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HOMEOSTATIC CONTROL: ECONOMIC INTEGRATION OF SOLAR TECHNOLOGIES INTO ELECTRIC POWER OPERATIONS AND PLANNING

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ABSTRACT

The economic and technical interfaces between the electrical utility and the distributed, nondispatchable electric generation systems are only minimally understood at the present time. This paper will discuss the economic issues associated with the interface of new energy technologies and the electric utility grid. The paper then introduces the concept of Homeostatic Control as developed by the author and others at MIT and discusses the use of such an economic concept applied to the introduction of nondispatchable technologies into the existing utility system. The paper concludes with a discussion of the transition and potential impact of a Homoeostatic Control system working with the existing electric utility system.

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I. Introduction

Rising energy prices during the early 1970's brought a major effort to develop a set of new energy technologies which held the potential for replacing scarce fossil fuels. One set of these new energy technologies, those frequently referred to as solar technologies, brought with them a new set of characteristics of supply which were not present in the traditional fossil fuel sources. The majority of the solar technologies are non dispachable: their performance is predictable during specific daily or annual time cycles but is not available at all during other specific periods. Because their output is generally time-dependent, their output is not independent of the demand for energy. In addition, many of these new solar technologies are at least as feasible at distributed locations as they are at centralized locations.

The objective of this paper is to evaluate the economic interactions between the operation of nondispatchable, new energy techologies and the electric power grid. It will discuss the general characteristics of these new energy technologies and focus on one specific set, those generating electricity. The paper will then introduce a new set of concepts, Homeostatic Control, which offer a means of increasing the cooperation and coordination between electric utilities and their customers. Finally, the paper will discuss the utilization of the concepts associated with Homeostatic Control in efficient integration of new energy technologies into the current electric power grid system.

Throughout the discussion there will be an effort to separate the questions of interaction into five time frames which reflect the operating decisions of the electric utility. These time frames are summarized in Table 1. As will be seen, the concepts of Homeostatic Control function in each of these time frames to help to maintain system equilibrium.

Table 1

Utility Time Scales

Time Scale	Function
0 seconds to 1 minute	Dynamic Control
1 minute to 10 minutes	System Dispatch
1 hour to 2 weeks	Unit Commitment
1 month to 2 years	Maintenance Scheduling
5 to 20 years	Capacity Expansion Planning

II. Solar Technologies: Utility Interface Characteristics

The nondispatchable, specifically solar-based technologies may be grouped into three categories:

- o end-use
- o electric generation
- o fuel.

The three have distinctly different operating characteristics and have significantly different impacts upon the electric utility system (Ref. 1).

End-Use: Direct conversion of solar energy for both hot water and space heating, whether active or passive, represents the conversion of solar energy into directly usable end-use energy. The requirements for utility interface to these end-use technologies are one-directional and of a "back-up" nature only.* This requirement may place a significant burden upon the utility in its short-term planning and operation as well as its long-term capacity expansion. Because each solar end use unit is weather dependent the sum of the individual units will also be weather dependent. As seen by the utility, the end-use solar technologies are similar in their characteristics to air conditioning or electric heating, in that the net load, as seen by the utility, is highly dependent on at least macroweather patterns. On a hot day with high humidity, most utilities will see a high coterminous peak brought about by a large number of air-conditioning units drawing heavily at any given time. The same phenonmenon takes place with solar heating and hot water units when there is a long period of cloudy skies such that the units themselves are not functioning, thus causing the back-up system to take effect.

Electric Generation: The second significant solar technology type is one whose major function is in the generation of electricity. This type of technology, primarily photovoltaic, small scale solar-thermal-electric, and wind, has a very different impact upon the electric utility grid. These technologies both provide power to the electric grid and, in the instances in which they are distributed technologies, also demand

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*The term "backup" is used in this discussion for lack of a better phrase. It should be noted that no unit in an electric utility system is without "backup." Solar technologies are dependent upon sunlight or wind and thus their backup requirements are not random as would be the case with, for instance, a coal or nuclear facility.

back-up from the electric utility. As a result, the generation technologies are more difficult to evaluate from the perspective of the electric utility. As central generation sources, the photovoltaic, solar-thermal-electric, and wind systems may be seen as a high-capital, low-operating-cost, generating plant. In this mode they are dispatched on the front part of the loading order because they are the least operating costs generators available. From the perspective of the system dispatcher, the plants represent a two-component uncertainty structure. The first component is one that is a function of the weather conditions, either solar or wind that will affect their availability. The second component of uncertainty is that of performance of the plants themselves. This component is identical to the uncertainty associated with any other generation plant on the system in that each generation plant has a finite probability of being in operation at any time, because of mechanical or electrical failure.

