Strategic Role of Distributed Resources in Distribution Systems

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REPORT SUMMARY

The purpose of this report is to describe the potential for distributed resources to be a strategic technology for creating value in electric distribution systems. Utilities will be able to reduce costs when distributed resources are part of least cost capacity expansion plans. The report identifies the characteristics of planning areas that determine whether distributed resources add strategic value.

Background

Interest in distributed resources has been rekindled following research efforts begun by EPRI, PG&E, and NREL in 1992. As a result of that interest, many claims have been advanced for the beneficial consequences of the use of distributed resources. Some of the claims have been supported by questionable analysis, while other claims have been asserted with virtually no analytic support. This report is based on the analysis of the results provided by a new methodology, the Area Investment Strategy Model, specifically designed to analyze investment decisions in a local planning area under uncertainty.

Objective

The purpose of this research is to determine the conditions under which distributed resources add strategic value to distribution system capacity expansion plans.

Approach

The Area Investment Strategy Model is used to identify the least cost capacity expansion plan for a distribution planning area. The capacity expansion problem is represented by several collections of data including: a collection of investment alternatives, specified with respect to capacity and costs; a local planning area, described with respect to load level, load shape, and uncertain load growth dynamics; and a collection other parameters, such as the cost of emissions, the cost of unserved energy, and the reliability of service, are specified for the area. The values are selected based on available data found in the literature or provided by member utilities. Two kinds of local areas are defined, transmission constrained areas and infrastructure constrained areas. The model identifies the least cost expansion plan in each area. The strategic value of distributed resources is measured with respect to their inclusion in the least cost plans for each area.

Results

The main results of this study are as follows:

- Distributed resources are strategically valuable in local areas that are transmission constrained, but have limited strategic value in local areas that are infrastructure constrained.

- Unless distributed resources can become much less expensive in both operating and capital costs, the least cost expansion plans in an infrastructure constrained area are composed of traditional infrastructure investments like substations and feeders.
- The value of distributed resources decreases as the area peak load growth rate increases in areas that are either transmission constrained or infrastructure constrained.
- Distributed resources provide benefit by deferring the need for the traditional capacity investments and not by eliminating the need for the investments.

EPRI Perspective

The notion of distributed resources has become an increasingly popular concept over the last ten years. Manufacturers and regulators are promoting the use of distributed resources in the distribution system. Distributed resources are being touted as the centerpiece of a new infrastructure strategy. The purpose of that strategy is to supplement and replace traditional distribution investments. Responding to pressure to change fundamentally the nature of their investments, funders of the Distribution Systems Target asked that EPRI examine the potential strategic value of distributed resources in electric distribution systems. This report summarizes the result of that effort.

The analysis reported here was made possible by work inside and outside of EPRI that has been underway for almost ten years, starting in the early 1990s at Pacific Gas and Electric Company. This long term effort has produced a body of understanding and has resulted in new economic analysis methodology. That methodology is embodied in the Area Investment Strategy Model.

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Keywords

Distribution Systems
Distributed Resources

ABSTRACT

The strategic value of distributed resources in the distribution system is studied. The method is based on the Area Investment Strategy Model, a mathematical model that determines the least cost capacity expansion plan for a local distribution area under uncertainty. The strategic value of distributed resources is measured by the degree to which those resources are integrated into the least cost expansion plan. Two kinds of distributed resources are defined, salvageable and non-salvageable, depending on whether the resource can be removed from service prior to the end of its useful life. Two kinds of planning areas are defined, transmission constrained and infrastructure constrained, depending on what additional capacity needs exist in the area for meeting future load growth. Load growth uncertainty is described using a dynamic probabilistic model. Other economic and engineering parameters related to emissions, reliability, and capital and operating costs are specified.

The main results are that distributed resources are strategically valuable in transmission constrained areas, but of limited value in infrastructure constrained areas. In some cases, for infrastructure constrained areas, requiring distributed resources to be present in the expansion plan increases the cost of the plan. In no case is it possible for distributed resources to eliminate the need for conventional capacity expansion investments. Rather, distributed resources can only serve to defer those investments.

EXECUTIVE SUMMARY

The purpose of this report is to describe the potential for distributed resources to be a strategic technology for creating value in electric distribution systems.

Distributed resources include generation technologies, storage technologies and specially designed demand-side management (DSM) programs that can be sited throughout the distribution system, near sources of load, and serve as an alternative to more conventional and customary investments in infrastructure. Conventional and customary infrastructure investments include transmission upgrades, substation transformer reinforcements or replacements, and feeder reconductoring or other wire improvements. Such investments are typically driven by increased demand.

Interest in distributed resources has been rekindled folowing research efforts begun by EPRI, PG&E, and NREL in 1992. As a result of that interest, many claims have been advanced for the beneficial consequences of the use of distributed resources. Some of the claims have been supported by questionable analysis, while other claims have been asserted with virtually no analytic support. This report is based on the analysis of the results provided by a new methodology, the Area Investment Strategy Model, specifically designed to analyze investment decisions in a local planning area under uncertainty. This is the first report on the use of the model to solve the distributed resources problem in general. Previous uses of the model were aimed at answering utility-specific questions. The methodology provided by the model is unique.

To represent the distribution system capacity expansion problem, several collections of data must be defined. First, a collection of investment alternatives is specified with respect to capacity and costs. Second, a local planning area is defined with respect to load level, load shape, anduncertain load growth dynamics. The treatment of uncertainty in load growth using dynamic probabilistic analysis is an important and unique aspect of the Area Investment Strategy Model. The load variables define the uncertain demand that must be met by the distribution system. Third, other parameters, such as the cost of emissions, the cost of unserved energy, and the reliability of service are defined for the area. The model then determines the optimal (least cost) sequence of investments that meets the load.

By varying the conditions that describe the area and the investment alternatives, it is possible to characterize the strategic value of distributed resources. Indeed, the value of distributed resources is based on a simple idea: if the least cost plan contains distributed resources, then clearly those resources add value. If not, then distributed resources are not very valuable.

The specific question posed in this report is this: under what local conditions will distributed resources add strategic value to the distribution system? And under what local conditions will distributed resources be of little value to the distribution system?

Two kinds of local areas are defined, transmission constrained areas and infrastructure constrained areas. A transmission constrained area has sufficient distribution infrastructure to meet foreseeable load growth, but is constrained by lack of transmission capacity. Increments to transmission capacity come in relatively large quantities and with attendant large capital cost. An infrastructure constrained area has sufficient transmission capacity to meet foreseeable load growth anywhere in the local area, but is constrained by lack of distribution system infrastructure, such as substations and distribution feeders. Increments to distribution capacity come in somewhat smaller quantities and costs compared with transmission upgrades. Further, the unit capital cost ($/kW) of distribution infrastructure capacity is somewhat smaller than that of transmission.

