CONSTRUCTION OF A DEMAND SIDE PLANT WITH THERMAL ENERGY STORAGE

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ABSTRACT

Utility managements have two primary responsibilities. They must supply reliable electric service to meet the needs of their customers at the most efficient price possible while at the same time generating the maximum rate of return possible for their shareholders. Regulator hostility towards the addition of generating capacity has made it difficult for utilities to simultaneously satisfy both the needs of their ratepayers and the needs of their shareholders. Recent advances in thermal energy storage may provide the ratepayers significantly lower electricity rates at greater comfort levels. Utilities benefit from improved load factors, peak capacity additions at low cost, improved shareholder value (i.e., a better return on assets), improved reliability, and a means of satisfying growing demands with the regulatory and litigious nightmares associated with current supply side solutions. This paper discusses thermal energy storage and introduces the demand side plant concept.

Utility managements have two primary responsibilities. They must supply reliable electric service to meet the needs of their customers at the most efficient price possible while at the same time generating the maximum rate of return possible for their shareholders. In times past, it was easy to achieve both of these demands. Today, however, regulators are increasingly skeptical of any attempts to raise rates because of capacity additions. The regulators, subjecting the utilities to increasingly intensive prudence reviews, have questioned every increase in capacity and disallowed many utilities' attempts to raise rates to pay for added capacity. The U.S. Department of Energy (DOE) described the situation, stating that "regulators have shown a reluctance to pass through the costs of new plants to customers even if these same regulatory bodies had initially approved the plants' construction and the plants were prudently built." For example, one utilities electric utility located in the energy patch failed to forecast the region's oil consumption in 1979 oil price shocks. Oil based generation is not a viable option.

Also, it is not the most secure natural resource with today's rising world (and domestic) consumption and declining exploration and development. America's oil imports are currently at the highest levels in our nation's history! Middle East OPEC's capacity to produce oil, when OPEC's capacity will become strained, raising the possibility of a repeat of the 1973 and 1979 oil price shocks. Oil based generation is not a viable option. OPEC's capacity will become strained, raising the possibility of a repeat of the 1973 and 1979 oil price shocks. Oil based generation is not a viable option. Oil based generation is not a viable option.

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U.S. already consumes 14% of Canada's gas to meet some of the peak demand requirements, but that is about all. Hydroelectricity is the cleanest form of power. Yet most of the high potential large-scale hydroelectric projects have already been built. Any remaining large-scale projects would almost inevitably result in the damming of a wild river, raising someone's ire (as witnessed recently in Colorado). The utilities are also worried about a repeat of the TVA’s small darter incident. Small scale hydro holds less promise than one might at first think. Gunnar Sarsten of the United Engineers and Constructors, while giving the keynote address of the Joint Power Generation Conference, pointed out that if small scale hydro alone were to meet our demand, we would need a couple of hundred thousand new dams flooding an area the size of New England. Hydro alone will not be able to add much capacity.

Other than hydroelectricity, most renewables are still not cost effective. We have had some successful applications of geothermal power, but the possible sites are few in number. Wind and solar power hold promise for some day in the future, but they are generally not cost effective today with the exception of remote, off-grid locations. They are also not the most reliable forms of electrical generation, one day these renewables may help, but that day has yet to arrive. Recent breakthroughs with superconductivity in transmission may offer a bright portrait of tomorrow. But the canvas is still blank today.

Utilities, frustrated in their attempts to add capacity, are increasingly turning to co-generators, independent power producers (IPP), and plant refurbishing as alternatives. Gunnar Sarsten pointed out that if co-generation as a form of power was 10% more cost effective, we would need three times the number of sites currently available. IPPs might be able to help in any environment that deregulates. But currently they are a rather unattractive game. IPPs are essentially constrained by publicly provided services until they are. Plant life extensions, taking 30 year old plants and refurbishing them so they will reach 60 or 50 years, will remain a worthwhile effort until the plants built to tighter environmental tolerances become ready for retirement. These plants will be much more difficult to refurbish as they go.