The more difficult analysis is of distributed solar generators. The utilities will be concerned that the energy entering the utility grid be of sufficient quality and that the systems be designed in such a manner as to guarantee the safety of those operating and repairing the system.

Fuel: Solar technologies such as those referred to as biomass and to a significant extent large scale solar thermal electric have a very different set of characteristics with regard to the electric utility. Biomass fuels are being considered or being used for electric power generation at a number of stations. These fuels utilize, generally, wood chips for a boiler fuel in a standard steam-turbine environment. As such they are little different from other fuels in terms of their technical characteristics in operating or interfacing with the utility.

Large-scale solar thermal electric facilities are in many ways more similar to biomass than to the smaller scale generation technologies in that solar energy is frequently only one fuel of a multifuel mix to be utilized in a steam boiler.

For the remainder of this paper, the primary concern will be the interaction of electric generation technologies and the electric utility system. The electric generation technologies under consideration will be predominantly those of wind and photovoltaics though the discussion can be easily expanded to consider all non-dispachable sources including small scale hydro and distributed solar-thermal electric.

III. Homeostatic Control: Discussion

Homeostatic Control (Ref. 2) is a new approach to the control and economic operation of an electric power system. As will be discussed later the implementation of some of concepts within Homeostatic Control have already or could begin today specifically for large industrial and commercial customers. Homeostatic Control is based on two major principles, utility customer cooperation and the independence of the customer. It is to the advantage of both the customer and the utility that the electric power system be planned and operated as economically and physically efficiently as possible subject to constraints on environmental quality and on system integrity. Historically this has been the task of the utility independent of the customer. Customers have only rarely been given any role or any information concerning the overall cost of operation of the electric utility or concerning the cost of maintaining the integrity of the utility system as a whole. As a result, the "communications" with the customer have been limited to a single price, for the most part, and to a fixed level of reliability. The result of this lack of communication has been that in general electricity has been utilized less economically efficiently than would be possible were customers to receive additional price information. Given major advances in communications and computation, an information exchange in real time is now possible.

At the same time that it is important to have a close interaction between customers and the utility, it is equally important for customers to make independence decisions. It is more efficient for a customer to make the decision to shed load than it is for an external source, such as an electric utility controller, to make the decision to shed customer load. To make this clear it need only be pointed out that the industrial customer is far more able to judge the value of electricity at any given point in time than is the utility controller who has little if any information concerning the industrial processes being affected.

Three Homeostatic Control concepts which follow from the general principles discussed above are:

- Spot Pricing
- Microshedding
- Decentralized Dynamic Control

These concepts could be implemented separately; however, when integrated, they provide a coordinated set of actions which form the basis for highly flexible and robust operating and control systems.

Spot pricing is a concept in which the price of electricity varies during the day depending on supply-demand conditions (customer and utility) and the cost of supply. Three types of spot prices are:

Buy Rate: Price paid by customers to buy firm power from utility.

Buy-Back Rate: Price paid by utility to buy power from customer.

Interruptible Rates: Lower Buy Rates which give the utility right to control a "percentage" of customer's demands (see next section, Microshedding).

Rates are computed by a Central Utility Controller and transmitted to the customer in any one of several ways. The simplest would be daily updates of hourly prices published in the newspaper. The most sophisticated would be utility computer to customer computer communications. Spot pricing would eliminate declining or increasing block rates, demand charges, ratchet clauses, hours use charges, and penalty charges for back-up power except as justified by cost of transformer-distribution line hardware.

Spot price rates are determined by consideration of

- o Economics: Cost of fuel, capital, maintenance, etc.
- o Quality of Supply: Present and expected future voltage, frequency, availability of power.

If, for example, total demand is approaching total available generation, quality of supply consideration could increase buy price and buy-back prices beyond that indicated by direct utility expenditures in order to reflect the extra pricing "forces" needed to prevent system collapse (Ref. 3). If a global economic pricing theory encompassing all costs (utility, customer, etc.) were available and implemented, it would automatically cover both economics and quality of supply. However for the present, it is necessary to distinguish between the two aspects of spot prices (Ref. 4).

