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DEREGULATING THE ELECTRIC UTILITY INDUSTRY

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ABSTRACT

"Deregulating the Electric Utility Industry"

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Many functions must be performed in any large electric power system. A specific proposal for a deregulated power system, based on a real-time spot energy marketplace, is presented and analyzed. A central T&D utility acts as a market maker, setting prices to equilibrate supply and demand. Decentralized competitive firms invest and operate in response to current and projected spot prices. The paper explicitly addresses the many practical engineering and economic functions and issues which must be taken into account by any proposal to deregulate electric power generation. It does not answer the question of whether deregulation is a good idea.

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I. INTRODUCTION*

This paper has two main purposes. The first is to provide a model for the presentation and evaluation of proposals to restructure electric power systems. An electric power system is complex, with many decisions being made at a variety of levels each second, hour, day, and month. Any proposal for change should specify who will make the decisions, and to what incentives the decision makers will respond. The proposal can then be evaluated by estimating how well the decisions will be made under the new structure compared with under other structures, and the welfare consequences of the resulting decisions. Most past proposals for deregulation have ignored a host of crucial decisions which will have to be made, and are therefore far from complete.

The second purpose of this paper is to present a specific proposal for deregulation, and to begin to analyze it. We feel, based on our knowledge of economic and electric power systems, that _if_ significant deregulation is desirable, it will follow the lines of our proposal. However, no one has done the full analysis of how well an electric power system would work under our or any other proposal. In Section VI we outline what we anticipate will be the key issues and some of the conclusions of that analysis when it is performed. However, at the present time WE DO NOT ADVOCATE OR OPPOSE DEREGULATION OF THE ELECTRIC POWER SYSTEM. We do advocate that it be seriously considered and studied. Only after study will it be possible to make intelligent value judgments about whether any form of deregulation, ours or another, is a good idea.

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*Our thanks for helpful coments from Arthur Berger, Michael Caramanis, Joe Pace, Richard Schmalensee and members of the MIT Deregulation/Homeostatic Control Seminar.

Using Markets to Control an Electric Power System

In any large electric power system, a variety of functions must be performed. These are listed in Figure 1. Throughout most of the United States these functions are usually performed by single, vertically integrated, regulated electric utility companies which own and control generation, transmission, and often distribution facilities. Despite the number and complexity of functions in Figure 1, this system of centralized decision and control has worked very well until the last decade. The question now is whether new conditions and new technology make alternate organization and control methods feasible and desirable.

The essence of our proposal is to replace wherever possible integrated centralized execution of most of the functions in Figure 1, with decentralized marketplace interactions. This is done by creating a real-time energy marketplace. The marketplace will be centrally administered, but the decisions to buy and sell energy will be made by individual, profit-maximizing, independent generating firms and customers, who will respond to current prices as signals. Thus the "invisible hand" of prices and the profit motive replaces direct central control. In order to achieve overall operating efficiency as good as that of central control, it will be necessary to have the electricity price fluctuate every few minutes. We call this "spot pricing" [Schweppe 1978]. Such pricing schemes are also called flexible pricing, real-time pricing and feedback pricing. Vickery [1971] appears to be the first advocate of such concepts.

Another requirement to make this marketplace effective is to divide ownership of generating units among a sufficient number of firms, to guarantee that they compete with each other. A single, regulated firm

Figure 1--Major functions which must be performed
in any large electric power system

- Investment planning: choosing what kind, where, how large, and when to build new:
  - --Generating units
  - --Transmission lines
  - --Local distribution systems
  - --End user equipment
- Unit commitment, maintenance scheduling, and fuel purchasing for individual generating plants
- Dispatching generation minute by minute, to minimize generating costs while satisfying fluctuating demand and maintaining system security, system frequency, etc.
- Coordinating dispatch with neighboring utility systems
- Operating the transmission system during normal conditions to maintain network security, minimize costs, etc.
- Controlling the overall system during abnormal conditions such as a sudden generator or transmission line outage, sustained oscillation, faults, etc.
- Choosing which customers will receive electricity during system emergencies
- Setting prices to customers
- Forecasting of future conditions.

will still control the high-voltage transmission system in a region, and perhaps the distribution system. This regulated firm will also be responsible for operating the energy marketplace. But it will not directly set prices; the forces of supply and demand at each moment will do that.

The concepts of spot pricing and decentralized ownership and control are certainly common in conventional unregulated markets, even in markets where demand or supply fluctuate radically over time. Commodity markets for grains are one example. Spot pricing is a fairly new proposal for electricity. Though spot pricing is currently used in inter-utility sales, the computation and communication methods have not, until recently, been available for the short time scales required in an electricity market of the type we are proposing. In fact, recent breakthroughs in microelectronics are a significant portion of what enables electric power generation to be removed from the category of a "natural monopoly."

Outline of the Paper

The bulk of this paper consists of a nontechnical presentation and discussion of our proposal. Section II presents the proposed structure in more detail. Sections III, IV, and V discuss how the various decisions in Figure 1 will be made under our proposed structure. Section III covers the power system dynamics issues, which will be unfamiliar to many readers but are nonetheless vital. Section IV covers short-term operations, and Section V covers long-term decisions, such as investment.

Section VI is a discussion of the relative merits of our proposed system, compared with the present centrally regulated system. Much of the controversy surrounding our proposal comes down to whether one believes that centralized or decentralized control of large, complex, stochastic systems is better. We point out the key issues, and give our opinions where we have them. Additional research will be needed to resolve these issues.

Section VII presents a possible path from our present, fully centralized and regulated system to the proposed system. The first steps of this path appear to be unambiguously desirable, whatever the merits of the proposed final system. Section VIII summarizes the major issues.

Background: Homeostatic Control and Spot Pricing

Our proposal for a deregulated power system is based on work we and others at MIT have done on controlling a traditional integrated power system. This work has developed the possibility of more sophisticated and mutually beneficial interactions between an integrated (generation, transmission and distribution) utility and its customers. These interactions would be brought about by means of an energy marketplace, using spot pricing and other mechanisms. This general approach has been named "Homeostatic Control," after the biological term "homeostasis." [Schweppe et al. 1980, Schweppe, Tabors, Kirtley, 1981]

A key result of the research on Homeostatic Control is the development of optimal spot prices for the sale of electricity to users. These spot price play a critical role in our proposed deregulated power system, since they are used for both sales and purchases of energy by the regulated transmission and distribution company, acting as a central market maker. These spot prices vary over time and by location. In a regulated system, they cause customers to follow social welfare maximizing behavior; in a competitive deregulated system, they are also the market-clearing prices. To understand how our deregulated system will work, it is useful to know how these prices will be determined. The following discussion, taken from the detailed mathematical development of Bohn, Caramanis and Schweppe [1981] and Caramanis, Bohn and Schweppe [1982], is necessarily a simplified discussion. Readers should refer to the above for greater detail.

Figure 2 lists the main components of spot prices, in either a regulated or a deregulated system. The most important is the first one, the short-run marginal generating cost at each moment. As supply and demand conditions fluctuate from hour to hour, this price rises or falls to maintain balance between generation and load. Higher price causes non-essential or reschedulable demands temporarily to back off. When total demand might exceed total available capacity, the "generation quality of supply component" becomes positive. It rises as necessary to restrain demand and avoid involuntary rationing by blackout.

Additional components of the spot price are location-specific, and reflect the need for "spatial dispatch" of a power system. That is, not only must total generation equal total load, but losses and possible overloading of the transmission and distribution system must be taken into account. For example, suppose a transmission line is being overloaded by high demand at one terminus. The spot price will rise at that terminus. This discourage demand and encourages generation at that point.*

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*The difference between the optimal spot prices at two points is the optimal wheeling charge for wheeling from one point to the other.

Figure 2--Major components of optimal spot prices

(Regulated <u>or</u> deregulated power system)

Optimal spot price at time t, location i =

short-run marginal generating cost at t

+ generation quality of supply component at t

+ transmission loss component at t for i

+ transmission quality of supply at t for i

+ dynamic quality of supply component at t for i

Note: Real and reactive energy each have their own spot prices. Real energy is generally much more important.

Finally, it is necessary to worry about dynamic behavior. This results in concepts such as "dynamics pricing" and microshedding/ spinning reserve pricing.

Spot prices calculated in this way are the socially optimal prices in any electric power system, regulated or deregulated.* What makes them important here is that they are also the prices which will arise naturally in a competitive power system deregulated along the lines we suggest.** With this in mind, we now turn to a description of our proposed approach.

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*This is subject to the standard caveats about income distribution. Also, transaction costs may lead to less elaborate variants of these spot prices being superior for some customers. See Caramanis, Bohn, Schweppe [1982] and forthcoming work on transactions costs.

**The proof of this is a dynamic version of the usual proof of the Pareto optimality of competitive equilibrium. See Bohn, Caramanis and Schweppe [1981].

II. A PROPOSED APPROACH

In this section we propose a structure for a deregulated electric power system. The essence of our proposal is that it replaces a centrally controlled hierarchical system with one in which marketplace transactions are used instead of direct commands. Central coordination is still achieved by marketplace mechanisms administered by a regulated market coordinator.