Distributed resources may add strategic value by deferring or eliminating completely the need for either transmission upgrades or distribution infrastructure capacity investments. It has been claimed that a large fraction of new load growth in either local area can be optimally addressed by distributed resources.

The main results of this study are as follows:

- Distributed resources are strategically valuable in local areas that are transmission constrained.

- The value of distributed resources decreases as the area peak load growth rate increases in areas that are either transmission constrained or infrastructure constrained.

- To the extent that the assumptions of the study are representative of real-world conditions, it may be possible to reduce the cost of capacity expansion by more than fifty percent, under the most favorable conditions for distributed resources to defer transmission investments.

- Unlike local areas that are transmission constrained, the infrastructure constrained area has limited strategic need for distributed resources. These limitations are based both on the characteristics of the area and the properties of the distributed resource alternatives.

- Distributed resources provide benefit by deferring the need for the traditional infrastructure capacity investments and not by eliminating the need for the investments.

- In an infrastructure constrained area, distributed resources provide benefit if they are load-following and salvageable. Non-salvageable distributed resources do not provide measurable strategic benefits under the assumptions made in this study.

- To the extent that the base case assumptions are representative of real-world conditions, it may be possible to reduce the cost of capacity expansion by as much as twenty-six percent, under the most favorable conditions for distributed resources to defer infrastructure investments. Under less favorable conditions, distributed resources <u>increase</u> the cost of expansion plans in infrastructure constrained local areas.

Unless distributed resources can become much less expensive in both operating and capital costs, the least cost expansion plans in an infrastructure constrained area are composed of traditional infrastructure investments like substations and feeders. In other words, in infrastructure constrained areas, build infrastructure.

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INTRODUCTION

The purpose of this report is to describe the potential for distributed resources to be a strategic technology for creating value in electric distribution systems.

Distributed resources include generation technologies, storage technologies and specially designed demand-side management (DSM) programs that can be sited throughout the distribution system, near sources of load, and serve as an alternative to more conventional and customary investments in infrastructure [1]. Conventional and customary investments include transmission upgrades, substation transformer reinforcements or replacements, and feeder reconductoring or other wire improvements. Such investments are typically driven by increased demand.

It is possible to restrict the definition of distributed resources by size (between 500 kW and 1 MW) [2], or by purpose (as an alternative to more conventional investments in generation, transmission, or distribution capacity) [3], or by location (near certain local sources of load) [4], or by technology (to stress the application of renewable generation sources) [5], or by ownership (non-utility ownership is sometimes claimed as a requirement) [6]. These restrictions are unimportant for the present purpose.

The results of this report are based on the following fundamental assumptions.

A1. Distributed resource decisions are investment decisions. Thus, they are evaluated in the same way any investment alternative is evaluated.

A2. Distributed resource decisions are based on local considerations. Therefore, global or “macro” assessments of the strategic value of distributed resources must be based on aggregating local decisions.

A3. Distributed resources do not comprise a unique, pure strategy for meeting local demand. Instead, all distributed resource decisions are made with respect to the role that distributed resources play in an integrated local expansion investment plan. Hence, the strategic value of distributed resources is based on the degree to which their integration improves the performance of the plan.

A4. Part of the value of distributed resources is their ability to serve as a hedge against uncertainty in load growth. Therefore, any method that attempts to estimate the strategic value of distributed resources must address the issue of load growth uncertainty.

A5. Part of the value of distributed resources is their ability to provide increased service reliability to local customers. Therefore, any method that attempts to estimate the strategic value of distributed resources must address the issue of service reliability.

A6. The fundamental requirement of an acceptable local expansion investment plan is to meet load with sufficient reliability at minimum cost.

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METHODOLOGY

The methodology applied in this report is based on the Area Investment Strategy Model [7]. The theory underlying the model was described in [8]. The purpose of the model is to identify the least cost expansion plan that meets uncertain peak load in a local distribution planning area. We shall not describe the model in detail in this paper. The interested reader may consult the references cited above.

What is fundamental about the methodology of this paper and the application of the Area Investment Strategy Model to the present problem is that, responding to assumptions A1 and A2, above, the strategic value of distributed resources is determined locally.

Assumption A1 requires that distributed resource investments are treated like any other investments. This is done by permitting distributed resources to compete fairly for investment budgets with other alternatives.

It is common in the literature to measure the value of distributed resources by such criteria as avoided costs or breakeven values (e.g., [5], [9], [10], [11]). This so-called avoided cost approach to distributed resource evaluation has been critically challenged and proven to be equivalent to maximizing deferral of conventional investments rather than minimizing the cost of an expansion plan involving distributed resources ([12], [13]). In other words, the avoided cost methodology does not identify the least cost expansion plan. Therefore, a different approach is adopted in this paper. Instead of measuring value by deferring an assumed expansion plan, the least cost expansion plan is derived directly. This is unique. The existence of the Area Investment Strategy Model, used to determine the least cost plans, is what makes this unique approach possible.

The following conclusion is immediate: If the least cost plan contains distributed resources, then clearly those resources add value. If not, then distributed resources are not very valuable.

Assumption A2 requires that the global or overall strategic value of distributed resources is based on aggregating the local contributions. This requires one to aggregate the results of the local analyses. An alternate approach, which attempted to assess the potential for distributed resources using a macro-economic methodology was given in [14]. The required aggregation is made possible, in principle, by the information provided by the Area Investment Strategy Model. The model permits avoidance of any macro-economic methodology for aggregating what are surely micro-economic (i.e., local area) considerations.

It is natural to ask how the local results can be aggregated. Fortunately, we need not solve this very difficult problem. We pose instead the question: under what local conditions will distributed resources add strategic value to the distribution system? And under what local conditions will distributed resources be of little value to the distribution system?

The answer to these questions is based on the degree to which distributed resources address the needs of the distribution system under various local conditions and provide benefits to the distribution system. These needs and benefits are:

1. Serve local peak load, a typical application of such distributed resources as engines and batteries.

2. Serve all local load, with particular attention to off-grid applications. This is a typical application of standalone resources, such as photovoltaics.

3. Add value by deferring large capacity, capital intensive, traditional distribution infrastructure investment. This is the typical consequence of serving local peak load by distributed resources.

4. Add value by deferring distribution investments, by using modular distributed resource investments to hedge against load growth uncertainty, as discussed in [8].

5. Add value by deferring large capacity, capital intensive traditional transmission infrastructure investments, another typical consequence of serving local peak load by distributed resources.

6. Add value by deferring transmission investments, by using modular distributed resource investments to hedge against load growth uncertainty, as discussed in [8].

