the effect is strictly limited (capacity need but energy benefit)



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•The investment question is under what conditions should traditional upgrades be avoided by exercising modular options to meet uncertain customer needs for reliable and economic service? When addressing this question, the analysis must take into consideration two facts.

• First, the marginal cost of those investments tends to increase, such that if modular investments are pursued aggressively, the cost of providing a fixed increment of capacity increases. This situation is illustrated in the top figure.

•Second, in the context of a distribution system, there is a physical limitation on the capacity effect of modular and DSM investments. It may not be possible to locate the distributed assets where they are needed. It is possible that the capacity effect of these investments will be limited. This situation is illustrated in the bottom figure.

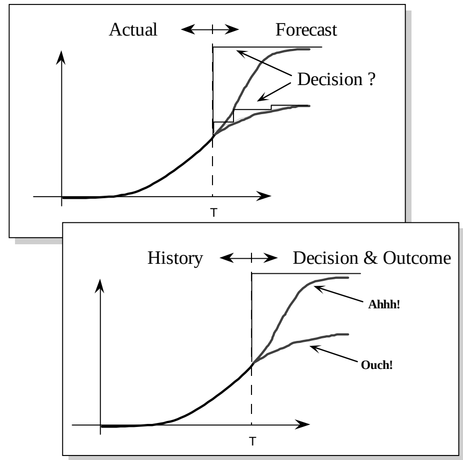
The Uncertain Load Problem

Uncertain load and lumpy investments create a planning challenge

- future load is probabilistic
  - can identify the potential for growth
  - but cannot accurately predict if and when it will occur

The need for new capacity depends on future load growth

Thus investment value is probabilistic and risky



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•Load uncertainty makes the scale of distribution investments an important strategy issue. Smaller scale units provide a hedge against the risk that loads do not materialize. Further, because learning may occur over time, small-scale investments provide the opportunity to delay and revisit large-scale investment decisions. However if load does eventually materialize or if the cost of the infrastructure increases as areas develop, there may be significant cost penalties associated with deferring distribution upgrades using small-scale distributed technologies.

•The figure above suggests that the preferred choice between a large or small capacity investment depends on the forecast of load growth.

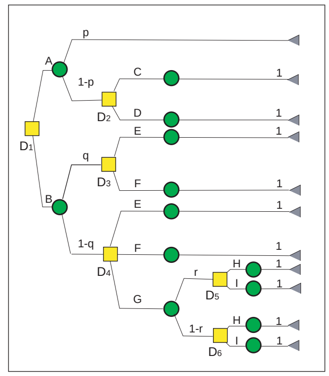
New Methodology

Purpose

- Can the system be made more efficient without sacrificing reliability and quality of service?
- Find least-cost plan under uncertainty
- Timed sequence of investments that are contingent on future occurrence of various states of nature

Overview of model operation

- Dynamic optimization represented as a decision tree
- Series of nodes (decision - uncertainty - decision - etc.)



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•The new methodology formulates and solves a dynamic optimization problem. The problem is represented as a decision tree. The tree contains a sequence of nodes; each node is either a decision node or a chance node. At a decision node, a choice of paths can be made. At a chance node, the path that actually occurs is not chosen but rather is governed by a probability distribution. All the uncertain variables in the problem are modeled using probability distributions on chance nodes.   A policy is a complete path through the tree, such that the choice made at each decision node is specified conditionally with respect to the sequence of resolutions of the prior chance and decision nodes, and the combination of choices and uncertainties determines the cost along each path. The optimal policy is the one that minimizes the expected cost through the tree.

•An example of a decision tree is provided in the figure above . Beginning at the left, the first decision is to choose between A and B. These could be two alternative capacity investments for a planning area. If A is selected there follows a chance node. The chance node could describe the uncertainty in future load growth. With probability p, no further decisions need be made, which is symbolized by the triangle at the end of the branch emanating from the chance node. With probability 1-p, the next decision is to choose between C and D. Regardless of which one is selected, no further decisions are required. If B is selected initially, there follows a chance node such that with probability q, the next decision is to choose between E and F. Regardless of which one is selected, no further decisions are required. Alternatively, after B is selected, with probability 1-q, the next decision is to choose among E, F, and G. Notice that the alternatives can change depending upon the condition achieved. Choosing E or F means that no further decisions are required. Choosing G leads to another chance node, such that, with probability r, the next decision is between H and I. Similarly, with probability 1-r, the next decision is between H and I. No further decisions are required.