A "basic structure" associated with our proposal is presented in Section II.1. Variants of this structure may be preferable, and are presented in Section II.2. We present these variants second because the basic structure seems to be the most clean-cut and easy to understand; the variants are essentially mixtures of the present system and our basic structure.

Section II.3 gives examples of how our proposed structure would operate. Section II.4 briefly discusses other deregulation proposals.

II.1 The Basic Structure

In our basic structure, there are three main types of participants:

- A single regulated company which controls the transmission and distribution system and acts as a middleman in the energy marketplace (the T&D company).
- Many independent generating companies which sell energy to the T&D company whose territory they are in. The amount sold at each moment is up to each generating company. All sales are at the current spot price.
- The users of electricity who buy from the T&D company as much energy as they want at the current spot price.

This basic structure is shown in Figure 3.

The transmission and distribution company acts as middleman both physically and financially. It buys all the energy offered for sale at each moment, and it sells all the energy demanded to users.* It also collects all payments by users at the end of the month and pays all generating companies for whatever they produced, keeping the difference for itself as the cost of maintaining and operating the T&D system and the marketplace.

The division of key responsibilities among participants is indicated in Figure 4 which is an extended version of Figure 1. Coordination of decisions made by the different participants will be achieved under our proposal primarily by marketplace mechanisms. Profit-maximizing generating companies and users will respond to current spot prices and to anticipated future spot prices in such a way that total generation equals total demand at all times. How this will work will be discussed further in the next three sections.

We now give a more complete description of the role of each participant in our proposed system.

The Regulated T&D Company

- Builds, maintains, and operates the transmission grid and distribution systems.
- Acts as the market maker determining the proper spot price at each moment and communicating it to the independent generators

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*Sales directly from generators to users will not be forbidden. However, when spot prices are properly calculated, they will be irrelevant; customers and generators will always do at least as well by dealing only with the T&D company.

FIGURE 3 BASIC MARKETPLACE STRUCTURE

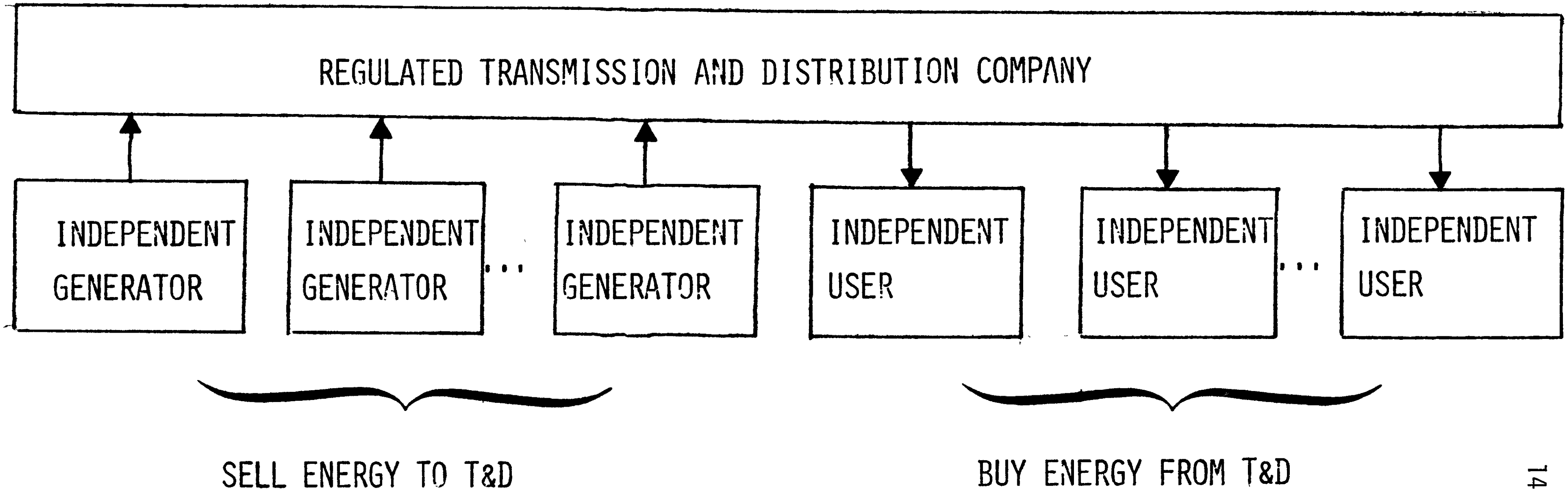

Figure 4

Division of Key Responsibilities Under Basic Deregulated Structure

	Central T&D Company*	Generating Companies	End Users	Marketplace "invisible hand"
Investment Planning				
Generation		X		
Transmission	X			
Distribution	X			
End User			X	
Unit Commitment, etc.		X		X
Real Time Dispatch		X		X
Coordinating Dispatch With Neighbors	X			X
Transmission System				
-normal operation	X			
-abnormal operation	X			
Allocating Electricity During Emergencies			X	X
Setting Prices to End Users	X			X
Forecsting Future Conditions	X	X	X	

*Acting under regulatory oversight.

and customers.

- Controls the stability of the electrical system through a combination of pricing and direct control of certain physical attributes.
- Collects money from users and pays money to generators.
- Is regulated in a traditional "rate of return" framework, so that its net revenue increases only if it builds more transmission or distribution lines or has an increase in operating costs.

Regulation of the T&D company is subject to many of the problems of today's regulatory environment. However the T&D will be significantly smaller than today's regulated utilities and hence regulation affects less of the delivered cost of electricity.

Generating Companies

- Build, maintain, and operate generation and storage units.
- Sell electricity to the T&D at the current spot price.
- Have to meet zoning, environmental and other restrictions like any industrial firm.
- Are not subject to regulation by Public Utility Commissions.
- Are barred by antitrust laws from explicitly cooperating with other generating companies in their area.
- Are barred by antitrust laws from owning too many units in one region.
- Are motivated by profit maximization.
- Are channeled by this motivation and by the energy marketplace to act in socially beneficial ways.

Today, ownership of generating units is based on geography. One utility owns almost all the units within its service territory. In contrast, we anticipate that in a competitive environment ownership will be based on functional type. Different generating companies will specialize in constructing and operating different plant types. This allows them to develop expertise, for example, in coal or nuclear power, instead of having to maintain proficiency in all generating systems even though they may operate only one nuclear or one coal power plant. This is analogous to the situation in conventional industrial markets. For example, one company owns and operates many plants across the country which make a particular type of plastic. It has some direct competitors which make the same type of plastic, and other indirect competitors which make entirely different kinds. Throughout the economy, competitors own geographically scattered plants. The structure of generation ownership could change from the over 200 local monopolies of today to a smaller number of interspersed competitors. Even with this consolidation, the electricity generation business would be less concentrated than many other industries in this country. We expect that many non-utility industrial firms would integrate backwards into generation.*

<u>Users</u>

- Build, maintain, and operate energy using equipment as before.
- Buy electricity from the T&D system.
- Pay the current spot price if they are large users.
- Sell any excess energy they self-generate to the T&D system.
- Decide when to voluntarily ration themselves in response to high

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*This is observed in Sweden [Camm 1981]. In the Swedish case, many industrial firms own generating subsidiaries some for internal load, some for public sales.

spot prices.

Electricity is used in a bewildering variety of ways. Some users have opportunities to cogenerate electricity and steam; others can store electricity in various forms (including thermal, mechanical, and chemical energy) and rescheduling the time of usage. Users who are willing to pay the additional metering costs should be allowed to participate in the open energy marketplace on an equal status with generators.

In addition to the three main types of participants, we envision other firms/entities coming into existence to make a spot marketplace work more smoothly. These include information consultants and energy brokers.

In any marketplace, knowledge about future prices is valuable. Short-range spot price forecasts will depend mainly on the weather, and just like weather there is no need for each firm to make its own forecast of the spot price. We envision small, independent companies called information consultants coming into existence. For a fee, they will forecast the spot price for both the short and long terms (hours to years). Of course, the regulated T&D company and many energy generation will make their own forecasts.

Just as for many commodities today, there may be a role for long-term futures contracts for electricity. Such contracts will allow firms (generators and users) to "lay off" the risks of long-term price fluctuations (Section 5.3). Energy brokers will go into business to bring buyers and sellers together. If there is enough demand, an organized futures market might exist. Although the T&D company could act as the broker and could take either side of a futures contract, it will be "cleaner" if the T&D does not become directly involved, to avoid possible conflict of interest charges and to avoid exposing itself to risk by taking a net short or net long position.

For the ease of later discussion, it is convenient to conceptually view the regulated T&D company as containing two parts:

- T&D network
- Market coordinator.

The market coordinator function brings together the complex of computers and human beings who operate the overall energy marketplace, i.e., the brains.

Figure 5 is an expanded version of Figure 3 which shows all participants of our basic deregulated generation structure.

II.2 Alternative Structures

Our proposed approach is not limited to the basic structure of Section II.1. Many variations are possible.