7. Add value by improving customer reliability. Distributed resources, located on either side of the meter, can, under some conditions, be expected to increase reliability.

The methodology will address each of these issues by modeling the various effects within the Area Investment Model and determining whether distributed resources are included in the least cost expansion plan. This is very different from the avoided cost approach, which would assign a value to each of the benefits listed above and conclude that the value of distributed resources is the aggregate value of the claimed benefits. Since the avoided cost method does not recognize whether distributed resources are actually optimal investments, we reject it.

We now proceed to describe how we formulate and analyze the distributed resources investment problem using the Area Investment Strategy Model. The formulation and analysis are built around a set of assumptions about a local planning area. These assumptions are sufficient to specify the set of input variables required by the Area Investment Strategy Model. The formulation is characterized by a collection of input variables, specified to reflect particular assumptions about distribution planning, investment alternatives, and the local area served by the distribution system. We refer to this set of assumptions as the Base Case. (See the appendix and the following discussion for a description of the variables in the base case.) Systematically varying these inputs will provide a collection of scenarios that provide insights about whether distributed resources add value.

Groups of data are referred to by the name given them in the Area Investment Strategy Model. Using these specifications, and the Area Investment Strategy Model, the reader can reproduce all results described in this paper. The interested reader can easily extend the results by varying parameters in any way that appears interesting. We certainly do not claim to have investigated exhaustively all possible alternatives.

The Base Case

The items listed below are grouped according to the input screens in the Area Investment Strategy Model. Readers who have the model may wish to run the cases. The input data file is available from EPRI upon request.

Basic Planning Data

We assume that the planning period for investment decisions is 15 years.

The real discount rate is 0.06. The inflation rate is 0.04.

All decisions are made with respect to Before-Tax Cash Flows.

Load Growth Specifications

We assume that the local area peak load is the observed outcome of an uncertain dynamic process. Load dynamics are governed by a probabilistic model of transitions among a set of possible annual load growth rates. The model requires specification of the growth rates that can occur in any year and the annual transition probabilities among the possible growth rates. The transition probabilities are specified by making assumptions about the future behavior of load and the relative likelihood of a load growth state persisting for more than one succeeding year.

In this study, we assume that at any time there can be at most three different load growth rates operating. This is an arbitrary number, although typically sufficient for characterizing load growth. The maximum number of load growth rates in the Area Investment Strategy Model is five.

We assume that load growth rates characterize a local area, and that there are three different area types: slowly growing, moderately growing, and rapidly growing. The annual percentage growth rates in each type area, respectively, are: {0.00, 0.01, 0.03}, {.02, .04, .05}, and {.04, .07, .10}. These values are based on data we have observed in studies of local areas for utilities such as Wisconsin Electric, PSE&G, PG&E, AEP, TU, and BG&E.

We assume that the expected number of years any growth rate will persist is 3. Hence, the diagonal terms of the transition probability matrix are each 2/3. (Letting p_{jj} represent the diagonal term in the matrix and t_j represent the expected time that the j^{th} growth rate persists, we note the relationship $t_j = (1- p_{jj})^{-1}$. See [7] for further details.) We also assume that transitions to other states are equally likely. Hence the transition matrix is

Table 2-1
Transition Matrix—Load Growth States

$$P = \boxed{\begin{matrix} 2/3 & 1/6 & 1/6 \\ 1/6 & 2/3 & 1/6 \\ 1/6 & 1/6 & 2/3 \end{matrix}}$$

This matrix will be varied systematically in the analysis. In particular, we will examine a case in which the transition probabilities are independent of load growth rate. In this case, no learning occurs, by which is meant that the forecast of future load growth is not updated based on the collection of past observations.

We assume that the initial area peak load is 100 MW. This is arbitrary, although this was the peak load in PG&E's Livermore-Pleasanton Area, the subject of an important study of the deferral benefits of distributed resources [15].

The initial growth rates are 1.02, 1.03, and 1.05 for the slowly growing, moderately growing, and rapidly growing areas, respectively.

We assume that the area saturates, such that the peak load will not exceed 200 MW over the indefinite future, and that load growth begins to slow down, in order to have peak load approach the limit asymptotically, when the peak load achieves 150 MW. See [7] for a discussion of the saturation phenomenon and how it is modeled in the Area Investment Strategy Model. For the present purposes, it is sufficient to observe that the Base Case includes this phenomenon, and that load growth is limited to twice the initial value.

Load Shapes

The load shape, given by the area load duration curve, is based on a typical feeder load duration curve for the PG&E system [1]. The load duration curve is described by five selected points plus two fixed points in (Hours per year, %Peak Load) coordinates. The two fixed points are: (0, 100%) and (8760 hr, 0%). The remaining five points, that characterize the PG&E feeder, are: (700 hr, 67%), (1752 hr, 50%), (4380 hr, 40%), (6132 hr, 33%), (8700 hr, 20%). This curve is somewhat peaked, such that the load is above three-fourths of the peak load approximately only 5% of the year.

Investment Alternatives

The collection of investment alternatives available to the local area planners describes the local planning area. In this study, we identify two kinds of areas, transmission constrained and distribution infrastructure constrained. A transmission constrained area cannot meet increased peak demand unless the transmission capacity is increased. We assume that there is sufficient distribution system capacity to meet the increased demand. An alternative to increasing the transmission capacity is to invest in distributed resources.

A distribution infrastructure constrained area cannot meet increased peak demand unless the capacity of the distribution system is increased. It is assumed that transmission capacity is sufficient to accommodate any increased peak load demand. The distribution infrastructure capacity is increased by investing in substation transformers, upgrading feeders, or adding so-called “bandaids” such as capacitors.

An alternative to increasing transmission or distribution system capacity is to invest in distributed resources. Such investments could reduce the peak load to be served by the transmission or the distribution system and thereby defer the need for the distribution capacity investment. In addition, some distributed resources may be able to reduce costly emissions and increase the reliability of service to customers.

We consider the following investment alternatives.

T. This is a large transmission system upgrade, category = load following, type = strategic, capacity = 50MW, capital cost = $15,000,000 ($300/kW), and a lifetime of 40 years. (For this, and all other alternatives in the base case, the lead time is zero and the cost escalation rate is unity (no growth).) {Category=load following} means that operating costs are based on the area under the load duration curve served by the capacity. {Type=strategic} means that the alternative can be placed in service at any time and in any sequence, subject to additional constraints that may be present.

S. This is a substation upgrade or a new substation, category = load following, type = strategic, capacity = 20MVA, capital cost = $4,000,000 ($200/kW), and a lifetime of 40 years.