The customer will respond to changing spot prices by considering those portions of his service requirements that are reschedulable and/or nonessential. The customer will respond to future forecasts (preceptions, etc.) of spot price behavior as well as the current spot price. Customers who have their own generation (solar, cogeneration, etc.) will respond in a similar fashion but by considering both the buy and buy back rates.

The second concept, microshedding, solves the dilemma of how the utility can have the direct load control that is often desirable without crossing the meter line. Under microshedding the utility and the customer negotiate a contract for quantity control in which at an agreed upon price the customer will shed a specified amount of load. It is the customer's choice as to how such microshedding load will be contracted for and, when called, specifically what operations will be shed. Microshedding is an interruptible rate that is negotiated as frequently as every few minutes or as infrequently as annually. The important concept is that the customer chooses what will be affected, the utility determines when. Again, as with spot pricing, short-term microshedding contracts would require highly advanced communications and computational facilities. Longer-term contracts would also require advanced customer control equipment if customers are to be able to respond rapidly to their contractual commitments.

The third concept, decentralized dynamic control, exploits the fact that certain electric loads are energy rather than power loads, i.e., loads that require that an average rather than an instantaneous condition be met. This includes such loads as resistive heating, melt pots, etc., as opposed to rotating machinery. Energy loads may be rescheduled within a short to medium time frame, thereby improving power system dynamics without affecting the customer's needs. For decentralized dynamic control to be effective, there are two types of information required:

- o A locally measured signal(s) indicates how the customer desire for service is being fulfilled. For example, is the temperature of the building being maintained within desired limits? Is the water level of a tank being maintained between desired limits, etc.?
- o One or several locally measured signals such as frequency, voltage, or power flows which provide information on overall power system dynamic behavior.

There are many modes of operation for decentralized dynamic control based upon the element being controlled, those particular signals/variables being sensed, and the specific governing relation used. Three particular concepts are:

- o Frequency Adaptive Power Energy Rescheduling (FAPER): Modification of power usage of energy type loads using locally measured frequency as a control input to help restore dynamic power supply-demand imbalances on the power system.
- o Voltage Adaptive Power Energy Rescheduling (VAPER): Modification of power use of energy type loads using locally measured voltage as a control input to help maintain desired voltage magnitude levels during disturbance.
- o Selective Modal Damping (SMD): Use of locally measured frequency, voltage, power flows, etc., as control inputs to provide damping of power system oscillations.

Each concept is a different approach to adjusting the load in order to improve different aspects of power system dynamic behavior.

The discussions above have focused largely on theoretical descriptions of nondispatchable technologies and Homeostatic Control. Homeostatic Control is, however, in use under other names in a number of applications both in the United States and, more significantly, in Europe. These applications have been studied relatively extensively and have been shown to be effective means of utility control. While these studies do not apply specifically to nondispatchable technologies, they are nonetheless of significance in their effective control of the interaction between customers and the utility. A summary of these are the following:

- Sweden has a complex structure for its largest industrial customers which contains many provisions analogous to spot pricing (Ref. 5).

- Great Britain adds a price surcharge during periods of anticipated supply shortfalls. This rate is applied to several hundred customers (Ref. 6).

- San Diego Gas and Electric Company calculates a demand charge at the time of system peak. This can be interpreted as a spot price (Refs. 7,8).

- Illinois Power and Light offers spot pricing as an alternative to curtailments during times of system stringency.

Although rates which are effectively spot prices have been in use for some time, the academic literature on spot pricing theory for electricity is quite sparse though there is a literature on predetermined or time-of-day pricing and in general on load control and/or load management. This literature has been well summarized by Morgan and Talukdar (Ref. 9) and others. The responsive, adaptive or spot price literature is that of Schweppe, Tabors, et al. (Refs. 1,11), Kepner and

Reinbergs (Ref. 12), Luh (Ref. 13) and high significantly Vickrey (Refs. 14, 15).

In summary the theory of Homeostatic Control, and particularly the application of spot pricing represents a proven--if only initially--concept in pricing for large industrial customers whose loads are schedulable to respond to varying prices. The utilities in the United States and in Europe have demonstrated the usefulness of such rates and have demonstrate the implementability of such rates in real time.