An obvious change is to separate the regulated T&D company into one regulated transmission company and many distribution companies which could be municipals, cooperatives or regulated private companies. These distribution companies would act like middlemen who buy power from the regulated transmission company and sell it to the users. We have chosen our basic structure with a combined T&D company because it is simpler to discuss the basic concepts without worrying about another layer of transactions. There are 2,900 municipal and REA cooperatives in existence today and it is unlikely that the number would decrease.*

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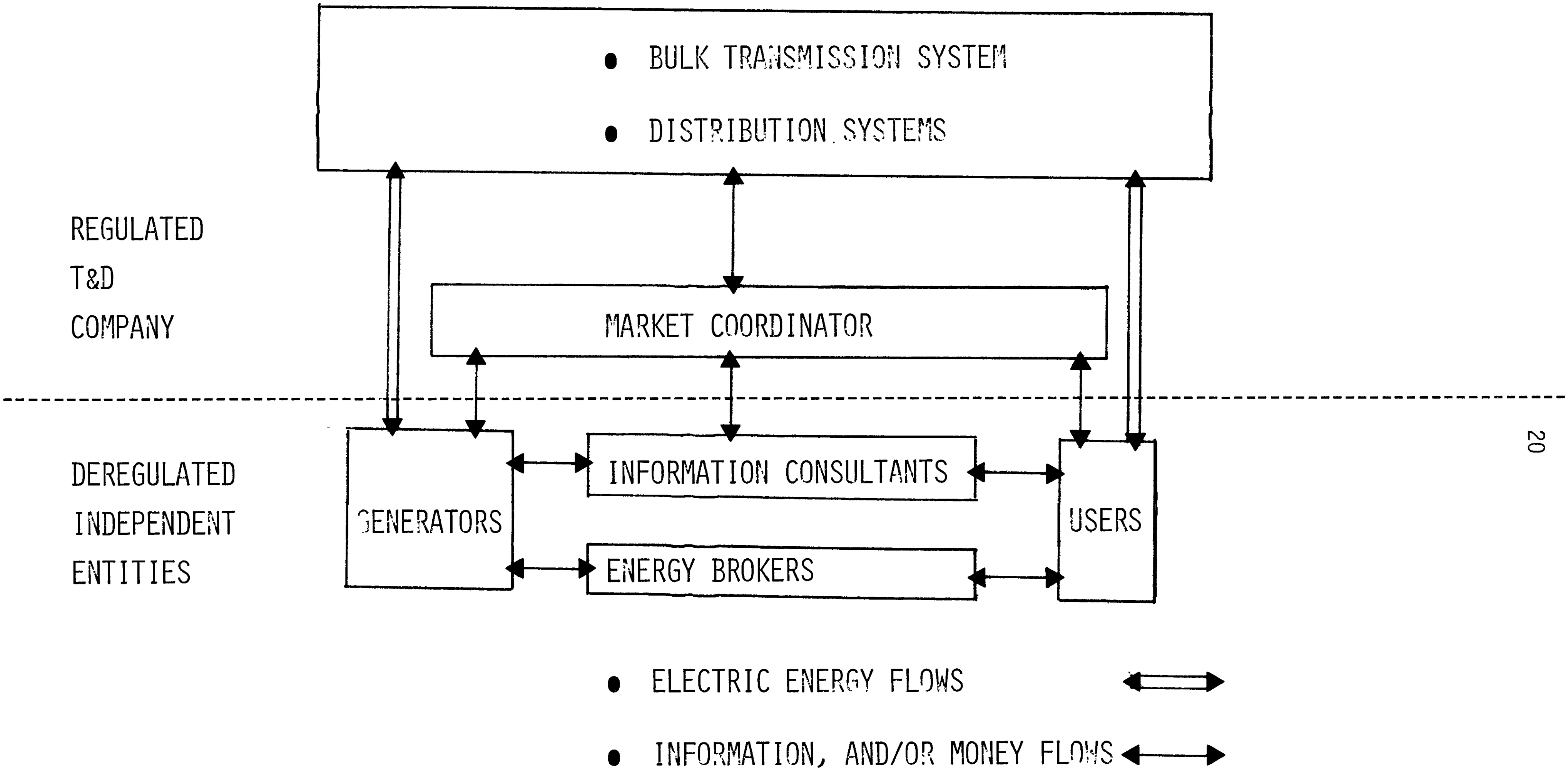
*The number of independent distributorships might even increase beyond the existing 2,900 if the distribution networks currently under the private utilities' ownership opt to break off as independent municipal entities.

FIGURE 5 BASIC MARKETPLACE STRUCTURE: EXPANDED



More significant changes involve the ownership of generation and transmission. Figure 6 compares four types of structures for the generators, users, and transmission system. Cases A and B are today's structure and the basic structure of Section II.1 respectively. Case C is the "ultimate" in deregulation; all transmission lines are owned and operated by private companies. We feel that Case C is very unlikely to be workable because of the likelihood of strong spatial monopolies being established. The case of a mixed structure (Case D) is of most practical interest in the near term. Almost any reasonable scenario involving evolution of today's structure (Case A) to a deregulated structure such as Case B has to move through one or many mixed structures. Furthermore, practical issues such as the cost of doing marketplace transactions, political concerns and capital availability factors may mean that the final deregulated system will be of a mixed type.

This paper emphasizes the working of an energy marketplace assuming the basic reference structure of Case B simply because it is easier to comprehend. Discussion of a mixed structure (Case C) should not start until after the basic reference structure of Case B is well understood. The mixed structure is easy to understand after looking at the basic structure.

II.3 Examples of Operation

We have found it useful to give some concrete examples of how our deregulated system would function and to compare this behavior with what would happen under the present regulated system.

Example 1: A sudden temporary outage of a large generating unit.

Under our deregulated structure the spot price increases

Type of Structure	Generation	Users	Transmission
A. Today's	o All regulated	o All see pre-specified prices	o All regulated
B. Basic Reference	o All private companies seeing spot prices	o All see spot prices	o All regulated
C. Completely Deregulated	o All private companies seeing spot prices	o All see spot prices	o All privately owned, operated
D. Mixed	o Some private Some regulated	o Some see pre-specified prices o Some see spot prices	o Mostly regulated o Some private ownership

Figure 6

Different Types of Structures

immediately. Generating units which were already on line increase their output to the maximum. Users' process control computers automatically delay the "on" cycle of air conditioners, refrigerators, furnaces, heaters, and similar equipment. Other generators begin to bring their units on line, although for some units this can take several hours. Owners of reservoir hydro units open their sluices to increase production. If the outage is severe, the regulated T&D company exercises some of its spinning reserve interruptible contracts for the first few minutes. (See Section 3.)

These measures gradually bring down the spot price, which continues to decline as more units come on line. If the spot price remains quite high, some customers close down portions of their plants to save money. Eventually, equilibrium is restored at a higher spot price than before the outage.

With regulated utility system, the same sequence of events occurs except there is no user involvement or response. Thus higher reserve margins must be maintained to give the same reliability level.

Example 2: A nationwide government order to shut down nuclear units

If all nuclear units are ordered closed, under our deregulated structure the spot price rises, especially in regions with significant nuclear capacity, and especially during periods of peak demand. Owners of non-nuclear units reap "windfall" profits, which is their reward for guessing right. Owners of the nuclear units take a huge financial beating. That is a virtue (or defect) of free markets--those who guess wrong, lose. Even in areas with little nuclear power, the spot price rises somewhat, as more energy is sold to regions with the government-induced capacity shortage. Interregional reallocation happens automatically since each regulated T&D company is connected with similar neighboring utilities.

All customers end up paying higher spot prices in the immediate aftermath of the shutdown. But entrepeneurs rush portable generating units into the areas with the highest prices. If the need/profit opportunity is large enough, gas turbines could even be brought in by ship and airplane from other locations. Construction of new non-nuclear units is accelerated by profit-seeking entrepreneurs.

This deregulated scenario contrasts favorably with what would happen under the current regulatory system. Obviously, under either regulation or deregulation, a nuclear shutdown entails severe economic costs to the nation. But under regulation, utilities with nuclear units also have to burn oil, coal, and natural gas for their non-nuclear units. Customers have to pay for this additional fuel, even while they may still be paying for the capital costs of the temporarily useless nuclear units. The price of electricity could rise even higher than under spot pricing. Moreover, under the current regulatory system, utilities with the nuclear units experience immediate financial problems. They are not likely to be able to rush out and finance new capacity. Their access to the capital markets is severely limited. Moreover, because of exclusive service territories, healthier corporations which have the resources and desire to enter the market are prohibited. Thus, the only firm with the right to build new capacity is unable to act, while capable firms are not allowed to act. And although a considerable regional re-allocation of electricity probably would take place, it is subject to institutional barriers and regulatory interference. Lastly, whatever electricity is available is not allocated efficiently because spot pricing is not available to ensure that it goes to those who value it the most.

