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ECONOMICS OF WIND ENERGY FOR UTILITIES

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As the cost of generating electricity by what has heretofore been considered conventional means continues to climb sharply, the nation has been looking toward alternative methods to produce electricity. Wind energy conversion is among the alternatives being considered.

Utility acceptance of this technology will be contingent upon the establishment of both its technical and economic feasibility. This paper presents preliminary results from a study currently underway to establish the economic value of central station wind energy to certain utility systems. The results for the various utilities are compared specifically in terms of three parameters which have a major influence on the economic value: a) wind resource, b) mix of conventional generation sources, and c) specific utility financial parameters including projected fuel costs.

For the study the economic value is derived from the total savings created as a result of reducing the need for conventional generation by making available energy that is generated by wind turbines. The results presented in this paper, however, are only for fuel savings and do not reflect any savings resulting from deferred or displaced conventional capacity.

The wind energy is derived from modeling either MOD-2 or MOD-OA wind turbines in wind resources determined by a year of data obtained from the DOE supported meteorological towers with a two-minute sampling frequency. In this paper, preliminary results for six of the utilities studied are presented and compared.

INTRODUCTION

In early 1976 the Energy Research and Development Administration (ERDA), subsequently integrated in the Department of Energy (DOE), issued a Request for Proposal (RFP) entitled "Candidate Sites for Installation and Field Testing of Large Experimental Wind Turbine Systems". ERDA solicited proposals from electric utility systems only and the response to the RFP resulted in the selection of 17 candidate sites. At these sites, where no meteorological towers existed, DOE provided funds to place towers and institute data collection in accordance with standards established by DOE.

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In early 1979 DOE initiated a program to estimate the economic value of wind energy conversion systems (WECS) to the utility systems providing these sites. JBF Scientific Corporation was contracted by the Solar Energy Research Institute (SERI) to determine this economic value for the host utilities at nine of these sites and a tenth utility using the wind resource from one of the nine sites. Table 1 contains a list of the utilities for which the economic value of wind energy was determined and indicates, as well, the candidate site from which the wind resource data was obtained.

Table 1. Utilities For Which the Economic Value of Wind Systems Is Being Determined

UTILITY	SITE
BLOCK ISLAND POWER CO.	BLOCK ISLAND
CLAYTON MUNICIPAL ELECTRIC SYSTEM	CLAYTON
CONSUMERS POWER COMPANY	LUDINGTON
HAWAIIAN ELECTRIC COMPANY	KAENA POINT
HOLYOKE GAS AND ELECTRIC DEPT.	HOLYOKE
LOS ANGELES DEPT. OF WATER & POWER	SAN GORGONIO
PACIFIC GAS AND ELECTRIC COMPANY	POINT ARENA
PUERTO RICO ELECTRIC POWER AUTHORITY	CULEBRA
SOUTHERN CALIFORNIA EDISON CO.	SAN GORGONIO
SOUTHWEST PUBLIC SERVICE CO.	AMARILLO

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For this study the economic value of the wind energy is defined as being the total savings in costs derived from the displacement of conventionally generated energy by the wind generated energy. These savings come from fuel and other incremental costs, operating and maintenance costs, and the carrying costs of deferred or displaced conventional capacity. There may be other costs incurred in order to maintain proper operation of the utility system as a result of incorporating wind energy into the generation mix; these were not considered in this study.

These savings that result from the displaced energy were calculated utilizing techniques that the utility industry has developed to determine the relative economic attractiveness of alternative generation expansion plans.

The differences between the industry developed approach and the approach used in this study relate to three specific factors which make electric energy derived from wind unlike any of the other electric energy sources traditionally evaluated in utility generation expansion planning. The first of these factors is the stochastic nature of the wind and the power it produces. Traditional energy sources are dispatchable. They produce power when called upon to do so within the limits of forced outages which occur on a relatively infrequent basis. Wind systems, although dispatchable up to the limit of what they are capable of producing from moment to moment, have a capacity which fluctuates as the wind fluctuates. Their capability can go from no output to the rated capacity of the unit within a relatively few minutes. Fortunately, as their incremental costs are essentially zero, wind systems are among the first units to be dispatched in an economic dispatch and, therefore, whatever energy they can produce will be accepted by the utility system. Consequently, it has been possible to adapt the methodology developed by the electric utility to accommodate a source with rapid and uncontrollable fluctuations in output.

The second factor is the wind system's dependence upon the local wind resource. The wind resource only a short distance away from a selected site could contain a substantially different amount of energy. This site dependency precludes the use of generic characteristics as input to the evaluation process and necessitates that a specific wind system be simulated operating in a specific wind resource and the resulting performance be evaluated in the generation expansion analysis.

The third factor which sets central station wind systems apart from traditional generating sources is the lack of meaningful information as to the projected purchase cost of such wind systems from their manufacturers. This factor, when combined with the previously mentioned observation that wind systems have essentially a zero incremental cost, makes it useful to adapt the traditional process to solve for the economic value of the wind system rather than assuming an estimated price.