ModS. This is a modular substation upgrade, category = load following, type = strategic, capacity = 10MVA, capital cost = $2,500,000 ($250/kW), and lifetime of 40 years.

SDR. This is a sequence of salvageable distributed resource investments, perhaps thought of as demand-side management programs or other forms of load control, type= bandaid, category = load following DSM. We have arbitrarily specified a sequence of six SDR programs, each of capacity = 2500 kW = 2.5MW, with increasing capital costs. The sequence of capital costs is the following: $1,250,000 ($500/kW); $1,875,000 ($750/kW); $2,500,000 ($1000/kW); $3,750,000 ($1500/kW); $5,000,000 ($2000/kW); $6,250,000 ($2500/kW). (Note that [15] reported that DSM costs could range from $433.33 /kW to $2191.48/kW; many programs cost approximately $1400/kW.) The lifetime of each program is assumed to be fifteen years. The choice of {type = bandaid} is to force successive SDR installations to follow the increasing sequence of costs. We also assume that these programs are salvageable if a large capacity investment, such as T, is chosen. “Salvageable” means that the investment can be removed from service before the end of its useful life. In that case, a salvaged investment recovers the remaining value of its useful life, expressed as the avoided capital rents over the remaining life. A non-salvageable investment remains in place for its entire useful life; the full capital cost is charged. The choice of {category = load following DSM} permits the operating costs to reflect the fact that SDR will avoid system energy costs based on the full capacity of the program. In the Area Investment Strategy Model, an arbitrary (non DSM) load following technology will avoid system energy costs only to the extent that the current peak load exceeds the original wires capacity. Hence, load following DSM tends to avoid more system energy costs.

DG. This is a modular non-salvageable type of distributed resource investment that can be thought of as a distributed generation technology, type = strategic, category = non load following. There can be an arbitrary number of such modular investments. Each one provides capacity 2500 kW, capital cost = $1,250,000 ($500/kW), with 20 year lifetime. DG costs are based on ([14], appendix), which indicates that a low value for distributed generation technology cost is $500/kW. The selection of the modular capacity 2500 kW is based on the combination of initial peak load for the base case of 100 MW with 2% expected growth rate. Thus, in one year, the peak load increment is approximately 2000 kW. Hence each modular technology can accommodate more than one year's expected growth.

Operating Costs

T. The fixed operating and maintenance (O&M) costs are $75,000 per year (which is one-half of one percent of the capital cost). The variable O&M cost is $.05/kWh. The cost of emissions is $.0025/kWh. (This is represented in the data in the "Other" columns, using the rate of 1 ton/kWh and the cost of $.0025/ton.) The cost of emissions is an approximation based on the pollution costs of central generation. That cost is assumed to be approximately 5% of the variable O&M. We could find no data that expressed this cost with any precision. (The base case assumption amounts to a 5% benefit for distributed resources that can avoid such emissions, such as SDR It is assumed that DG can be either more or less costly, depending on the technology. This is discussed further, below.)

S. The fixed O&M cost is $20,000 per year. (This is also one-half of one percent of the capital cost.) Variable O&M and emissions costs are equal to those for T.

ModS. The fixed O&M cost is $12,500 per year. Variable O&M and emissions costs are equal to those for T and S.

SDR. These are load-following technologies, so they do not achieve positive avoided system production costs. The fixed O&M is $6250 for SDR1 through SDR6. This is based on the capital cost of SDR1 and is one-half of one percent of that cost. There are no other operating costs associated with any SDR program. SDR then has some of the characteristics of an ideal photovoltaic technology.

DG. The base-case distributed generation technologies are block-loaded, so they are able to avoid system production costs. The fixed O&M cost is $6250 for each modular unit, retaining the factor of one-half of one percent of capital cost. (This is surely low, at $2.50/kW-yr, for such technologies as photovoltaics and fuel cells. The fixed O&M cost for distributed resources is between $12-$50/kw-yr in [14].) The variable O&M is $.07/kWh, the system avoided cost is $.05/kWh, and the emissions costs are identical to the system emissions costs, $.0025/kWh. For other distributed generation technologies, the emissions cost will be set to zero and the variable O&M can be as low as zero (for photovoltaics [14]) or $.002/kWh (for fuel cells [14]).

Losses and Unserved Energy

We use this feature of the Area Investment Strategy Model to measure how distributed resources might improve service reliability to the customer. Two parameters are sufficient to specify unserved energy. The outage time is the fraction of operating hours that the demand for energy in the local area is not served. The value for outage time is 0.25 hr/1000 hr in [14] for system resources, such as generators, and distribution resources, such as substation transformers. The cost of unserved energy is expressed as an interval between $4/kWh and $10/kWh in [16] and is set at $7/kWh in the base case.

Therefore, the cost of unserved energy is based on the load duration curve. This input to the Area Investment Strategy Model is a function that specifies the cost of unserved energy as a function of peak load for each strategic alternative. As explained in the User's Guide to the Area Investment Strategy Model [7], the model allocates the cost of unserved energy to each of the strategic alternatives installed, depending on the load actually served by the alternative. The curve is found by approximating the load duration curve by the simple curve defined by the three points: {(0 hr, 100%), (8760 hr, 20%), and (8760 hr, 0%)}, which is a right triangle atop a rectangle. For each strategic alternative, the cost function is the collection of pairs {(Peak Load (MW), $000)} = {(100, 0), (125, 48), (150, 160), (175, 308), (200, 479)}. This is based on the cost of unserved energy at $7/kWh, and is linear in that variable.

We assume that the cost of unserved energy, as defined by these two parameters, is reduced by some fraction if distributed resources are present. This assumption is a surrogate for an actual reliability analysis and attempts to respond to the claim that distributed resources will provide reliability benefits to the distribution system. The base case assumption is that unserved energy will be reduced by 50%. There is no compelling reason to assume this value, and it will be varied in the analysis.

Losses are set to zero in the base case.

Installation Constraints

The installation constraints are used to characterize the local area. If the area is transmission constrained, then the alternative T must precede all other alternatives, and only one such investment can be present along a trajectory. If the area is distribution infrastructure constrained, the number of repetitions of T is zero, and the precedence constraint is removed.

We express SDR1 through SDR6 as bandaids. This means that the distributed resources SDR1 through SDR6 must be installed in the sequence given by the order in which they are listed as alternatives, 1 through 6. This is the order of increasing cost. Further, all bandaids in the base case are presumed to be salvageable, which means they can be taken out of service if a conventional investment is made. This may not be realistic for many actual DSM programs, but salvaging bandaid costs tends to make the bandaids (SDR investments) more economical.