Utility managers are keenly aware of all of this. They are just as aware of their fiduciary responsibility to their shareholders. Thus, the characteristic conservative utilities have been making even more conservative forecasts. The result: peak demand has consistently been outpacing forecasts while generation continues to be built to forecast. The sustained dynamic economic growth of the 1980s combined with an unusually hot summer strained North America’s power grid to unprecedented levels in 1988.

The North American Electric Reliability Council’s 1988 Annual Report was filled with citations of record demand. The East Central Area Reliability coordination Agreement’s 1988 summer peak exceeded the 1994 forecast; it was 16.9% over forecast and 10.3% higher than the record. Net energy load grew by 5.9%. The Mid-Atlantic Area Council (MAC) received a winter peak 9.9% above the year before and 7.4% above record. MAC forced a system-wide 5.0% voltage reduction. Net energy load grew by 5.4%. The Mid-Atlantic Interconnected Network’s summer peak was 9.0% above record. The Mid-Continent Area Power Pool’s summer peak was 9.0% over forecast and 7.4% higher than 1987. Electric utility use was 8.3% higher than 1985. The Southwestern Electric Reliability Council’s summer peak was 9.5% over forecast. The Western States Coordinating Council demand increased 8.5% in 1988; the peak was 5.0% over forecast.

DEMAND SIDE OPTIONS

Eventually the capacity problems the utilities face will have to be addressed. However, these are complicated issues involving many parties. The utilities can do little by themselves. The utilities can, however, work on the demand side of the equation. Through the use of incentives, promotions, and innovative rate structures, the utilities can dramatically reduce their summer and winter peaks. While interaction with regulators is necessary to implement demand side management programs, there is every indication that cooperation will be forthcoming. Demand side management allows the need for capacity additions and allows the electricity end user to realize reduced prices through the utilization of new technologies and/or changes in behavior. This is especially true for large industrial users and provides a means for the utilities to meet their requirement to provide reliable service to their customer base.
At the same time, demand side management can help utilities fill in the valleys of a demand profile, improving load factors and revenues. The utilities realize greater revenue per kilowatt of generating capacity, satisfying the utilities' requirement to maximize shareholder value. Demand side management is consistent with the fiduciary obligation of utility management to their shareholders.

The need for further demand side management has more urgency than is suggested by a mere revenue enhancement. In proof terms with variations existing for individual utilities, utility load factors have been declining since the advent of air conditioning. If this decline continues, some utilities may be faced with the unpleasant circumstances where base load generating facilities must be cycled or shut down. In terms of maintenance costs, plant reliability, and load revenue, cycling base load plants is a grim scenario indeed. This gives utilities added incentive to improve load factors by whatever means are available.

Residential Thermal Energy Storage (TES), a new, developing technology from the heating, ventilating, and air conditioning (HVAC) industry, is close to fruition and marketplace introduction. TES represents an awesome potential for utilities. Close to 1/3 of our nation's aggregate energy is consumed for HVAC in the country's residential and commercial buildings. Daily variations in temperatures combined with end use behavior patterns result in tremendous peaks and valleys for the HVAC demand profile. Lopping off the peaks and filling in the valleys of the HVAC demand profile with the unpleasant circumstances where base load generating facilities must be cycled or shut down. In terms of maintenance costs, plant reliability, and load revenue, cycling base load plants is a grim scenario indeed. This gives utilities added incentive to improve load factors by whatever means are available.

The impact of TES

A significant innovation in residential TES is currently in advanced development at Lennox Industries. This system stands to revolutionize the HVAC industry. It represents the most significant innovative concept for residential and commercial HVAC air conditioning since air-cooled condensing units with hermetic compressors were introduced during the 1950s! Utilities will soon have a TES system available that will allow them to dramatically improve load factors and the need for new plant construction. This system will reduce condensing capacity of a given system to 50% or less of what is required for a conventional system. Total electrical load is 60% of a conventional system. The aggressive utility can construct a demand side plant using this system that dramatically improves the revenue per kilowatt. Additional capacity is gained at very low cost. And there is no prudent review.