The approach applied in this study for determining the value of wind generated electricity does follow the accepted utility practice for evaluating generation expansion alternatives with some modifications made to accommodate the three above-mentioned factors. Two general categories of input data are required to calculate the value of wind energy. The first category consists of data related to the wind system, its installation, and performance. The second consists of data related to the specific utility under investigation.

This paper presents some preliminary results from the study for several of the utilities. These results are for savings in incremental, and operating and maintenance costs only. No consideration of deferred or displaced capacity is included in this paper except in describing the methods used in determining the total value of wind turbine systems.

The primary emphasis of this paper is to compare the results from the various utilities with respect to three factors which influence the economic value of wind systems to those utilities. These factors are the amount of wind energy produced by the specific wind turbine in the specific resource, the mix of conventional generation used by the utility to cover its load, and the pertinent economic parameters for that utility including items such as fixed charge rates and fuel costs projections.

METHOD FOR DETERMINING ECONOMIC VALUE

Figure 1 presents an overview of the approach that was utilized for determining the economic value of wind systems to an electric utility. The process contains three basic segments.

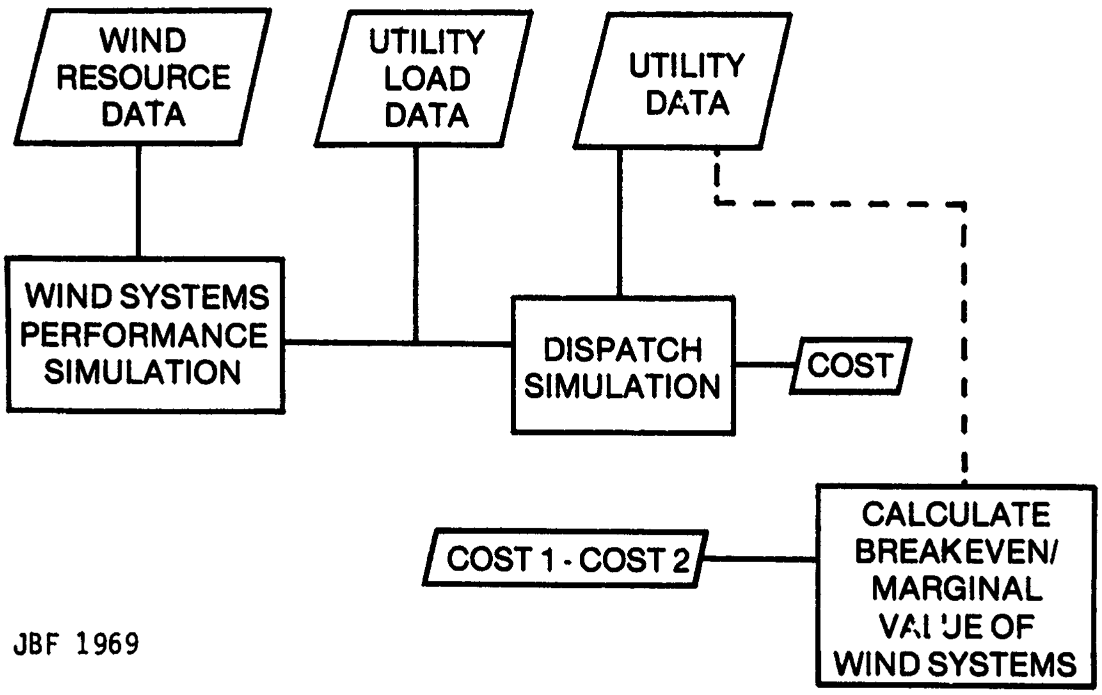

Figure 1. Method for Determining Economic Value of Wind Systems to Utilities

The first segment processes the wind resource with the wind system performance characteristics to develop the expected hourly wind derived energy. This segment relates to the first of the factors described in the introduction which differentiate this process from the conventional utility process. An input to this process is the wind resource data obtained from the DOE meteorological tower at the particular utility site. The other major input to this segment is the performance characteristics of the wind system under consideration. The output of this segment is the expected wind system energy on an hourly basis. This time correlated energy with its associated zero incremental cost is passed into the generation expansion segment to be dispatched on a first priority basis against the expected utility load.

The generation expansion assessment is made in the next segment of this economic approach. This is the most comprehensive segment with substantial amounts of input required. The principal processes in this segment are the simulation of the economic dispatch operation of the utility system and the analysis of the utility system's reliability.

As electric consumption continues to grow, utility organizations continue to face the problem of adding sources of generation in order to meet their obligations of covering these increasing loads. A major objective in their generation expansion program is to provide energy at the lowest possible cost consistent with established levels of reliability. Not all generation alternatives have the same costs or even cost structures. Substantial variations exist in the relationship betweeen fixed and variable costs over the range of alternative generating sources. Fixed costs are incurred just by the ownership of generation and are present regardless of the energy produced by such generation. Incremental costs, on the other hand, are those costs specifically related to producing energy and are, therefore, a function of the amount of energy produced. As a general rule, generating units that have low incremental costs, which makes them economically attractive for long hours of use, have higher fixed costs. These higher fixed costs are the result of capital investments made to achieve greater efficiency from less expensive fuels. Once a utility acquires a certain set of units to provide generation, such a set is loaded in increasing economic order by incremental cost. This process yields the lowest total cost of generation to the utility.