Real Utility Example

Case description--capacity expansion

Assumptions

Case 1: No salvage of DR

Case 2: Salvage of DR

Case 3: No learning

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•This example is based an an actual utility capacity problem. The alternatives for meeting future needs are to add a feeder from an adjacent substation or replace the existing substation with a new and larger substation. If the substation is added first, it will meet future capacity needs and the feeder will not be required. If the feeder is added first, the substation can be added later as load dictates the need for additional capacity.

•As an alternative to both the substation and the feeder, small generators could be used to meet small increments in load and to defer the larger investments. Based on engineering and siting analysis, the system planners determined that as many as four distributed generators could be placed in the area. However, because of limits on where generators can be sited, each generator's effective unit capacity is lower than its nameplate capacity, and the cost per kilowatt increases as the generators are added.

•The base case assumptions are listed below.

•We will explore three cases: (1) no salvage of the DR technology, (2) salvage of the technology, and (3) the situation where nothing is learned by waiting to make a decision.

Assumptions

ASSUMPTIONS – CASES 1 & 2

Technologies	Life	Size(kW)	Cost ($1000)
S: Substation	40	20,000	$2,000
F: Feeder	30	6,000	$900
E1: Engine 1	30	3,000	$1,500
E2: Engine 2	30	1,500	$750
E3: Engine 3	30	3,000	$2,500
E4: Engine 4	30	3,000	$2,500

Trend Transition Probabilities

	Low (1%)	*Medium (2%)*	*High (5%)*
Low (1%)	0.75	0.25	0.00
Medium (2%)	0.125	0.75	0.125
High (5%)	0.00	0.25	0.75
Initial Load Growth Rate			"Low" 1.0%

COMMON ASSUMPTIONS FOR STUDY

Time Horizon	12 years
Discount Rate	5.77%
Inflation Rate	4%
Accounting Method	Before Tax Cash Flow
Initial Peak Load	44,608 kW
Maximum Area Peal Load	70,000 kW
Load Saturation On-Set	60,000 kW
Salvage Value Specifications	
- Price of Capacity at Terminal Time	$10/kW-yr.
- Escalation of Price of Capacity	1.0
- Operating Cost of Capacity	$0/kWh
- Escalation of Operations Cost	1.0
- Final Load Growth Rate	1%
O&M Cost – S & F	$0.02/kWh
O&M Cost – Engines	$0.05/kWh
Avoided Energy Costs	$0.03/kWh
Emissions Rates & Costs	0

Load Shape	*Time (hrs)*	*% of Peak*
	0	100%
	88	95%
	264	90%
	8759	25%
	8760	0%

Load Growth Trends

	Growth Rate
Low	1.0%
Medium	2.0%
High	5.0%

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•This slide summarizes the planning assumptions required in the Area Investment Strategy Model for the planning study. Case 1 assumes that the local generators, once installed, are not removed (salvaged) when the larger traditional investments are made. Cases 2 and 3 assume that the generators can be salvaged if removal makes economic sense. (The model permits the user to specify whether band-aids, in this case engines, are salvageable. See the Area Investment Strategy Model User Guide for further details.) Case 3 also assumes that there is no learning associated with the load uncertainty behavior. (The implications of this idea are briefly discussed below.

•The slide also shows the model inputs for cases 1 and 2.