II.4 Other Deregulation Proposals

Various other authors have proposed deregulation. Pace [1981] reviews much of this literature. Recent discussions of deregulation include Hyman [1981], Schuler and Hobbs [1981], Schulz [1980] and Stelzer [1981]. Discussions in the popular press include Emshwiller [1981], Levy [1981], and Radin [1981].

One proposed approach to actual deregulation is to have large, government-owned or regulated transmission and distribution companies which buy power from independent, privately owned generation companies under predetermined long-term contracts [Landon and Huettner 1976; Cohen 1979]. A second approach is simply to "apply PURPA to all new plants." Presumably this means that existing electric utilities are allowed to build new plants (perhaps owned by captive subsidiaries) which sell power back to the parent utility at the "avoided cost," buyback prices specified in PURPA [Alm 1981].

Published versions of these proposals are unspecific about how the various functions in Figure 1 would be performed, and by whom. It is therefore difficult to evaluate them. Pace [1981b] discusses general proposals to "use long-term contracts." He suggests that a centralized mandatory control system would still be necessary in such systems, for example, to handle generation dispatching. We generally agree that fixed price long-term contracts cannot be the central method of purchasing energy in any truly deregulated system. If fixed-price, fixed-quantity, long-term contracts are used, there will be no way to dispatch the system properly. (However, such contracts may be a useful supplement to a spot market. See Section V.3). If fixed-price, variable-quantity contracts are used, the resulting system will be effectively like the present centrally controlled system.

Various elements of other deregulation proposals may nonetheless be useful and consistent with our proposal. For example, properly written fixed-price, fixed-quantity contracts may supplement a system based on spot prices. They will permit risk shifting without affecting the efficiency of "invisible hand" marketplace coordination. Similarly, "applying PURPA to new plants" may be a useful transition strategy, _if_ PURPA prices are properly calculated as optimal spot prices, and _if_ the new plants are not owned by the existing integrated utility. One factor which sets our proposal apart is that we think that operational management and control of generating facilities should be dispersed among firms. Our generating firms will be independently owned _and_ operated.

We would like to see other fully articulated deregulation proposals. When they are presented it will be possible to analyze them further, using a framework analogous to Section VI of this paper.

III. SYSTEM DYNAMICS: (0 to 5 minutes)

This is the first of three sections which discuss in greater detail the operation of the electric utility system under our proposed system of deregulation. The sections are divided by time frame; the first covers periods of less than five minutes. Here we discuss a set of economic incentives which encourage the "proper" response by both users and generators to maintain satisfactory dynamic behavior. Alternately it is possible to consider mandating proper response through a system of standards. These are not discussed here though clearly they can be developed for handling certain aspects of system dynamics.

The type of power system dynamics to be discussed in this section is of primary concern to power system engineers. Other readers of this paper may not be familiar with the issues and hence may wish to just skim this section before proceeding with later sections which deal with operating and long-term economic issues.

III.1 Pricing Tools for Dynamics

The market coordinator will use two basic types of market pricing tools to handle power system dynamics:

- Dynamics pricing
- Microshedding and spinning reserve options

Two basic approaches to "dynamics pricing" are

- Time Response Pricing: Economic incentives are based on the explicit time history of a generator's or user's response to a particular situation.
- Dynamic Characteristic Pricing: Economic incentives are based on a generator's or user's general behavior characteristics.

One example of "time response pricing" is to pay users extra when system frequency is deviating significantly from 60 Hz if they decrease demand when frequency is low and increase demand when frequency is high. An example of "dynamic characteristic pricing" is to pay generators less if their equipment tends to cause low amplitude, lightly dampened power system oscillations. Another example is to charge users whose equipment generates harmonics.

Dynamics pricing is a way of using economics to motivate generators to install governors, voltage regulators, etc., which help the power system's dynamic behavior. However, it also motivates users who have energy loads rather than power loads. Energy loads require that an average rather than an instantaneous condition be met. This includes such loads as space conditioning and melt pots, as opposed to rotating machinery, lights, and computers. Energy loads may be rescheduled for seconds to minutes to improve power system behavior without affecting the customer's needs. For such load control to be effective, two types of information are required:

- A locally measured signal(s) which 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 within desired limits?
- One or several locally measured or provided signals such as frequency, voltage, or power flows which provide information on overall power system dynamic behavior.

The Frequency Adaptive Power Rescheduler (FAPER) is a device which illustrates these concepts and which has been built in our laboratory

[Schweppe et al., 1980]. This device is based on a small microprocessor which accepts a temperature or water level measurement, measures local frequency, and then takes the appropriate action.

Microshedding [Kirtley and Sterling, 1979; Schweppe, Tabors, Kirtley, 1981] is a mechanism for load shedding which permits the customer maximum autonomy. Under microshedding the regulated T&D company and the customer will negotiate a contract for quantity control under which the customer will shed a specified amount of load at the option of the market coordinator. It is the customer's choice as to how such microshedding load is contracted for and, when called, specifically what operations are shed. Microshedding is an interruptible rate that is renegotiated 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. Microshedding can be viewed as a method for a customer to buy the particular mixture of firm and non-firm (microsheddable) energy that fits the customers' needs. The analogous supply concept to microshedding is contracts between the generators and market coordinator involving "spinning reserves." These will give the market coordinator rights to command rapid surges of power from the generators.

The choice between influencing generator/user behavior by using predetermined spinning reserves and microshedding contracts, or by using dynamics pricing is not clear-cut. For example, both approaches allow users to choose their own reliability level, and are therefore preferable to the current situation where all customers pay for a very high level of reserve capacity, no matter how much they value such capacity. Microshedding provides a means for the T&D to get advance information about how users will respond in the event of a disruption. Such advance information has value, compared with relying on dynamics pricing. But by the same token, signing a microshedding contract precommits users to behave in certain ways which is costly to users because it makes them less responsive to changes in their own internal situation.

III.2 Examples

Engineers on today's electric utility systems are concerned with problems such as:

Long-Term Dynamics: Interaction between generation and load at a seconds to minutes time scale involving boiler-turbine dynamics, average system frequency, etc.

Dynamic Stability: Low amplitude, sustained oscillations or light damping involving interaction between loads and individual generators, exciter systems, governors, etc., through the transmission network.

Transient Stability: Response of generators and loads to major large amplitude disturbances such as result from lightning strikes on transmission lines, and subsequent relay-controlled circuit-breaker opening and reclosing operations.

Load Frequency Control (or AGC): Maintenance of system frequency and tie line flows within acceptable limits.

These four areas are briefly discussed as examples illustrating how system dynamics can be handled under deregulated generation.

Long-term dynamic controls will be provided partly by dynamics pricing but major control action will be obtained when the market coordinator exercises its spinning reserve or microshedding options. Microshedding will often be faster and more responsive than using spinning reserves.

Dynamic stability problems will be handled in several ways. For unexpected dynamic stability oscillations which occur without advance warning, spot energy prices will be used to readjust the generation load patterns so as to remove the conditions causing the instabilities. In the longer term, dynamic pricing on the characteristics of the various independent participants will be used to remove the basic causes of the dynamic stability problem. For example, if a particular generator has dynamic characteristics which aggravate unstable system behavior, that particular generator will be charged an extra premium for connection to the network until it modifies its characteristic behavior.

Under deregulated generation, transient stability will be of less concern than it is presently. Major power plants and loads will be protectively relayed so that protection of their own equipment is of prime concern. There will be much less emphasis on control systems which always try to keep a generation plant in synchronism with the rest of the system. With the marketplace mechanisms, the premiums to maintain individual generation connected to the grid at all times are greatly reduced because their loss is easily compensated for (at a second to minute time scale) by short-term load rescheduling.

Load frequency control (or automatic generation control) can be viewed as either a system dynamics or system operation issue. Here we discuss it under system dynamics. Under deregulated generation, the nature of the control will depend on the spatial extent of deregulation. If deregulation occurs in only one portion of the country, the market coordinator for that region may compute an area control area based on frequency and tie line flow directions similar to today's operation. In this case the regulated T&D company can "look the same" to the interconnected neighbors as it does today. In a more fully deregulated situation, individual market coordinators will simply treat their neighbors in a fashion similar to any generator or user. In either case, the market coordinator will send out "control signals" to both generators and loads for them to adjust as desired. The generators and loads respond because dynamics pricing makes it economically advantageous to do so. The signals will go to loads as well as generators so that both can respond depending on their relatively efficiencies and costs. The correction of the time errors will be done with spot pricing.

Overall, the use of marketplace pricing mechanisms in place of centralized ownership and control does not radically change power system dynamics. The biggest difference is that users as well as generators participate in system dynamics control. Another difference is the increase in communication, metering, and computational costs necessary to implement the use of economic incentives for obtaining satisfactory system dynamic behavior.