The best way to understand the demand side plant concept is through an example. The following hypothetical case will help explain the concept.

**Base Scenario**

Assume that a utility's average residential customer has a peak load usage of 13,200 kwh per year with a peak demand of 6.00 kw. Of this base, 3,600 kwh and 1.60 kw is for air conditioning (assuming a 3 ton system with a 13 SEER and 1,000 hours of use). The utility charges $0.090 per kwh and has marginal generation cost of $0.025 per kw (i.e., the cost of generating an extra kw is $0.025). The utility's revenue per customer breaks down as follows:

- **9,600 summer kWh + 1,600 a/c kWh = 11,200 total kWh**
- **13,200 kWh X $0.090/kwh = $1,188.00 gross revenue**
- **13,750 kWh X $0.025/kwh = $330.00 gross profit**
- **$1,188.00 - $330.00 = $858.00 gross profit**
- **$858.00/6.00 kw = $143.00 gross profit/kW**

This represents the "marginal" revenue and gross profit per kilowatt and is thus effective and to the point where new generating capacity is needed. The capital costs of new capacity are not addressed. In this sense, gross profit might also be stated in terms of the "difference" between the cost of adding one household and the added cost of supplying that household with electric service, provided that the household does not require any additional fixed or semivariable overhead (i.e., no additional manpower to connect power to the household, and so on) and no additional equipment to connect service to the household, providing power to the household, and so on). The "gross profit" would all be contributing to the pure variable costs of providing service.

**Utility Costing**

Utility TES and a demand metered time-of-use (TOU) rate, the average cost of electricity to the homeowner is lowered. In this example, from $0.090 to $0.072/kwh. With TES, the homeowner is using more electricity to cool the house. The air conditioning electricity usage

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jumps from 3,600 kwh to 4,500 kwh. Total consumption is now 4,56 kW. The utility's revenue per customer in this scenario breaks down as follows:

\[
\begin{align*}
9,600 	ext{ base kwh} &+ 4,500 \text{ a/c kwh} = 14,100 \text{ total kwh} \\
14,100 \text{ kwh} \times 0.072\text{kWh} & = 1,015.20 \text{ gross profit} \\
14,100 \text{ kwh} \times 0.025\text{kWh} & = 352.50 \text{ cost} \\
1,015.20 &- 352.50 = 662.70 \text{ gross profit}
\end{align*}
\]

By encouraging the use of TES with a TOU rate, the utility, in this example, was able to raise revenue/kW for the average customer by 12% and gross profit/kW by 2%. All of this occurred without the addition of a single kW of capacity. In fact, the peak capacity required by this customer was cut by 24%. The residential customer comes out a winner; he saves $172.80 a year on his electric bills. The utility wins since its return on assets improves and there is now additional capacity to use elsewhere.

DEMAND SIDE PLANT CONCEPT

The utility can expand upon this concept to construct a demand side plant. Using the average residential customer described above, the utility could construct a 50 kW demand side plant with less than 35,000 customers at an annual opportunity cost of $135.63 per kW and a net present value (NPV) of $94.25 per kW (assuming a 15 year life and a 6% discount rate). The demand side plant is constructed as follows:

\[
\begin{align*}
6.00 \text{ kW} &- 4.56 \text{ kW} = 1.44 \text{ kW offset from TES/site} \\
50,000 \text{ kW/site} &+ 1.44 \text{ kW} = 34,722 \text{ sites} \\
34,722 \text{ sites} \times 858.00 \text{ gross profit} & = 29,791,667 \text{ gross profit before TES} \\
34,722 \text{ sites} \times 862.70 \text{ gross profit} & = 23,010,417 \text{ gross profit with TES}
\end{align*}
\]

\[
\begin{align*}
$29,791,667 &- $23,010,417 = $6,781,250 \text{ cost} \\
$6,781,250/50,000 \text{ kW} & = $135.63/kW opportunity cost \\
$145.33 \text{ gross profit/kW} & - $135.63/kW opportunity cost = $9.70/kW current value
\end{align*}
\]

With a positive NPV of $94.25 per kilowatt, the utility can construct a demand side plant. And throughout the construction period, the return per kilowatt of capacity increases one customer at a time, all without a prudence review.