Terminal Conditions

The simplest terminal condition is to assign a terminal value to remaining capacity. This avoids the necessity of having to make assumptions about the future load growth and operating costs and procedures. In the terminal lottery, the actual amount of capacity installed at the end of the planning period is sold for a variable price. The expected value of that price is specified. In the base case, that price is $21.79/kW-yr, based on an approximate value of $300/kW discounted at 6% over a 30 year lifetime.

This completes the specification of the base case in the Area Investment Strategy Model.

3

ANALYSIS

Transmission Constrained Local Areas

Consider a local area that has sufficient distribution infrastructure to meet foreseeable load growth, but is constrained by lack of transmission capacity. Increments to transmission capacity come in relatively large quantities and with attendant large capital cost. It is natural to expect that distributed resources will have value in such areas since the distributed resources can be used to meet increasing peak loads and thereby eliminate the necessity for system generation capacity to serve those loads. If that need is eliminated, then additional transmission capacity is not required. (The idea here is that new load must be served by some energy source. If that source is the bulk system, then the transmission capacity must be increased or upgraded. If that source is local, i.e., a distributed resource, then the transmission capacity need not be increased.) The main value of the distributed resources, then, is in deferring the transmission expense. This was the basis of the analysis of the effect of targeted DSM in the PG&E system. ([1], [15], [17]).

Results & Conclusions

The results given by the Area Investment Strategy Model are the following. ("TR" denotes Transmission Constrained Area Result.)

TR1. The base case under low load growth rates, with no distributed resources of any kind (both SDR and DG eliminated through constraint specifications) has total cost of $22,286,040. This cost reflects only investments in transmission upgrades and further infrastructure.

TR2. The base case under moderate load growth rates, with no distributed resources of any kind (both SDR and DG eliminated through constraint specifications) has total cost of $26,104,920. This cost reflects only investments in transmission upgrades and further infrastructure.

TR3. The base case under large load growth rates, with no distributed resources of any kind (both SDR and DG eliminated through constraint specifications) has total cost of $34,540,960. This cost reflects only investments in transmission upgrades and further infrastructure.

TR4. Permitting the distributed resources identified as SDR1-SDR6, above, to be included in the choice of investments results in a reduction in cost under low load growth rates to $9,402,240; under moderate load growth rates to $22,211,620; and under large load growth rates to $32,972,600.

TR5. Permitting the distributed resource DG to be included in the choice of investments results in a reduction in cost under low load growth rates to $10,354,560; under moderate load growth rates to $24,817,100. Under large growth rates, costs do not decrease. If the distributed resource DG is constrained to defer the large transmission upgrade under large growth rates, the cost actually increases to $34,761,43.

TR6. There is no synergy found in combining SDR1 through SDR6 with DG. When both types are permitted, the optimal policy never includes DG.

These results are summarized in Table 3-1.

Table 3-1
Transmission Constrained Results ($000)

Growth Rates	Base Case (no DR)	SDR Only	DG Only
Low	22,286	9,402 (43%)	10,355 (46%)
Moderate	26,105	22,212 (85%)	24,817 (95%)
High	34,541	32,973 (95%)	34,761 (101%)

The following conclusions are suggested by these results. (“TC” denotes Transmission Constrained Area Conclusion.)

TC1. Distributed resources are strategically valuable in local areas that are transmission constrained.

TC2. The value of distributed resources decreases as the local area peak load growth rate increases.

TC3. Distributed resources provide benefit by deferring the need for the large capital investment in transmission capacity.

TC4. Distributed resources provide benefit whether they are load-following or not and whether they are salavageable or not in local areas that are transmission constrained.

TC5. To the extent that the base case assumptions are representative of real-world conditions, it may be possible to reduce the cost of capacity expansion by more than fifty percent, under the most favorable conditions for distributed resources to defer transmission investments.

Discussion

The idea that distributed resources can be used to defer large capital expenditures is one of the fundamental assertions of the proponents of the application of distributed resources. (Virtually all the references cited in this report make that point at least once.) The model results support that claim, but it is clear that the validity of the claim depends on the local area load growth conditions.

In particular, as the load growth rates increase, the value of the distributed resources decrease. This is because the amount of deferral provided by modular distributed resources decreases as load growth rates increase. Hence the greater unit capital cost ($/kW) of distributed resources becomes less easy to justify as the amount of deferral benefit decreases. A similar argument, not illustrated by these cases, however, is based on the certainty of load occurring. As that certainty increases, the value of distributed resources decreases; or, conversely, as load growth becomes more uncertain, it follows that the need for the transmission upgrade becomes more uncertain, and hence the distributed resources become more valuable. This argument was advanced in [18], using an earlier version of the Area Investment Strategy Model.

Although each of the distributed resource types that are present in the base case, SDR1 through SDR6 and DG, add value, the salvageable resources appear to be more valuable. Since distributed resources can be salvaged only after additional capacity investments have been made, the fact that salvageable resources add more value than non-salvageable resources indicates that after a capacity investment has been made, the value of peak load reduction decreases. This point was made in earlier studies ([15], [17]).

The cost reduction provided by distributed resources can be large in a transmission constrained area. This is because transmission investments are large with respect both to capacity and total capital cost. The model results identify savings that range from 57.8%, in the low load growth case, to 4.9%, in the moderate load growth case and 4.5% in the high growth case. In one of the high growth cases, the non-salvageable distributed resource did not provide any benefit. Combining these results, it is not credible to state any single claim of the amount of cost reduction. This is true because the amount of cost reduction depends on the specific local area conditions.

An issue not addressed in this research is the question of the appropriate capacity for the individual distributed resource investments. In the base case, the capacity of each distributed resource investment is five percent of the capacity of the transmission upgrade. We chose this relationship based on the expected growth rate in the area. For each area, there will be an appropriate distributed resource investment capacity. This capacity depends on the expected rate of growth, the uncertainty in the rate of growth, the peak load level, and the capacity of the transmission investment. It is inappropriate to conclude that because distributed resources provide strategic value, all capacity increments will be equally valuable. Indeed, the incremental capacity provided is one of the important determinants of the value of a distributed resource investment.

What seems most important is that it is reasonable to conclude that transmission constrained local areas are places where distributed resources can provide strategic value. It is reasonable to expect that such strategic value can be large.

Infrastructure Constrained Areas

Consider a local area that has sufficient transmission capacity to meet foreseeable load growth anywhere in the local area, but is constrained by lack of distribution system infrastructure, such as transmission substations and distribution feeders. Increments to distribution capacity come in somewhat smaller quantities and costs compared with transmission upgrades. Further, the capital cost of distribution infrastructure capacity is somewhat smaller than that of transmission. It is natural to expect that distributed resources will have value in such areas since the distributed resources can be used to meet increasing peak loads and thereby defer or eliminate the necessity for distribution capacity increments to serve the load. Furthermore, it is expected that distributed resources will increase reliability, decrease pollution, or decrease operating costs and thus yield strategic value. We used the Area Investment Strategy Model to examine these effects in a strategic way, to determine the value added by distributed resources as part of the least cost distribution expansion plan.