IV. SHORT-TERM OPERATIONS: (5 minutes to hours)

Today utility system plants are dispatched at a time frame from 5 minutes to several hours in order of their increasing marginal operating cost subject to constraints on system security.* This is called economic dispatch. Its objective is to minimize total operating costs while meeting the load. A centrally dispatched utility system or pool is generally considered to be an economically efficient operating system. Within this time frame, therefore, the objective of a deregulated generation structure is to mimic as nearly as possible the economic dispatch of the centralized system. Spot pricing fulfills this requirement. The general mathematical theory for optimal spot pricing of Bohn, Caramanis, and Schweppe [1981] and Caramanis, Bohn and Schweppe [1981] is summarized in Figure 7 (which complements Figure 2). A heuristic development of the quality of supply aspects is given in Outhred and Schweppe [1980].

IV.1 Use of Spot Pricing to Coordinate Generation and Load

The market coordinator will try to keep supply and demand in balance by continuously adjusting the spot price. On the generation side, for example, the appropriate spot price will be set low enough on nights when demand is low so that only generating units with low operating costs stay on line (e.g., nuclear or wind powered units, and perhaps some coal fired units). As demand rises during the morning, the spot price will also rise. Less efficient units will begin generating. Eventually, the spot price may rise to the point where owners of pumped hydro units and other electricity storage forms begin selling back energy which they had

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*This rule is not applied in environmentally sensitive areas in which dispatch may be, for example, to minimize NO_x.

SUMMARY OF OPTIMUM SPOT PRICING THEORY

Figure 7

- IF
  - Generation-transmission-distribution outages, weather, and customer desire are exogenous random variables
  - Decisions on real and reactive energy generated and used by each participant are constrained by
    - Individual device capacities
    - (Total generation) - (Total usage) - (Losses) = 0
    - Network Constraints
      - Line Flows
      - Voltage Magnitudes
  - Criterion of optimality is to maximize

    Global Social Welfare = Value to User - Cost of Fuel for Generation - Investment Cost
      - Generation
      - Network
      - Usage

  - Communication/Computation Costs are ignored.

- THEN
  - Optimum behavior results if each individual participant maximizes own welfare given a spot price for energy (real and reactive) set by:

    Spot Price = Marginal Fuel Costs + Quality of Supply + Losses

  - Quality of Supply is not zero if
    - Insufficient generation is available or
    - Network contraints are active
  - Spot prices are equal for generation and usage

COROLLARIES

- Optimum spot price involves
  - No demand charges
  - No capacity credits-debits
  - No backup charges
  - No ratchet clauses

- Ideally, generation investment costs are covered from net revenues

- Ideally, T&D operating and investment costs are met from

  Net Marketplace Revenue = Total Money Paid by all Users - Total Money Paid to all Generators

  = loss revenues plus network quality of supply revenues purchased and stored during the night, and gas turbines begin to come on line.

Because the spot price is an energy price, how, it is often asked, can investors in generation recover their investment? This is discussed in Section V.

On the demand side some users will find it advantageous to pay the spot price, rather than a predetermined price. They will reschedule their electricity intensive operations to times of low spot prices.

Applying spot pricing to users has the additional advantage of providing a way to avoid rotating blackouts or voltage reductions. With today's regulated system, it is impossible to provide enough generation to meet demand 100% of the time. Under conventional pricing this means that some users must involuntarily do without any electricity. Spot pricing, on the other hand, ensures that customers voluntarily curtail their least critical uses of electricity as the price rises. If enough customers are on spot pricing, then rotating blackouts due to capacity shortages do not occur. As the spot price rises demand falls enough to equal available supply, just as in any other commodity market where the price is allowed to adjust freely.

IV.2 Security Monitoring and Control

Security is the ability to avoid major disruptions. Under deregulated generation, the market coordinator will perform security functions such as contingency evaluation, state estimation, etc. just as is done today. It will use the available reactive control inherent in the network as much as possible to maintain voltages within limits. However, when the voltage control capabilities of the network are exceeded and/or when line flows are exceeding or are predicted to exceed their thermal or dynamic limits, the generation and usage patterns of the various participants will be changed by introducing transmission quality of supply components into the spot price for energy.

Today's control centers try to maintain sufficient generation reserve so that the system can respond to major unexpected losses of generation, tie-line support, etc. Under deregulated generation, the market coordinator will be responsible for the maintenance of such reserves. However, the reserves will be carried on both generation units and on load units (microshedding) in short-term option contracts which can be exercised as needed (see Section III).

IV.3 Specification of Spot Prices

As the market maker, it will be the responsibility of the market coordinator to specify the spot price and to make it available to the generators and users of electricity. The mathematical theory underlying Figure 7 tells us what the price should be in an idealized world. The following discusses how it will be specified in practice.

As background, consider first the case of a regulated generation-transmission-distribution utility whose customers are on spot pricing. In this case, the utility's control center knows the operating cost characteristics of all the generators so the "marginal operating costs" component of spot price in Figure 7 is computed by formulae very similar to those used in today's economic dispatch (marginal cost is effectively "system lambda"). Similarly, effects of losses are calculated by well-defined formula. When demand tries to exceed supply, the quality of supply component is added to the computed marginal operating cost component. The mathematical theory relates this quality of supply component to the marginal "production cost function" of the various customers but the regulated generation-transmission-distribution system does not have access to such information. Thus instead of solving explicit equations, the control center determines the quality of supply component empirically; i.e., observe how the demand responds to different prices at different times and thus learns by experience how to set the quality of supply component.

In the basic marketplace structure of prime concern here, all generation is deregulated so the regulated T&D company's market coordinator will not have access to the operating cost characteristics of the individual generators. Hence for deregulated generation case, the marginal operating cost component of spot prices will be determined empirically, just like the quality of supply component, by using observations of behavior to learn how it should be set. Since the market coordinator does know the details of the transmission and distribution system, the spot price losses and T&D quality of supply terms will be determined by well-defined equations.

The mathematical theory says that, ideally, generators' and users' spot prices should be updated at the same time and that because of the losses and T&D quality of supply terms, generators and users located at different points of the network should see different spot prices. In practice, it will be necessary to consider computation and communication costs. Thus, in actual implementation, various approximations to these theoretical best formulae will be used. In general, large generators and users will receive frequently updated spot prices (say every five minutes) based on reasonably accurate loss, etc. formulae. Smaller participants will tend to see less frequent, real-time updates based on more aggregated equations.

As will be discussed more later, the spot pricing theory summarized in Figure 7 does not involve any explicit constraints that the prices be such that capital costs are recovered. This is as it should be for deregulated generation. However the regulated T&D company is assumed to be operating under a "guaranteed rate of return" and it is unlikely in the real world that "net marketplace revenue" will actually match the regulated T&D company's operating and capital costs. Thus it is necessary to provide some T&D surcharge or refund mechanism in addition to the spot prices themselves. One obvious criterion in the choice of this refund-surcharge mechanism is to try to minimize the impact of such refunds or surcharges on the operating decisions of the generators and users. There is no perfect way to do this but a variety of approaches can be used. In practice, we do not expect T&D based refund-surcharges to have significant impacts on short-term system operating efficiencies.

Another criterion in the specification of refunds or surcharges is the maintenance of incentives for the regulated T&D company itself to operate and plan efficiently. Regulation of a T&D company which acts as a market maker will present different problems than today's regulation of vertically integrated generation-transmission-distribution companies.

An obvious question arises. Is there a loss in generating-operating "efficiency" by using deregulated generation? The answer is no if the empirically based spot price is determined exactly. In practice it is not obvious whether deregulated empricial spot pricing will be superior or inferior to centralized computation based on explicit generator marginal operating cost characteristics. Both are subject to errors of various types. However, in neither case are the errors expected to be very large. Naturally, the inclusion of users in the energy marketplace via spot pricing can only increase overall operating efficiencies. Also, in our basic structure there will be automatic coordination of generators in different utility territories, analogous to the coordination by members of a large power pool. This will increase operating efficiency in regions which previously did not use pooled dispatch.

V. LONG-TERM OPERATIONS (HOURS TO YEARS) AND PLANNING (1 TO 20 YEARS)

V.1 The Generic Problem

Long-term operations (hours to years) and planning (1 to 20 years) for any electric power utility require the same basic structure. At each moment it is necessary to forecast forward a set of critical variables. Decisions are made based on the forecast. At the next moment the forecasts are compared with actual events, new forecasts are made, and the decisions made are evaluated and possibly altered. Then the process is begun again.

The generic notion of this process is the same whether it is done by a single regulated generation transmission and distribution utility or in the basic deregulated generation marketplace structure of Section II-1. However, major differences lie in the nature of the variables being forecast.

V.2 Forecasting in a Deregulated World

In the utility system of today all of these forecasting and decision activities are undertaken by the central utility--in theory acting as a single decision maker. Demand and equipment availability are the critical variables forecast for unit commitment, plant maintenance and fuel purchases decisions. For longer-term investment planning decisions, other variables such as future fuel prices, the cost and availability of capital, labor conditions and the possible availability of alternative generation technologies are also forecast.

Under the basic deregulated generation structure of Section II.1, separate forecasts will be made by the individual generation companies and the regulated T&D Company.

Each individual generation company will base its own unit commitment, plant maintenance, and fuel purchases on forecasts of future spot prices over the appropriate time span. These spot price forecasts replace the demand and unit availability forecasts used in the regulated case. Similarly, individual generation investment decisions will be based on the same variables used in the regulated case (fuel prices, capital prices, etc.) except that spot price forecasts replace demand and unit availability forecasts.