IMPACT OF CONSUMER BEHAVIOR

Of course, the above examples completely ignored the potential for behavioral changes on the part of the residential customer once TOU rates are in place. The refrigerator is the only major appliance not affected by the homeowner's behavior. The range, dishwasher, washer, and dryer are all affected by behavior. If behavioral changes from the TOU rates are assumed to affect demand for the average customer by 1.56 kW, cutting total demand from 6.0 kW to 3.0 kW, the following example applies (note that the average price paid per kWh with TOU rates falls from $0.072 to $0.067 with the behavioral change assumption, as more activities are performed off-peak utilizing the lower rates).

\[
\begin{align*}
9,600 \text{ base kwh} &+ 4,500 \text{ a/c kwh} = 14,100 \text{ total kwh} \\
14,100 \text{ kwh} \times 0.067\text{kWh} & = 944.70 \text{ gross revenue} \\
14,100 \text{ kwh} \times 0.025\text{kWh} & = 352.50 \text{ cost} \\
944.70 &- 352.50 = 592.20 \text{ gross profit}
\end{align*}
\]

In this case, the utility raised the revenue/kW for the average customer by 59% and gross profit/kW by 38%. Again, all of this occurred without the addition of a single kW of capacity. Peak capacity required by this customer would be:

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In demand side plant construction, there is no prudence review, revenue is realized during the entire construction period, and additional financing is not needed. It is a pay-as-you-go proposition. Figure 1 compares revenue turn per kilowatt from the scenarios above and figure 3 summarizes the demand side plant construction.

The utility has now constructed a demand side plant with a NPV of $1,056.69 per kilowatt with a secondary fluid circulating system. All connections to the storage module, simplifying installation. Today's HVAC contractor already has the skills needed to install this system.

The design of the system results in less pumping power being supplied solely by the compressor. The system requires only liquid and suction line connections to the storage module, simplifying installation. Today's HVAC contractor already has the skills needed to install this system.

To start, the system is a refrigerant based system and does not use a secondary fluid (such as brine or a glycol solution). The system thus avoids heat exchange losses associated with a secondary fluid circulating system. All pumping power is supplied solely by the compressor. The system requires only liquid and suction line connections to the storage module, simplifying installation. Today's HVAC contractor already has the skills needed to install this system.

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The Lennox TES system makes demand side construction possible. This system fundamentally differs from the TES systems which are typically applied to large commercial structures today. These differences are worth noting.

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Figure 2 summarizes the demand side plant construction possible. This system funded itself readily to new construction applications will require less electric wiring capacity. Bill of the remits than a conventional high efficiency system. Two-speed compressor heat pumps will be suitable to this system. High speed will promote cycling by the condensing unit during periods of partial load. For high load design conditions, the system will operate as a capacity reduced unit. Thus, better comfort conditions are provided.

The system is capable of supplying a total indoor evaporator capacity as much as three times the condensing unit capacity. The system lends itself readily to residential and light commercial structures. The system is applicable to new construction, the replacement market, and to retrofitting homes currently without central air conditioning (through ductless systems). It will be applicable to air conditioning only or to heat pumps.

One of the principle differences between this system and the type of TES typically applied to large commercial buildings today is that it is load leveling rather than load shifting. This is illustrated by Figure 1. The load leveling feature of the system results in cost effective application for the homeowner.