IV. HOMEOSTATIC CONTROL AND THE NON-DISPATCHABLE TECHNOLOGIES

As has been discussed above, Homeostatic Control is made up of a set of concepts which work to maintain a balance within a utility system. The nondispatchable technologies, specifically those which are distributed throughout the utility system are often perceived to work against this balance. Homeostatic Control offers one means to integrate the nondispatchable technologies to the utility. The section of paper which follows will discuss Homeostatic Control and its application to the new technologies for each of these time frames. Table 1 has been enlarged as Table 2 to include an expanded set of variables which relate directly to the actions of Homeostatic Control and the nondispatchable distributed technologies. For each of the time frames presented there is now a corresponding discussion of the relevant component of Homeostatic Control.

In the dynamic control time frame the new technologies have an impact upon the utility system that is heavily dependent upon their stochastic operating characteristics and upon the quality of the devices such as inverters with which such systems are interfaced with the utility (Ref. 1). Decentralized dynamic control devices are the most useful of the Homeostatic Control concepts within the dynamic control time frame. The most intuitive of these devices to work in conjunction with nondispatchable technologies is the FAPER, the Frequency Adaptive Power Energy Rescheduler, a device for sensing shifts in system frequency and thereby reacting to shed or to shift load of an individual energy (as opposed to power) consuming device. It is often argued that nondispatchable sources come on and off of the system with little warning and, as a result from the perspective of the system dispatcher, it is necessary to carry additional spinning reserve to cover the possibility that these devices will have outages cuased by environmental variations (solar insolation or wind.)* Under such circumstances the FAPER can modify energy loads in the very short run to allow for change in valve points or for starting of a gas turbine or diesel facility rather than depending upon spinning reserve. The FAPER operates by sensing small changes in system frequency. If the system frequency dips below a prespecified point the FAPER acts as a switch to slow the response of an energy demanding device thereby smoothing the short-term fluctuations in energy demand or significantly for the nondispatchables, short-term changes in energy supplies.

There is at the same time a set of significant economic issues which relate to the dynamic control time period. A recent paper by Bohn, Caramanis, and Schweppe (Ref. 4) has focused on the use of the

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*It is beyond the scope of this paper to argue that the actual level of the spinning reserves can be shown to be far less than is generally believed to be the case by many dispatchers (Ref. 16).

Table 2

Utility Time Scales and Homeostatic Control

	Technical Issues	Economic Issues	Homeostatic Control Mechanism
Dynamic Control	Dynamics given inverters with no inertia; power factor; harmonics	Real vs. reactive power	Decentralized dynamic control
System Dispatch	Relibaility and reserved	System lambda (marginal costs) spinning reserves	Spot pricing and microshedding
Unit Commitment	Reliability, system control and safety	System lambda scheduling of reserves	Spot pricing
Maintenance Scheduling	System/plant maintenance; reserves	Operating costs and reliability	Spot pricing
Capacity Expansion Planning	System reliability	Least cost operation capital availability	Spot pricing

Homeostatic Control concept of spot pricing as one means of charging for the quality of power (in terms of power factor) which is either produced by a distributed generator or consumed by a customer's facility. From the perspective of the utility there is no difference between a distributed consumer and distributed generator except in the direction of new power flow. It is important only to recognize that there is a need for the pricing of electricity to and from distributed sites to be identical, i.e., that there by no difference between buy and buyback rates and that the individual customers be charged a spot price both for the kWh consumed and for the kVarh consumed. This concept of charging for both real and reactive power is clearly not a new one on the part of the utilities; it is however different when one considers that it is being charged on a spot basis. The concept of charging for both real and reactive power again is a two-way phenomenon in that a customer who is providing capacitance to the system either through his generation or his consumption will be charged an amount different from the customer that is providing a reactive load to the system.

The second time frame of importance to this analysis is that of 1 to 10 minutes, roughly the time period in which the system operator dispatches his facilities. It is in this time frame that the concepts of spot pricing are most important and in which the role of Homeostatic Control may find its maximum usefulness for the integration of nondispatchable technologies into the grid. Spot pricing offers a means of setting an economically efficient buy and buyback rate for electric power between the small generator and the electric utility. The language that has been established in the Public Utilities Regulatory Policy Act (PL 95-617), represents the best example at the present time of the need for a system of spot prices. The language of PURPA requires that the interchange between the utility and the customer be based upon avoided costs. The interpretation of this cost level is that of short-term marginal cost to the utility, the cost that has been avoided by virtue of the fact that the small generator or cogenerator is providing electricity to the central utility. Only under the circumstances in which there is an active market for electricity between the utility and the customer can the conditions of PURPA be met efficiently.*