The regulated T&D company has to make long-run maintenance and investment decisions based on the expected future demand and generation patterns. Since with deregulated generation, the regulated T&D company will not have direct control over future generation investments, it must forecast both the generation and the demand patterns.

All of these various forecasts are done in the same generic way. A "model" is developed from observation of past behavior. Such a model may be informal or a sophisticated computer program. In order to yield a forecast for the variable of concern, such models usually require exogenous inputs of expected future weather, economic conditions, etc. which are forecast separately. Obviously the introduction of deregulated generation requires some new classes of models to be developed. The development of these models will require extensive development but no fundamental problems are foreseen. The basic statistical and mathematical modeling techniques are available today. The necessary data will become available at an appropriate rate as the actual, gradual evolution of the power system into a deregulated configuration takes place.

A key question concerning the desirability of deregulation is whether the necessary forecasts and resulting decisions will be better or worse than under the present system. As with many issues associated with deregulation, we cannot give a precise answer. Different factors influence the argument in different ways. For example, it has been argued that since one generation company does not necessarily know the plans of the other generation companies, it is more difficult to forecast future spot prices than to forecast demand and unit availability separately. On the other hand, price feedback will be stabilizing which will tend to make spot prices easier to predict than demand. Furthermore, to the extent that futures markets exist, they will forecast the spot prices*.

In both the regulated and deregulated worlds, multiple year forecasts involve large uncertainties. One definite advantage held by the deregulated case is that many different, independent forecasts and subequent decisions will be made. Thus decision errors will tend to cancel out. Some individual generation companies may go bankrupt because of forecast errors but others will not make the same forecasting errors.** This is more desirable than the centralized case where a single company's forecasting errors can influence all of the generators in a given part of the country.

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*This is discussed in Grossman [1981]. He proves, under certain assumptions, that a central planner with all the economy's information could plan no better than a competitive economy where each participant has access only to information about its own plans. This theorem requires rational expectations, and also, unfortunately, a complete set of futures markets.

**Bankruptcy of its owners will not in and of itself disrupt the operation of a generating unit. If the electricity it can produce is more valuable than the fuel it uses, it will continue to operate, under new management.

An argument in favor of centralized forecasting and against the deregulated case can be based on the cost of individual generation companies maintaining good forecasting staff and capability. A counter argument is that we expect "Information Consultants" to enter the energy marketplace to fulfill such needs. If a projection of the trends for spot prices over the next week, month, or ten years is desired, it may be more practical to purchase the services from an existing information consultant than to create it in-house. Given a reasonable demand it is likely that a set of these consulting services would spring up to compete with each other. The better the track record on prediction of spot prices, the more clients and therefore the more financial success of the consultant.

V.3. Risk and Long Term Contracts

The risks borne by generators and users will be different under our proposed structure than they are today. Under deregulation, it will be easier for marketplace participants to shift risks they do not want to bear. This shifting can be achieved through long-term forward contracts. These contracts will not affect the operation of the spot energy marketplace or of the T and D company. These contracts will be purely financial contracts, not directly related to production.

Generating electricity is a risky business in the present system or a deregulated system. At present, a large cause of risks is regulatory action or inaction in response to changes in demands and costs. In a competitive marketplace, prices will adjust automatically as conditions change. These price changes can help or hurt a firm. Prices may drop below the level that some generators require to cover their capital costs if spot prices drop relative to operating costs for a sustained period of months or years. Such sustained drops are possible if demand falls or if competitors build unanticipated new generating units.

Long-term forward contracts will permit generators to hedge some of this risk.* Such contracts will be purely financial instruments, just like commodity futures contracts in agricultural and metals markets. They may be purchased, in theory, by producers, customers, or speculators. They will not affect the efficient operation of the spot energy marketplace, since they will be based on fixed quantities of energy at fixed prices.

A simplified example illustrates how these contracts will work. Suppose firm A sells to firm B a series of forward contracts for 200 MWh of energy each hour for the next five years, at a price of $50 per MWh. The actual spot price of that energy will still vary hour by hour; exactly how much is uncertain. Each hour, the two firms close out that hour's contract by comparing the actual spot price with the agreed-on forward price for the hour. For example, if the spot price turns out to be $60 per MWh (6¢/kwh), firm A pays firm B $2000, or (60-50) x 200.

Owning generation equipment automatically puts the firm into a "long" position in electricity. Generators could hedge this long position by going short with forward contracts, i.e., taking the role of Firm A. Conversely a user or distribution company could hedge their implicit "short" position by going long, i.e., buying forward contracts. For example, "Firm A" might own a 200 MW coal-fired power plant. It might

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*Another protection against this is geographic diversification. A single company can build generating units in many regions, thus diversifying the risk of sustained price fluctuations in one region.

want to "lock in" the $50/MWh price to satisfy lenders. When it signs the forward contract, its net revenues each hour are then composed of two parts. One is a financial gain or loss from closing out the forward contract This gain or loss is almost completely independent of how much it generates.* The other part is its net revenues earned by generating electricity, which depend on the actual spot price paid by the T&D company minus its variable operating costs. Thus hour-by-hour dispatching should not be affected by the existence of a forward contract.

If the spot price is too low, the firm won't generate; but in that case, it still gains revenues from the futures contract. For example, suppose the spot price one hour is only $10/MWh. B then pays A $8000, or (50-10) x 200, <u>regardless of how much A generates or how much B consumes that hour</u>. Generator A can only sell its output for $10/MWh. If this is less than its incremental generating cost, it will remain shut down for the hour. Therefore, it earns nothing from generating electricity that hour. However, the $8000 gain on its contract fully hedges A against the change in the electricity price. Conversely, B can buy energy for only $10 per MWh for that hour; but it pays out $8000.

If the spot price is high, firm A generates at 200 MW and makes larger operating profits. However, it loses on the futures contract. Thus, in effect, it gets to keep only $50 per MWh generated. The T&D company need not be involved or care that firms A and B have a forward contract between them.

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*Under perfectly competitive assumptions or if the generator is very small relative to the system, the gain or loss is completely independent. If the plant is large or the market is imperfect, the firm could affect the spot price.

Will a forward market come into existence? This depends on whether potential participants value risk reduction more than the transactions costs of operating such a market. These contracts might improve the availability of new capital in a deregulated market. "Energy brokers" will be useful to bring buyers and sellers of these contracts together in an efficient manner. Judging by recent experience with bulk commodities, it is likely that forward markets will spring up.

VI. THE ECONOMICS OF DEREGULATION

Regulatory intervention in a market is generally undertaken to change its performance. In response to problems with electric power in the 1920's, public policy was used to change the free-market status quo. In response to the conditions of the 1980s it may be appropriate to return to the free market. Section II summarized our overall approach while Sections III, IV and V provided details on time scales varying from fractions of seconds to many years. During the discussion, various comparisons were made between our proposed approach and the present regulated situation. The present section repeats some of the early comparisons and adds new ones. The purpose of the present section is to summarize our view of the trade-offs between the present system and our deregulated system.

VI.1 General Economic Issues

Before beginning a comparative economic evaluation of the present regulated system and our approach to deregulation two general issues will be discussed. These are:

- Will competition exist in our deregulated system?
- What will the final generation mix be in our deregulated system?

A critical assumption underlying our proposal is that competition will actually exist in given regions. Competition must exist at two levels, investment and production. In each, the amount of competition will be influenced by whether a single firm will have too much power, and whether there will be collusion between firms. Research currently beginning is attempting to identify those conditions which would make competition unlikely. Preliminary results point toward what may be obvious. Competition will be weak (spatial monopoly will exist) in those instances in which there is low demand density and a weak transmission system. Rural farm areas could fall into this category. Island areas may form another zone of spatial monopoly.* Temporary periods of spatial monopoly can occur in otherwise competitive systems when the transmission system is at capacity. Other than these instances, however, it appears that properly deregulated systems will have sufficient competition between generators to allow the marketplace to function as suggested.

The final generation mix in a deregulated system may look different than at present. A number of opposing forces will be at work. Were there no plant level economies of scale in generation, the trends under a deregulated system would be toward smaller, lower-cost facilities since these can be built more quickly in response to changing conditions. With plant level economies of scale this trend is anything but clear.

The mix between peaking and baseload units is also not clear. Spot pricing to customers will definitely flatten the load duration curve, thus making baseload generation relatively more attractive. However with quality of supply pricing in place of rationing, there will be need for total generating capacity; resulting periods of high spot prices will encourage peaking unts. Furthermore, intermittent generation (solar, wind, run of river hydro) may also be encouraged. See Tabors [1981].

VI.2. Deregulation: Comparative Efficiency

The comparisons which follow are twofold. First, between today's regulated utility structure and today's regulated structure with

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*For other approaches see Schuler and Hobbs [1981] and Weiss [1975].

customer spot pricing. As we have already stated, customer spot price could be implemented independent of deregulation. Second, between today's regulated structure and a future deregulated system with spot pricing. The discussion will follow the information presented in Figure 8.