Results & Conclusions

The results given by the Area Investment Strategy Model are the following. ("IR" denotes Infrastructure Constrained Area Result.)

IR1. The base case under low load growth rates, with no distributed resources of any kind (both SDR and DG eliminated through constraint specifications) has total cost of $4,165,420. This cost reflects only investments in distribution infrastructure upgrades (substations and modular substations).

IR2. The base case under moderate load growth rates, with no distributed resources of any kind (both SDR and DG eliminated through constraint specifications) has total cost of $9,688,380. This cost reflects only investments in distribution infrastructure upgrades (substations and modular substations).

IR3. The base case under large load growth rates, with no distributed resources of any kind (both SDR and DG eliminated through constraint specifications) has total cost of $19,385,880. This cost reflects only investments in distribution infrastructure upgrades (substations and modular substations).

IR4 Permitting the distributed resources identified identified as SDR1-SDR6, above, to be included in the choice of investments results in a reduction in cost under low load growth rates to $3,081,010, and under moderate load growth rates to $9,294,020. If SDR1 is constrained to be used under large load growth rates, the cost of the best constained expansion plan is 24,447,880. In the low load growth rate scenario, only SDR1 and SDR2 are used. In both the moderate load growth and high load growth scenarios, only SDR1 is used.

IR5. Permitting the distributed resource DG to be included in the choice of investments never results in a reduction in expansion policy cost. The cost of an expansion policy that constrains DG to be used to delay infrastructure investments under low load growth rates is $4,405,300; under moderate load growth rates is $10,352,820; under large growth rates is $25,267,410.

IR6. There is no synergy found in combining SDR1 through SDR6 with DG. When both types are permitted, the optimal policy never includes DG.

These results are summarized in Table 3-2.

Table 3-2
Infrastructure Constrained Results ($000)

Growth Rates	Base Case (no DR)	SDR Only	DG Only
Low	4,165	3,081 (74%)	4,405 (106%)
Moderate	9,688	9,294 (96%)	10,353 (107%)
High	19,386	24,448 (126%)	25,267 (130%)

A natural question to ask is how sensitive these results are to the base case assumptions. We experimented in the following ways.

IR7 It is claimed that distributed resources will add strategic value by reducing pollution costs and permitting avoidance of central generating station pollution. We tested this claim by raising emission costs by a factor of two, to $.005/kWh, for infrastructure investments and reducing the emission costs of the DG distributed resource to zero. This had no effect on the optimal policy. We raised the emission costs again by a factor of two, to $.01/kWh. This also had no effect on the optimal policy.

IR8. It is claimed that distributed resources will add strategic value because some of the generating technologies that can be sited locally will have very low operating costs. We set the emission costs of infrastructure investments to $.005/kWh and set the emission costs of the DG distributed resource to zero, as in IR7. We then reduced the variable operating costs of the distributed resource DG from $.07/kWh to $.05/kWh. This had no effect on the optimal policy. We further reduced the operating costs of the distributed resource DG from $.05/kWh to zero. This also had no effect on the optimal policy. We then reduced the fixed operating and maintenance cost to zero. For this combination—zero emissions costs, zero variable operating costs, and zero fixed operating costs—the distributed resource is used to defer substation investments. For the low load growth case, the optimal policy cost is reduced from $4,201,220 (no distributed resources) to $4,145,770 (DG Only), a reduction of 1.3%.

IR9. We investigated the effect of load growth uncertainty on the strategic value of distributed resources. We changed the load growth rates to {1.01, 1.02, 1.08} to explore a local area that might experience rapid growth for some years during the planning period. In addition to the original transition matrix, we used the following transition matrix—Table 3-3.

Table 3-3
Transition matrix—Increased Predictability

$$P' = \begin{bmatrix} 2/3 & 1/6 & 1/6 \\ 2/3 & 1/6 & 1/6 \\ 1/6 & 1/6 & 2/3 \end{bmatrix}$$

This matrix partitions the growth rates into two classes, small and large. The transition probabilities in this matrix will tend to create growth trajectories with 1.01 the most likely small growth rate and 1.08 the most likely large growth rate. Each of these rates tends to persist for three years. The result is that there is greater variance in the peak load over time for matrix P′ than for matrix P. However, information about the current load growth rate has greater predictive power for matrix P′ than for matrix P. That is, the current growth rate is a better predictor of the future for matrix P′ than for matrix P. Thus, we investigated the strategic value of distributed resources for two different levels of predictability of growth. The following results were found.

For matrix P, with no distributed resources present, the optimal policy cost is $8,596,930. Adding distributed resources reduces this cost to $8,256,040. For matrix P′, with no distributed resources present, the optimal policy cost is $7,828,000. Adding distributed resources reduces this cost to $7,241,880. The strategic value of distributed resources is, on a percentage basis, somewhat greater when it is possible to forecast future conditions more accurately (under P′ rather than P): for P, the percentage reduction is 4% and for P′ the percentage reduction is 7%. These results are summarized in the first two rows of Table 3-5.

There are other differences in cost that merit discussion. Consider the costs in the cases where no distributed resources are present, $8,597 and $7,828, in Table 3-5 Infrastructure Constrained Results—Increased Predictability ($000) This difference is based on the ability of the planner to react to changes in future load forecasts. Indeed, the investment policies for the cases are different. Moreover, the average load growth is greater for P compared with P′. The increased load induces greater costs, both operating and capital. This greater load also explains the difference between the costs in the first two rows of the column labeled SDR.

In addition, we consider a case that has no learning. In this case, the transition matrix has identical rows—Table 3-4. Each row is the so-called steady-state probability, which is the relative occupancy of each load growth value. For matrix P′, that row is (.50, .17, .33). This means that approximately half the time the load growth rate is 1%, approximately 1/6 of the time the load growth rate is 2%, and approximately 1/3 of the time the load growth rate is 8%. This defines a new matrix, P_{nl} that describes the load dynamics when no learning occurs, which means that the likelihood of making a transition to a given rate does not depend on what rate currently applies.

Table 3-4
Transition Matrix—No learning

$$P_{nl} = \begin{array}{|ccc|} \hline 1/2 & 1/6 & 1/3 \\ 1/2 & 1/6 & 1/3 \\ 1/2 & 1/6 & 1/3 \\ \hline \end{array}$$

The costs associated with that matrix are shown in the third row of Table 3-5. Clearly, when there is no learning possible, the cost of the policy with no distributed resources is greatest, the effect of distributed resources on that cost is very large (12% decrease), but the policy cost is smallest when distributed resources can be used in a situation where it is possible to learn about the future load conditions. (Here we are comparing the costs $7,242 and $7,949.)