It should be recalled from the discussion in Section III that spot prices would be set at the marginal cost of generation corrected for distribution system conditions. Using system lambda as a basis of setting of spot prices guarantees that the utility is able to operate at its maximum point of efficiency and that customers are able to respond according to their efficiency points given the reative price of electricity and other short-term choices of fuel, i.e., storage or self-generation, and long-term choices in capital stock. In addition, from the perspective of the customer with the nondispatchable technology, the setting of prices to marginal utility costs guarantees that that customer is able to evaluate his own generation in light of the costs which would be borne were he to be purchasing electricity from the utility, or the benefits that could be gained by selling his generated power back to the utility.

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*It is beyond the scope of this paper to prove the efficiency and optimality conditions of Homeostatic Control when applied to all transactions between the utility and the customer and specifically to those between a utility and a generating customer; these conditions have been shown to apply (Ref. 4).

From the perspective of the system dispatcher, the new, nondispatchable energy technologies will appear as a diminution in the load seen by the remainder of the utility generation facilities. As a result, the dispatch process will be against a smaller load, thereby guaranteeing a lower marginal cost to all customers. From the perspective of the owner of a small, distributed, nondispatchable technology, the availability of system lambda as a spot price for energy generated will guarantee that the customer receive the market value of energy sold back. It must be remembered that the small nondispatchable generator will also be a distributed consumer and as a result his pattern of consumption will also be influenced by the availability of energy at spot or marginal prices. Given this situation the owner of a nondispatchable energy system will have the choice between consumption of his generated energy within his own plant and consumption of a net quantity from the utility and/or sales of a net quantity from his distributed generation source to the utility. Given the economic efficiency criteria the price set by the utility will influence the direction of power flows between the customer and the utility, particularly at times of high marginal costs, i.e., at peak times for the utility itself.

In the three longer-term time periods considered in Table 2, Homeostatic Control plays a further significant part in the interaction between the utility and the nondispatchable technologies. In the range in which we consider unit commitments, i.e., that of an hour to two weeks, again spot pricing and anticipated spot pricing offer a means of predicting, on the part of the utility, the availability of nondispatchable generation that will be sold to the utility at any given operating point, and the likely response of nondispatchable generators to changing utility prices as a function of the nonavailability of one or more of the major generating units. This same argument can be made with respect to the time frame of one month to one year in which maintenance is scheduled upon major plants within the utility. As is done at present, maintenance scheduling evolves around a projection of time periods in which the demand for electricity will be such that individual units can be taken off line without danger of system failure. This has generally meant that maintenance on large-scale base units is done during the spring or fall time periods. With Homeostatic Control, specifically spot pricing, the utility can estimate the quantity of electricity which a customer will be willing to sell at a given price and given weather conditions. By the same token the customer is able to project his operating schedule and his revenues from a nondispatchable technology given information about the utility's future patterns for maintenance scheduling.

In terms of long-term planning, the interaction between Homeostatic Control and the integration of new energy technologies represents a major advantage from the perspective of the potential owner of a nondispatchable technology. At the present time the vagaries of the regulatory system make the actual reimbursement for energy sold back to the utility an unknown in terms of the nondispatchable technology's owner. This is the case because while PURPA may be available at the present time, its implementation within the individual states has yet to be confirmed and fully defined. As a result, the owner of a non-dispatchablte technology cannot be certain as to the interpretation of avoided costs or the manner in which an individual utility may deal with calculation of avoided costs. In addition, there are always questions as to how regulations will change over time. This is particularly critical when one is faced with making a large capital investment, either on the utility side or on the customer side for generation technology. Given the use of spot pricing as the market for energy flow between the utility and the customer, it is possible for a customer to project forward the structure of the utility and thereby the likely operating characteristics and prices for his power. At the same time it is possible for the utility to project forward the most likely customer response to utility planning and thereby influence that planning to incorporate information about the likely amount of nondispatchable generation which will be built within the system.

V. CONCLUSIONS

In conclusion it can be seen that the structure being proposed for Homeostatic Control offers an efficient means of smoothing the economic and technical interface between the new, nondispatchable electric generation technologies and the current electric utility system. Homeostatic Control works at each of the utility time frames to offer a means for efficient integration of nondispatchable technologies into the grid. Its most powerful actions take place in the intermediate time frame when the concepts of spot pricing and microshedding can be utilized to offer an efficient marketplace for the purchase and sale of electric power between the utility and the nondispatchable technology owner.