Investment

Generation: Today's electricity generating capital stock contains many facilities that are economically obsolete due to dramatic increases in oil prices. Utility companies, because of low profits, are not well positioned to raise the capital necessary to replace them. Under deregulation, investment decisions will be forward looking. Profit opportunities will be seized by investors, just as they are in other industries. Prior mistakes will not hinder future investments. This differs from today, when, it is sometimes argued, utilities have an incentive to operate technologically obsolete plants so they can demonstrate them to be "used and useful", keeping them in the rate base.

Currently, utility investments are centrally planned to yield an "efficient" capital stock. Large computer models define plans that minimize expected long-run costs given utilities' forecasts of future demand and long-run costs. If utilities could, they would, in fact, build according to these plans. In reality, because of difficulties in raising capital due to low anticipated profits, they are forced to minimize capital outlays, so long as they are able to meet their demand [see Stelzer 1981:14]. This strategy does not minimize production cost. Under our proposal, the lure of profits will help lead to proper investments. (See Bohn, Caramanis, Schweppe [1981] and Section V). In

Figure 8

Comparison of MIT Deregulation Proposal With Current Regulated Environment*

	Customer Spot Pricing Alone	Deregulation With Customer Spot Pricing
Investment		
Generation	+	+++
T&D	=	?
Customer	+++	+++
Operations		
Plant Management/Operations	=	+
Unit Commitment	=	- ?
Least Cost Dispatch	=	= ?
Economy Interchange	=	++
Transmission System Operation	+	-
Customer Curtailments	+	+
Customer Pricing	++	+++
Dynamics		
System Dynamics	=	- ?
Transaction Costs		
Monitoring/Communication	-	-
Regulation	-	+ ?
Public Attitudes	?	+
Transition Effects		
Income Transfers	-	-
Disruption Costs	-	- - -

= equal to current regulated environment
+ better than current regulated environment
- worse than current regulated environment

*This table is prepared from a public policy perspective. Comparisons are subjective opinions of the authors.

fact, generating companies will continually forecast price in each region, and begin construction in anticipation of profits. As these firms enter, they will hold prices down. Deregulation may add one complication into their investment process. They must consider not only what investment will be profitable, but how the investments of their competitors will affect profits.

One frequently raised objection to deregulation is that "capital will not be available to generating companies without a guaranteed rate of return." We disagree. Unless one is willing to argue that investments in other capital-intensive industries are unsuitable for free enterprise, this problem should not be considered as rendering competition unsuitable for electric generation. We see such investments being made in other capital-intensive processes (oil refining, minerals exploration, etc.) Second, forward markets (Section V.3) would give a guaranteed price, even with spot pricing. Fortunately, this issue may be resolvable by an experiment.*

Investment in a deregulated environment will lead to both learning curve and scale economies. Under a deregulated system one company might choose to build only one type of plant, say a 500 MW fluidized bed coal plant. They might do so at a sigificant number of permissible (spatially dispersed) sites. This firm would presumably capture learning or experience economies from "volume" construction. In addition

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*The experiment would be to have a large utility offer to guarantee to pay its system lambda for all energy sold to it by a large independent generating plant for the life of that plant. Both state and federal regulators would also have to commit themselves not to interfere, and to allow the utility to pass through all of its costs. If companies were willing to build plants under these conditions, that would show that they would also be willing to do so in a fully deregulated system.

this specialization would bring about economies of scale in operations as the firm, given good transport, could maintain fewer spares at a central location, could have highly specialized maintenance crews, etc. We anticipate that a deregulated environment will, on balance, lead to an improvement in the investment behavior in the generating sector.

Transmission and Distribution: Analysis of investment in the T&D sector is more difficult, since it requires a model of the behavior of the regulators when generation is divested. One argument is that since T&D costs are a small portion of the delivered cost of electricity, regulatory commissions will be under less political pressure to constrain the regulated transmission tariffs. In that case, the T&D utility would expect to earn its cost of capital, which would make new capital easily accessible.

An opposing argument is that since commissions would only have limited impact on rates, when political pressure reacts to price rises, the commissions will use the only tool they have to affect prices, namely, the T&D transmission tariffs. If so T&D utilities would not earn their cost of capital and therefore would have difficulty obtaining capital.

Another potential problem with T&D investment is coordination with generation investments. The issue is that the optimal transmission system depends on where generators are built, but optimal generation siting depends on the transmission system. (This is analogous to the problem of coordinating new coal mines and transshipment points with new railroad lines.) Even in today's integrated utilities, final decisions are more the result of a heuristic iterative decision process than of any "global optimization." This is especially true for transmission decisions which affect more than one utility.

More thought is needed on this issue but several methods of coordination in our basic structure are immediately visible. For example, the T&D company could be given some responsibility for site selection. Generating companies could be given some responsibility for paying to interconnect with the grid. Certainly generation companies should have the right to build their own transmission lines to link them to the grid if they desire to do so. Therefore, in Figure 8 we assume that we cannot determine a priori whether T&D investment under our structure will be more or less efficient than at present.

Customer: If the T&D utility uses spot pricing for customers, investment efficiency will increase at customer sites. Spot pricing will permit customers to use properties of their consumption process, such as storage and load shifting, to reduce their bills and thereby reduce the total costs of the system.

Operations

Plant Management: Spot pricing to users alone has no effect on plant management and operations. Deregulation has at least a slight positive effect. In the business-as-usual scenario the plant operator is likely to be measured by the consistency of operation of his facility and its heat rate over the year, i.e., its average efficiency of operation. With deregulation the plant operator will be motivated by an ability to make a profit when spot prices are high and hence will push his facility during system peaks.

Unit Commitment: Today, day-to-day unit commitment procedures permit highly efficient operations for most state-of-the-art utilities. In general, the coordination and control available because of horizontal integration can be successfully exploited to reduce daily running costs. It is probably unrealistic to expect that independent, competing generators will do any better on unit commitment than present dispatchers.

Least Cost Dispatch: While the use of real-time spot pricing will come close to minimizing total operating costs, it is unlikely that it will exceed present dispatch. With deregulation some efficiency may be lost.

Economy Interchange: Customer spot pricing does not affect interchange among utilities. Deregulation will have two significant impacts. The incentives for interchange are increased since generators now can earn the buyers marginal cost rather than one-half the difference between buyer and seller system marginal costs. Furthermore, they get to keep 100% of this difference instead of passing it through to rate payers. Second, the nature of the full spot pricing formulation [Caramanis, Bohn, and Schweppe, 1982] provides for the automatic pricing of energy wheeled across a transmission system. Thus optimal interchange between utilities is automatic in a deregulated system, unlike today. This may be a significant savings in some regions.

Transmission System Operation: Spot pricing alone improves the operation of the transmission system because of the spatial pricing of energy. At times of transmission capacity shortage, spot prices reflect the costs within the system. Deregulation will tend to make transmission system operations more complex although no major obstacles are foreseen.

Customer Curtailments: Again the spot pricing of energy to the customer carries the dominant weight rather than deregulation in facilitating customer response. Customer spot pricing provides the signal which allows the customer to curtail electric demand within his/her facility to maximize efficiency. Load management becomes automatic as customers voluntarily back off the system as the spot price rises. The task of blacking out sections of demand thereby can be avoided in many cases.

Customer Pricing: Economic theory states that the price seen by consumers should equal the marginal cost of production. Otherwise resources are not used efficiently. If the supply of electricity is competitive, the spot price will equal the instantaneous marginal cost of electricity. Those customers that see the spot price can use their electricity efficiently.

Producers will base their output on their marginal cost, assuming they have no market power. They will produce when the spot price equals or exceeds their marginal cost. While today's economic dispatch yields similar results, deregulation will lead to at least two areas of substantive improvement in dispatch. Cogenerators would be sure to receive the full value of their output and hence self dispatch efficiently. Second, purchased power exchanges between utility regions will be automatic.

As with the above discussion on curtailment, customer response to normal price signals is a major benefit of spot pricing and for deregulation with spot prices. Customers are receiving information in close to real time concerning the price for energy. Their response represents their decision on the value of electricity in their production process at any given time [Bohn, 1981]. This decision therefore allows for overall social efficiency in resource allocation between production (generation) and consumption (load) in the deregulated environment in which both consumers and generators can voluntarily participate in the marketplace.

Dynamics

System Dynamics: The operation of dynamics pricing and microshedding/spinning reserve pricing under deregulation were discussed in Section III. Spot pricing alone has only minimal impact on dynamics as it operates in too long a time frame. The impact of deregulation on dynamics is highly uncertain. Deregulation will make control of dynamics more complex but no major obstacles are foreseen.