Table 3-5
Infrastructure Constrained Results—Increased Predictability ($000)

Transition Matrix	No DR	SDR
P	8,597	8,256 (96%)
P'	7,828	7,242 (93%)
P_{nl}	9,048	7,949 (88%)

IR10. It is claimed that distributed resources will provide the customer with more reliable service. We increased the cost of unserved energy to $14/kWh and changed the effect of distributed resources so that 75% of the unserved energy would be eliminated by distributed resources. This did not change the optimal policies.

IR11. Some authors suggest that the capital cost of distributed generation could be as low as $250/kW [20]. We reduced the cost of the distributed resource DG to $250/kW. For the low load growth case, non-salvageable DG had a strategic value, and it is used to defer substation investments. The optimal policy cost with DG is $3,555,480 (compared to the cost reported in IR1, $4,165,420), hence DG provides a reduction in cost of 14.6%.

The following conclusions are suggested by these results. ("IC" denotes Infrastructure Constrained Area Conclusion.)

IC1. Unlike local areas that are transmission constrained, the infrastructure constrained area has limited strategic need for distributed resources. These limitations are based both on the characteristics of the area and the properties of the distributed resource alternatives.

IC2. The value of distributed resources decreases as the local area peak load growth rate increases.

IC3. The distributed resources provide benefit by deferring the need for the traditional infrastructure capacity investments and not by eliminating the need for the investments.

IC4. In an infrastructure constrained area, distributed resources provide benefit if they are load-following and salvageable. Non-salvageable distributed resources do not provide measurable strategic benefits under the assumptions made in this study.

IC5. To the extent that the base case assumptions are representative of real-world conditions, it may be possible to reduce the cost of capacity expansion by as much as twenty-six percent, under the most favorable conditions for distributed resources to defer infrastructure investments. Under less favorable conditions, distributed resources <u>increase</u> the cost of expansion plans in infrastructure constrained local areas.

IC6 Non-salvageable distributed resources with very low operating costs may have some strategic value in infrastructure constrained areas.

IC7 To the extent that the base case assumptions about emissions and unserved energy are representative of real-world conditions, the value of distributed resources in infrastructure constrained areas is limited.

IC8. If it is possible to reduce the uncertainty in forecasting future load growth based on observations of past load growth, then the strategic value of distributed resources increases. This is because distributed resoures permit learning to occur before committing to large scale investments.

IC9. To the extent that the base case assumptions are representative of real-world conditions, reducing the capital cost ($/kW) of non-salvageable distributed resources is critical for such resources to play a strategic role in infrastructure constrained local areas. Non-salvageable distributed resources with unit capital costs ($/kW) approximately twenty percent larger than the unit capital cost of infrastructure investments can be used to defer those investments. Salvageable distributed resources can have greater unit capital costs and still add strategic deferral value to infrastructure investments.

Discussion

The main conclusion of this analysis is that unless distributed resources can become much less expensive in both operating and capital costs, the least cost expansion plans in an infrastructure constrained area are composed of traditional infrastructure investments like substations and feeders. In other words, in infrastructure constrained areas, build infrastructure.

Distributed resources add strategic value in infrastructure constrained areas that have slowly growing peak load or in which the load growth is uncertain but in which the uncertainty can be somewhat resolved over time. This latter condition leads to the contingent investment policies that are enhanced by distributed resource investments.

Distributed resource technologies that add strategic value in infrastructure constrained areas are salvageable, or if not salvageable have relatively low unit capital cost. If the unit capital costs are large, then, in order to add strategic value, distributed resource technologies should have low operating costs. The effects of emissions cost and reliability have been found to be less important than the technology costs and the behavior of area load.

A major reason that the Area Investment Strategy Model was built was to test the claims that were advanced in early reports about the benefits of distributed resources ([1], [4], [5], [10], [11], [14], [15], [17]). Such claims are part of the continuing discussion of distributed resources at present (e.g., [19], [20], [21]). As measured by the model, the benefits of distributed resources in infrastructure constrained areas are relatively modest. This seems to be because infrastructure investments are relatively inexpensive and can be modular (as the ModS, modular substation). We conclude that (1) unless there is a chance that the load does not materialize, in which case the infrastructure investment would be wasted; or (2) unless the cost of providing energy from the bulk system is too great, perhaps because of emissions, operating, or capital costs; or (3) unless the reliability of service decreases, perhaps due to aging infrastructure that has been poorly maintained, distributed resources are unable to provide anything that cannot be provided at less cost by traditional infrastructure investments.