Case 1 "No Salvage"

Engines are constrained to remain in place once installed

Least-cost policy: install 20 MW substation

Decision (Stage 1)	Chance	Decision (Stage 2)
PV Cost = 5783.31		
S at t=0.00, L=44608	p=0.139, t=28.53, g=1.013	Terminate at t=12, L=52129
	p=0.576; t=20.14; g=1.018	Terminate at t=12; L=55623
	p=0.294; t=12.47; g=1.030	Terminate at t=12; L=63709

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•The least cost policy is shown above. When the engines are constrained to remain in place, the best policy is to install the substation now. This meets all potential future load that is anticipated for the area. This policy is not surprising given that the cost of the substation is $100 per kW while the engines cost a minimum of $500 per kW.

Case 2: "Salvage"

Engines can be removed and reused

Least-cost policy depends on evolution of load growth

Decision(Stage 1)	Decision(Stage 2)	Decision(Stage 3)	Decision(Stage 4)
PV Cost 4797.14 E1	E2	F(-E1, -E2)[1] S(-E1, -E2) S(-E1, -E2)	T E1 E1 T T
	E2	S(-E1, -E2) S(-E1, -E2) S(-E1, -E2)	T T T
	E2	S(-E1, -E2) S(-E1, -E2) F(-E1, -E2)	T T E1 E1 S

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•The least cost policy is shown above. E1 and E2 are engine investments, and T indicates that the end of the planning period has been reached. In this case engines can be removed when large capacity is added.

• The least cost policy is very different compared with case 1. Now, even though engines cost far more per kilowatt than either the substation or feeder, engines are part of the strategy. The fact that engines can be removed when the larger investment is made reduces the contribution of the installed engines to present value costs.

•It now makes sense to use the small modular investments to delay the traditional investments until load dictates that the larger investments are needed. It is also interesting that only two engines enter the optimal policy. This is due to two factors: (1) after the first two engines, the cost per kilowatt increases substantially and (2) compared with the feeder and substation alternatives, the capital cost per kilowatt of engines is relatively high. The engines are best used to delay large investments. Engines are not an economically efficient choice for providing large amounts of capacity.

•The slide indicates only part of the optimal policy. Details have been omitted because the optimal policy over the 12 year planning period has up to seven decision stages. The first four stages are shown here to illustrate the nature of the policy.

Case 3: "No Learning"

No trends in load growth

Learn nothing by waiting

Results: least-cost policy is independent of how load growth evolves

- Install engines
- When growth exhausts engine capacity, install substation

ASSUMPTIONS Ğ CASES 3

Trend Transition Probabilities

	Low (1%)	*Medium (2%)*	*High (5%)*
Low (1%)	0.125	0.75	0.125
Medium (2%)	0.125	0.75	0.125
High (5%)	0.125	0.75	0.125
Initial Load Growth Rate			ÒLowÓ1.0%

Decision(Stage 1)	Decision(Stage 2)	Decision(Stage 3)	Decision(Stage 4)
PV Cost = 5320.41 E1	E2	S(-E1, -E2)	T

•In cases where past observation of the load growth rate does not alter the assessment one would make about likelihood of any future load growth rate, no learning is possible. That is, the so-called "no learning" case assumes that the load growth in the next period is independent of the current growth rate. This means that one learns nothing about future growth rates by waiting to observe the present load growth rate. This behavior is modeled by changing the transition probabilities so that they are the same for all current (in this case, three) growth rates. The slide shows the transition probabilities assumed for this case.

•The slide summarizes the least cost policy. Here the optimal policy is independent of how load growth evolves. The best policy is to install engine 1, engine 2, and, when load growth exhausts the capacity of the two engines, salvage the engines and install the substation. Contrast this with the optimal policy in the previous slide.

•If trends in growth exist, such that learning is possible, you can develop polices that take advantage of the information provided by past observations of load growth. The resulting policies can, in some cases, have far lower costs.

About EPRI

EPRI creates science and technology solutions for the global energy and energy services industry. U.S. electric utilities established the Electric Power Research Institute in 1973 as a nonprofit research consortium for the benefit of utility members, their customers, and society. Now known simply as EPRI, the company provides a wide range of innovative products and services to more than 1000 energy-related organizations in 40 countries. EPRI's multidisciplinary team of scientists and engineers draws on a worldwide network of technical and business expertise to help solve today's toughest energy and environmental problems.

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