Transaction Costs

Monitoring/Communication: Under spot pricing these costs will change dramatically. From a requirement of simple metering and essentially no utility/customer communications, we enter one of time based metering and, for some customers and sectors, real time communications between the market coordinator and the customer. These equipment costs will represent significant investments relative to anticipated savings for smaller customers, but far less significant investments relative to potential savings for larger customers. When one considers deregulation with full spot pricing the additional cost of monitoring and recording the performance of individual generators will be added. The better the current control hardware and software the less costly the transition. All of these factors will tend to increase the transactions cost of operation both of a spot priced and a deregulated system. At the same time, a new industry is being developed, a microprocessor based industry for electric power system monitoring and control.

Regulation: The process of actually setting rates is not a simple procedure. It involves complex adjudicatory proceedings which consume considerable resources in lawyers, accountants and economists on both the state PUC and the utility sides of the battle. The procedure is cumbersome, frequently slow, and rarely satisfactory to anyone.

Under customer spot pricing alone the regulatory process will be different. Rather than setting actual rates, the PUC will approve formulae by which spot prices are calculated. These formulae reflect marginal cost and therefore be straightforward. But the handling of revenue reconciliation will be less straightforward and require adjudicatory proceedings.

Deregulation will eliminate the revenue reconciliation problem for generators but it will continue for the T&D company. As a result deregulation will eliminate some of the requirements for lawyers, accountants and economists. On the other hand there are likely to be another set of roles which develop that require the preparation and supervision of contracts, the projection of long-term price and response trends and the accounting of profits and losses. On the whole there may be different and lesser demands on this group.

Public Attitudes: A less tangible benefit of deregulation may be an improvement in the quality and emotional level of public discussion and public policy concerning the electric power industry. Present monolithic monopolistic utilities are the favorite target of intervenor groups [Joskow 1976:314]. Regulatory hearings provide a convenient forum for issues, which while important might best be handled by the political process in a more appropriate setting. Under deregulation, public issues relevant to electric generation, such a plant siting, pollution control and the use of nuclear power, will still be subject to regulatory oversight by appropriate bodies, just as they are in other industries.

Transition Effects

Income Transfer: Probably the most politically undesirable price effects of deregulating generation are income transfers; some individuals, firms, and groups are better off when prices are artificially controlled by regulators than when they are set by a competitive market. In particular, some industrial and other customers have long been subsidized by declining block rates for electricity, or by long term contracts at much less than the marginal cost. The Pacific Northwest offers another example. A large amount of subsidized government hydro power has permitted very low electricity prices [Gordon 1981b:7-15]. As demand increases (in large part because of the low prices) more expensive sources become necessary. A competitive market would raise the price to the cost of these new generating sources. Determining who will win and who will lose under deregulation is difficult. The implementation of deregulation may require some method to compensate the losers [Golub, 1982].

Disruption Costs: Any massive change such as deregulation will cause disruptions, for example when existing integrated utilities spin off their generating plants. Transition paths (Section VII) should be chosen with this in mind.

VI.3 Discussion

In Figure 8, we summarized our evaluation of the economic properties of our deregulation approach. We have tried to separate out to some extent the relative impacts of customer spot pricing from those of complete deregulation. The evaluations of Figure 8 are very subjective and many readers will not agree with them. In fact some of these evaluations are compromises, as the authors of this paper are not in complete agreement. We present Figure 8 as a starting point for further discussion. We have not attempted to assess the net benefits and costs of the proposal.

VII. A PATH TO DEREGULATION

Even if it is desirable to deregulate generation, much still depends on how the change is executed. Here we suggest a sequence of events. Starting with conventional vertically integrated, investor-owned regulated utilities, we want to end with deregulated generation, but regulated transmisson and distribution. This approach could be applied at the state level, but is more appropriately applied simultanteously to a multi-state region.

1. Use spot pricing for all power which the central utility buys back from customers and dispersed generators. Existing legislation (PURPA) mandates such buy-backs but is vague about the price to be paid for power. Spot pricing gives the correct price, and encourages construction of independent generation even before the system is fully deregulated.

2. Announce a schedule for subsequent steps. This allows customers, vendors, and potential generating firms to begin long lead-time processes, such as obtaining environmental permits.

3. Repeal the Public Utilities Holding Company Act. It is ànachronistic today. It would be counterproductive in a deregulated world where the creation of national generation firms would be desirable.

4. Make spot pricing mandatory for the largest customers.

5. Allow any customers to pay the spot price if they wish to do so.

6. In existing utilities, separate management and operation of generation, from transmission and distribution.

7. (Optional) Sell off distribution networks to municipalities, if they want them.

8. Have existing utilities divest their generating assets,

leaving the transmission network and with possibly some distribution facilities subject to regulatory control. The central dispatching center of the old utility would be adapted to serve as the region's market coordinator.

The sum of the values of the deregulated and regulated portions of the old utility is likely to be higher than the value of the utility before deregulation. How much the utility's stockholders keep of the windfall is a question which must be resolved politically. For a discussion of issues involving the deregulation of assets previously subject to rate of return regulation, see Golub [1982].

A few steps of this procedure could be done without state or Federal legislation. But to reduce the uncertainty of potential investors, it is desirable to have a clear procedure, schedule, and authorizing legislation at or near the beginning of the process. National debate and legislation along the lines of that on AT&T will be required. Deregulation will not work if potential investors fear that it might be reimposed later, after they have built new generators.

The above scenario leads all the way to the basic structure of Section II.1 by evolving through a variety of mixed structures. In pratice many of the potential advantages of deregulation can be attained if the final result stops somewhere along the scenario with a mixed system combining regulated and deregulated generation, provided there is enough competition that the marketplace can still function efficiently.

VIII. SUMMARY

One goal of this paper was to establish a framework for the discussion of deregulation by delineating some of the many relevant aspects of electric power system control, operation, planning, and financing. Admittedly, not every issue related to deregulation was discussed here. However, any proposal for deregulation must address the issues discussed in this paper.

The second goal of the paper was to present a specific proposal for deregulation and to discuss it in the context of the key issues. Our proposal is based on an energy marketplace. One marketplace structure is summarized in Figure 5. A regulated company owns the T&D network and the market coordinator (which is the brains). All generators and users are independent entities who buy and sell from the market coordinator. Two other independent entities are the information consultants who provide spot price forecasts, and energy brokers who help facilitate risk sharing. The marketplace of Figure 5 involves extensive information flows among the participants. The necessary metering, communication, and computation are practical today because of the microelectronic revolution. Without these microelectronic breakthroughs in cost and performance, our proposed approach to deregulation could never be practical.

Figure 5 summarizes a pure marketplace structure which assumes that all generation is deregulated, all users see spot prices, and that the transmission and distribution networks ownership are combined. It is important to reemphasize that none of these assumptions are critical to our basic proposal. Our ideas also apply to mixed systems involving partial deregulation, partial spot pricing, and separation of transmission and distribution. The paper's discussion is concentrated on the pure structure of Figure 5 because it is a good vehicle for conveying the fundamental ideas. The structure of Figure 5 may never evolve in its pure form. Even if something approaching it does eventually occur, the transition phase will be long and will involve mixed systems of many types.

Our proposal relies entirely on using economic incentives to create the response required to maintain a functioning, efficient electric power system. In almost every case, it is possible to think of compromises which could be made to reduce economic forces and increase the amount of regulation. We expect some compromises of this type to be part of any real deregulated world.

if it is desirable to make significant moves toward deregulation, we believe that our proposal is the best presently available. However, deregulation of the electric utility system is an extremely complex problem and we look forward to studying other proposals. Our advocacy of one approach to deregulation does not imply that we advocate deregulation itself. There are still far too many unanswered questions for us to take a firm position either for or against deregulation. Deregulation has great potential, but it has major pitfalls as well.

Since deregulation combines great potential with dangerous pitfalls, more work in the area is needed. Three next steps which should be taken in parallel are:

- Research & Development on Techniques and Methods for Deregulation
- Evaluation of Specific Measures of the Values and Shortcomings of Deregulation
- Experiments

Our proposed approach requires more research and development. We are working on some of them now, but a much higher level of effort is needed. Perhaps the area needing most development is the details of how mixed systems will actually work. The desirability of implementing deregulation cannot be ascertained except in the context of explicit proposals on how it is to be accomplished. We have only started to develop methods to quantify the advantages and disadvantages of our proposed approach. Analyis must cover all aspects of the problem ranging from power system dynamics to the price users pay, and to how such changes affect the national economic well-being. Some of the desired measures will require extensive, long-term research before appropriate methodologies to evaluate them are available. Although we advocate further conceptual, theoretical, and computer simulation studies, "paper studies" alone are not sufficient.

Field experimentation is essential to uncover real-world problems that are always overlooked in paper studies. Such experimentation can be done in various ways. Most present-day inter-utility and inter-pool energy exchanges already approach the conditions of an open energy marketplace and hence provide a vehicle for further learning. PURPA provides an existing framework for industrial involvement in electric power generation (with an unfortunate limitation on megawatts). The establishment of spot pricing as the avoided cost would provide more needed field data. Another possible experiment is suggested in Section VI.2. Establishment of spot pricing to selected users would provide data relative to deregulation. Of course, experiments involving spot pricing to users would be extremely valuable even if deregulation itself never occurred. Spot pricing for users has value in a regulated environment.

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