A load leveling system operates continuously on the peak design cooling day, making ice with available excess capacity at night and using the ice the next day during the peak period. A load shifting system must be of sufficient capacity to meet night time cooling demand and build sufficient stored cooling to meet all of the peak load the next day. The load shifting system typically requires a condensing unit with the same capacity and electric demand as a conventional system. The load leveling system only requires 50% of the capacity.

The load leveling system, therefore, has a smaller condensing unit with smaller electric demand. Thus, it has a finite electric demand equal to the maximum electric demand of the condensing unit. With a peak shifting system, the possibility exists that an owner of the system could inadvertently or intentionally operate the condensing unit during periods of peak demand creating a very expensive demand charge the following year. This type of demand charge could result in a customer and public relations nightmare for a utility, especially if the demand charge follows the sale of the home. This problem is eliminated with a load leveling system. Since the load leveling system uses a smaller condensing unit, the cost of the system is lowered relative to load shifting TES. In addition, the load leveling system's storage module is only 30% of the size of the storage module for a load shifting system. And new construction applications will require less electric wiring capacity. All of this results in a TES system that only costs slightly more than a conventional high efficiency system.

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Figure 1: TES Utility Impact

Figure 2: Demand Side Plant Utility Impact
Typical Peak A/C Residential Load Profile

True Load Shifting Thermal Storage Load Profile

Lennox Load Leveling Thermal Storage Load Profile

LOAD LEVELING TES VERSUS LOAD SHIFTING TES

FIGURE 3: TES LOAD PROFILES
by the utilities.

**Homeowner Benefits From TES**

With TES, homeowners should see significant savings in their electric bills. Application of TES under the right TOU rate can easily reduce a consumer's electric bill by 14% in a moderate climate. In a sunbelt climate, the savings significantly improve. Even greater savings are possible from the behavioral changes in the use of electricity.

With TES, homeowners should enjoy greater levels of conditioned comfort. The operating characteristics of a level loading TES result in more consistent and constant comfort levels than conventional coolings provides.

**Utility Benefits From TES**

With TES, utilities have a means of improving load factors. With the off-peak kicker the level loading system provides, base load plants are helped to run at capacity.

With TES, utilities have a low-cost means of adding peak capacity. The demand side plant concept illustrated in the example above for the most climatically average Mid-American home would imagine yielding a net present value of the utility of $1,056.69 per kilowatt.

With TES, utilities are provided with a means of improving shareholder value. Wide-scale use of TES in a given utility's service area will increase the utility's return on assets.

With TES, utilities are given a means for improving reliability. Redundancy is inherent in the demand side plant concept. A 50 megawatt generating plant always has the potential of failure and must be shut down for maintenance sooner or later. In the transmission lines and connections for a generating plant are also subject to failure. The 50 megawatt demand side plant consists of thousands of small TES modules. Down time at the generator does not affect the demand side "addition" to peak capacity. Transmission line failure is not a possibility with the demand side plant.

With TES, utilities have a means of satisfying growing demand without the regulatory changes and litigious nightmares associated with current supply side solutions. The demand side plant satisfies all of the regulators' agendas. If it is to work at all, electricity rates will be lowered. The need for regulatory "finder's fees" is eliminated since it is implemented as it is built and as it is planned.

**Utility Support**

Without the appropriate electric utility support, TES will not be successful in the marketplace. To be effective in addressing utility interests, this technology must have correct and appropriate utility incentives.
volvement and assistance.

CONCLUSION

Supply side solutions may not solve the utilities' growing capacity problems by themselves. Demand side solutions should play a supporting role. TES, a significant HVAC technology about to be launched, can help to meet capacity needs while simultaneously lending dramatic improvement to utility financial performance over time. This technology will help the electric utility industry maintain reliable electric service while improving shareholder value and satisfying regulatory requirements. Utility involvement and assistance, however, is critical to the success of TES in the marketplace. All told, support for this technology is an exercise in fiduciary responsibility for utility managements.

REFERENCES