4
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A

APPENDIX—DATA FOR TRANSMISSION CONSTRAINED AREA

```
TITLE: DR--BASE CASE—TRANSMISSION CONSTRAINED

CASE DESCRIPTION:
----------------
Base Case
Local Area Assumptions
for DR
Evaluations of
Transmission Constrained Case


MISCELLANEOUS:
-------------
Time Horizon:    15
Discount Rate:     0.0600
Inflation Rate:      0.0400
Acccounting Method: Before Tax Cash Flow.


LOAD GROWTH SPECIFICATIONS:
--------------------------
NOTE: The growth rates may have been modified for use by the load model
Num     Trend   Growth Rate      Probability and Description
    1       LO        1.0000             0.660       0.170       0.170       Low Load Growth
    2       ME        1.0100             0.170       0.660       0.170       Medium Load Growth
    3       HI         1.0303             0.170       0.170       0.660       High Load Growth
           1.020      Initial Load Growth Trend
 100000.000      Initial Load (kW)
           1.010      Load Growth Base (computed for use in model)
Saturation effect included
200000.000       Maximum Area Load
150000.000       Saturation Onset Load (kW)
```

```
LOAD SHAPE:
-----------
Num    Time (hrs)    Pct of Peak
  1        0.0000       100.0000
  2      700.0000        67.0000
  3     1752.0000        50.0000
  4     4380.0000        40.0000
  5     6132.0000        33.0000
  6     8700.0000        20.0000
  7     8760.0000         0.0000


ALTERNATIVES:
------------
Num   Alternative  Class      Type            Description
  1   T            Strategic  Load following  Large Transmission Upgrade
  2   S            Strategic  Load following  20MVA Substation
  3   ModS         Strategic  Load following  Modular Substation
  4   SDR1         Band-Aid   Load following  Peak Relieving DR
  5   SDR2         Band-Aid   Load following  Peak Relieving DR
  6   SDR3         Band-Aid   Load following  Peak Relieving DR
  7   SDR4         Band-Aid   Load following  Peak Relieving DR
  8   SDR5         Band-Aid   Load following  Peak Relieving DR
  9   SDR6         Band-Aid   Load following  Peak Relieving DR
 10   DG           Strategic Non-load following Block loaded DR
Band Aids are salvageable

Num   Alt.   Capacity   Capital($000)    $/kW   Escal.  Lead Time   Life
  1   T      50000.0     15000.0         300.0  1.000        0.0    40.0
  2   S      20000.0      4000.0         200.0  1.000        0.0    40.0
  3   ModS   10000.0      2500.0         250.0  1.000        0.0    40.0
  4   SDR1    2500.0      1250.0         500.0  1.000        0.0    15.0
  5   SDR2    2500.0      1875.0         750.0  1.000        0.0    15.0
  6   SDR3    2500.0      2500.0        1000.0  1.000        0.0    15.0
  7   SDR4    2500.0      3750.0        1250.0  1.000        0.0    15.0
  8   SDR5    2500.0      5000.0        2000.0  1.000        0.0    15.0
  9   SDR6    2500.0      6250.0        2500.0  1.000        0.0    15.0
 10   DG      2500.0      1250.0         500.0  1.000        0.0    20.0
```

```
O&M, GAS COST, HEAT-RATE, ETC.:
-------------------------------
Num  Alt.   Fixed O&M  GasCost  Heat Rate  Var. O&M  System Energy
  1  T         75.000    0.000      0.000     0.050          0.000
  2  S         20.000    0.000      0.000     0.050          0.000
  3  ModS      12.500    0.000      0.000     0.050          0.000
  4  SDR1       6.250    0.000      0.000     0.000          0.000
  5  SDR2       6.250    0.000      0.000     0.000          0.000
  6  SDR3       6.250    0.000      0.000     0.000          0.000
  7  SDR4       6.250    0.000      0.000     0.000          0.000
  8  SDR5       6.250    0.000      0.000     0.000          0.000
  9  SDR6       6.250    0.000      0.000     0.000          0.000
 10  DG         6.250    0.000      0.000     0.070          0.050

EMISSION RATES AND COSTS:
-------------------------
Num  Alt.   NOX Rate     SOX Rate     CO2 Rate     Other Rate
  1  T      0.0000e+000  0.0000e+000  0.0000e+000  1.0000e+000
  2  S      0.0000e+000  0.0000e+000  0.0000e+000  1.0000e+000
  3  ModS   0.0000e+000  0.0000e+000  0.0000e+000  1.0000e+000
  4  SDR1   0.0000e+000  0.0000e+000  0.0000e+000  0.0000e+000
  5  SDR2   0.0000e+000  0.0000e+000  0.0000e+000  0.0000e+000
  6  SDR3   0.0000e+000  0.0000e+000  0.0000e+000  0.0000e+000
  7  SDR4   0.0000e+000  0.0000e+000  0.0000e+000  0.0000e+000
  8  SDR5   0.0000e+000  0.0000e+000  0.0000e+000  0.0000e+000
  9  SDR6   0.0000e+000  0.0000e+000  0.0000e+000  0.0000e+000
 10  DG     0.0000e+000  0.0000e+000  0.0000e+000  1.0000e+000

Num  Alt.   NOX Cost  SOX Cost  CO2 Cost  Other Cost
  1  T        0.000     0.000     0.000     0.002
  2  S        0.000     0.000     0.000     0.002
  3  ModS     0.000     0.000     0.000     0.002
  4  SDR1     0.000     0.000     0.000     0.000
  5  SDR2     0.000     0.000     0.000     0.000
  6  SDR3     0.000     0.000     0.000     0.000
  7  SDR4     0.000     0.000     0.000     0.000
  8  SDR5     0.000     0.000     0.000     0.000
  9  SDR6     0.000     0.000     0.000     0.000
 10  DG       0.000     0.000     0.000     0.002
```

LOSSES AND UNSERVED ENERGY:

For Plan: Large Transmission Upgrade

Load (kW)	Losses ($000)	Unserved Energy ($000)
100000	0.00	0.00
125000	0.00	48.00
150000	0.00	160.00
175000	0.00	308.00
200000	0.00	479.00

For Plan: 20MVA Substation

Load (kW)	Losses ($000)	Unserved Energy ($000)
100000	0.00	0.00
125000	0.00	48.00
150000	0.00	160.00
175000	0.00	308.00
200000	0.00	479.00

For Plan: Modular Substation

Load (kW)	Losses ($000)	Unserved Energy ($000)
100000	0.00	0.00
125000	0.00	48.00
150000	0.00	160.00
175000	0.00	308.00
200000	0.00	479.00

CUMULATIVE PERCENT LOSS REDUCTION:

	Pre	T	S	ModS
SDR1	0.00	0.00	0.50	0.50
SDR2	0.00	0.00	0.50	0.50
SDR3	0.00	0.00	0.50	0.50
SDR4	0.00	0.00	0.50	0.50
SDR5	0.00	0.00	0.50	0.50
SDR6	0.00	0.00	0.50	0.50
DG	0.00	0.00	0.50	0.50

```
CUMULATIVE PERCENT UNSERVED UNSERVED ENERGY REDUCTION:
----------------------------------------------------
        Pre     T       S       ModS
SDR1    0.00    0.00    0.00    0.00
SDR2    0.00    0.00    0.00    0.00
SDR3    0.00    0.00    0.00    0.00
SDR4    0.00    0.00    0.00    0.00
SDR5    0.00    0.00    0.00    0.00
SDR6    0.00    0.00    0.00    0.00
DG      0.00    0.00    0.00    0.00


USER SPECIFIED CONSTRAINTS:
---------------------------
Num     Description
   1    Number of T <= 1
   2    S must be preceded by: T
   3    ModS must be preceded by: T


AUTOMATICALLY GENERATED CONSTRAINTS:
------------------------------------
Num     Description
   4    Number of SDR1 <= 1
   5    Number of SDR2 <= 1
   6    Number of SDR3 <= 1
   7    Number of SDR4 <= 1
   8    Number of SDR5 <= 1
   9    Number of SDR6 <= 1
  10    SDR2 must be preceded by: SDR1
  11    SDR3 must be preceded by: SDR2
  12    SDR4 must be preceded by: SDR3
  13    SDR5 must be preceded by: SDR4
  14    SDR6 must be preceded by: SDR5


TERMINAL VALUE SPECIFICATIONS:
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Uses Terminal Lottery on Capacity Price
        21.790  Price of Capacity at Terminal Time
NOTE: This option assumes that all assets are sold at the end of the planning horizon
```