The nondispatchable technologies represent a class of customer that is able to provide generation capability to the utility in exchange for a "fair and reasonable" return for paying the nondispatchable technology owner an amount which reflects the value to the utility of the electricity generated. In so doing the utility will operate in a real-time environment in order that the amount paid for energy be neither greater than nor less than the amount saved by the utility. The experiments completed to date with spot pricing types of rates have indicated that such rates offer significant benefits to the utility and to its customers. Application of these rate concepts to nondispatchable technologies will offer these same advantages to both parties while guaranteeing that the conditions of economic efficiency are met by both the technology owner and by the utility. The basic theoretical work has been completed for utilization of Homeostatic Control concepts as a means of integrating new, nondispatchable energy technologies into the utility system. It is necessary now to begin the live experiments required to confirm the theoretical findings.

Bibliography

1. Tabors, R.D. and White, D.C., "Solar Energy/Utility Interface: The Technical Issues," forthcoming, Energy: The International Journal.

2. Schweppe, Fred C., Richard D. Tabors, James L. Kirtley Jr., Hugh R. Outhred, Frederick H. Pickel, and Alan J. Cox, [1980] "Homeostatic Utility Control," IEEE Transactions on Power Apparatus and Systems, Vol PAS-99, No. 3, May/June 1980.

3. Outhred, H. and F.C. Schweppe [1980], "Quality of Supply Pricing for Electric Power Systems," IEEE Summer Power Meeting, Vancouver, Canada, July 1980.

4. Bohn, Roger, Caramanis, Michael and Schweppe, Fred., "Theoretical Analysis of Optimal Spot Pricing" MIT Energy Laboratory Working Paper, March 1981.

5. Camm, Frank, [1980] Industrial Use of Cogeneration Under Marginal Cost Electricity Pricing in Sweden, RAND report WD-827-EPRI, 1980.

6. Acton, Jan Paul, Ellen H. Gelbard, James R. Hosek, Derek J. McKay, [1980] British Industrial Response to the Peak Load Pricing of Electricity, RAND report R-2508-DOE/DWP, Santa Monica, California, February 1980.

7. Bohn, Roger, [1980a] "Industrial Response to Spot Electricity Prices: Some Empirical Evidence," MIT Energy Laboratory Working Paper MIT-EL-080-016WP, February 1980.

8. Bohn, Roger, [1980b] "Long Term Electricity Contracts for Customers on Spot Pricing," unpublished memo, December, 1980.

9. Morgan, M. Granger, and Sarosh N. Talukdar, [1979] "Electric Power Load Management: Some Technical, Economic, Regulatory and Social Issues", Proceedings of the IEEE, Vol. 67, No. 2, February, 1979, pp. 241-313.

10. MIT Energy Laboratory, [1979] New Electric Utility Management and Control Systems: Proceedings of Conference, MIT Center for Energy Policy Research and Electric Power Systems Engineering Laboratory, Report EL 79-024, June 1979.

11. Mitchell, Bridger, Wilard G. Manning, Jr., and Jan Paul Acton, [1979] Peak Load Pricing: European Lessons for U.S. Energy Policy, Ballinger Publishing Co, Cambridge, 1978.

12. Kepner, John and M. Reignbergs, [1980] "Pricing Policies for Reliability and Investment in Electricity Supply as an Alternative to Traditional Reserve Margins and Shortage Cost Estimations," unpublished manuscript, 1980.

13. Luh, Peter B., Yu-Chi Ho, Ramal Muralidharan, [1980] "Load Adaptive Pricing: An Emerging Tool for Electric Utilities," unpublished manuscript, October, 1980.

14. Vickrey, William, [1971], ""Responsive Pricing of Public Utility Services" Bell Journal of Economics and Management Science, Vol. 2 Number 1, Spring 1971, pp. 337-346.

15. Vickrey, William, [1978], "Efficient Pricing Under Regulation: The Case of Responsive Pricing as a Substitute for Interruptible Power Contracts," (Columbia University), unpublished manuscript, June 1978.

16. Tabors, R.D., Cox, Alan, and Finger, S., "Economic Operation of Distributed Power Systems within an Electric Utility, IEEE Transactions on Power Apparatus and Systems.

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