In order to select which equipment should be added to the mix of generation currently operated by the utility, the equipment mix which would reliably satisfy a projected load profile at the lowest total cost of generation must be identified.

The total cost of generation for a given equipment mix serving a given load profile is the sum of the fixed costs of the equipment involved and the total incremental cost that would be incurred in satisfying the load requirements. The fixed costs relate to the annual cost of carrying the investment in the generation. Incremental costs have to be calculated by simulating the dispatch of generating equipment to satisfy the projected load requirements. The electric utility industry has developed numerous computer models to perform this simulation with varying degrees of sophistication.

The approach for evaluating wind systems as part of an expanding mix of generation equipment utilized one of these models to simulate generation dispatch but includes additional functions to address the three factors which differentiate wind sources from traditional sources.

The major inputs to this segment were the projected utility hourly load data, utility generation data, as well as the hourly energy output from the wind system. The processes of this segment were used numerous times in order to determine the effect varying system conditions will have on the utility operation. An initial base case was run utilizing the hourly utility loads and the generating sources as projected without including any wind source. This established the base costs from which savings were computed as well as the system reliability which serves as a target from which to develop capacity credit.

Subsequent cases were then run with various sets of conventional generation sources which can provide the target reliability. The inclusion of wind generation in the utility equipment mix will improve a utility system's reliability. Consequently, the utility can reduce its capacity of conventional sources and still maintain its target reliability. This reduction in the conventional installed capacity that must be maintained by a utility results in a capacity cost savings that can be directly related to the inclusion of WECS into the utility's equipment mix.

The output of this segment was a series of single-year production and related capacity cost savings for various penetration levels of wind. Although capacity credit was computed in the study, capacity credit results are not included in this paper.

The third segment develops the life-cycle economic vaue of a wind system to a utility from the calculated single-year cost savings. Other inputs necessary for the value analysis include the various utility financial and economic parameters. The initial step in this process was to develop annual wind system generated savings for each year over the projected life of the wind system. These savings are developed from the computed single year savings using the utility's projected economic parameters. From these the accumulated present worth of the annual WECS generated savings for each year over the projected life of the wind system was calculated. Again, with the use of the utility financial and economic parameters, these accumulated savings are converted into an equivalent first-year investment. This investment represents the maximum investment that could be put into the wind system without adversely impacting the utility economically. This equivalent investment is also referred to as the economic value of the wind system to the utility. This value decreases as the level of WECS penetration into the utility system increases. Comparison of the values of each successive WECS unit installed with the WECS manufacturer's price schedule would determine the economic viability of the wind systems.

In this study the analysis was done for three years, an early 1980 year, 1985, and 1995. The selection of the early 1980's year was based upon the availability of appropriate data. Additionally, the analyses was done for various penetrations of wind systems. Penetration is defined as the percent that the wind energy system capacity is of the utility system peak demand. Penetrations of 5 and 10 percent were analyzed in each year along with a penetration of 2.5 percent in the first year.

ANALYSIS RESULTS

This paper presents some preliminary analysis results for six of the electric utilities being studied. They range from a small isolated municipal system to large interconnected investor-owned systems. Table 2 presents a list of the utilities as well as indicates the utility abbreviations used on the graphs upon which the results are presented.

Table 2. Utilities for Which Preliminary Results are Presented

UTILITY	ABBREVIATION
CLAYTON MUNICIPAL ELECTRIC SYSTEM	CMES
CONSUMERS POWER COMPANY	CPC
LOS ANGELES DEPT. OF WATER & POWER	LADWP
PACIFIC GAS AND ELECTRIC COMPANY	PG & E
PUERTO RICO ELECTRIC POWER AUTHORITY	PREPA
SOUTHERN CALIFORNIA EDISON CO.	SCE

JBF 1981

The amount of wind energy available to each of the utilities is determined by simulating the performance of a wind turbine in the appropriate wind resource. The matching of the wind sites with the utilities was provided in the introduction. A year of two-minute wind data was extrapolated to the hub height of the wind turbine and processed through an input-output curve for the specific wind turbine to develop the power every two minutes. These were combined to produce the hourly power to be compatible with normal utility power data.

Two of the ten utilities that are the subject of this study, including one for which results are presented in this paper, are small isolated utility systems. Both these system are too small to be able to incorporate MOD-2 wind turbines into their generation mix without exceeding the penetration levels for wind energy that were established for this study. Coincidentally, both of these utilities are participants in the DOE large wind turbine programs and have MOD-OA wind turbines. For these reasons, MOD-OA wind turbine performance was simulated in each of these utilities to develop the amount of wind energy available to each of these utilities. Figure 2 shows both the average wind speed calculated from the data obtained at that site for 1979 and the capacity factor for the MOD-OA wind turbine operating in that resource. Of the two locations, Block Island, Rhode Island has a slightly better average wind speed and a significantly better capacity factor.

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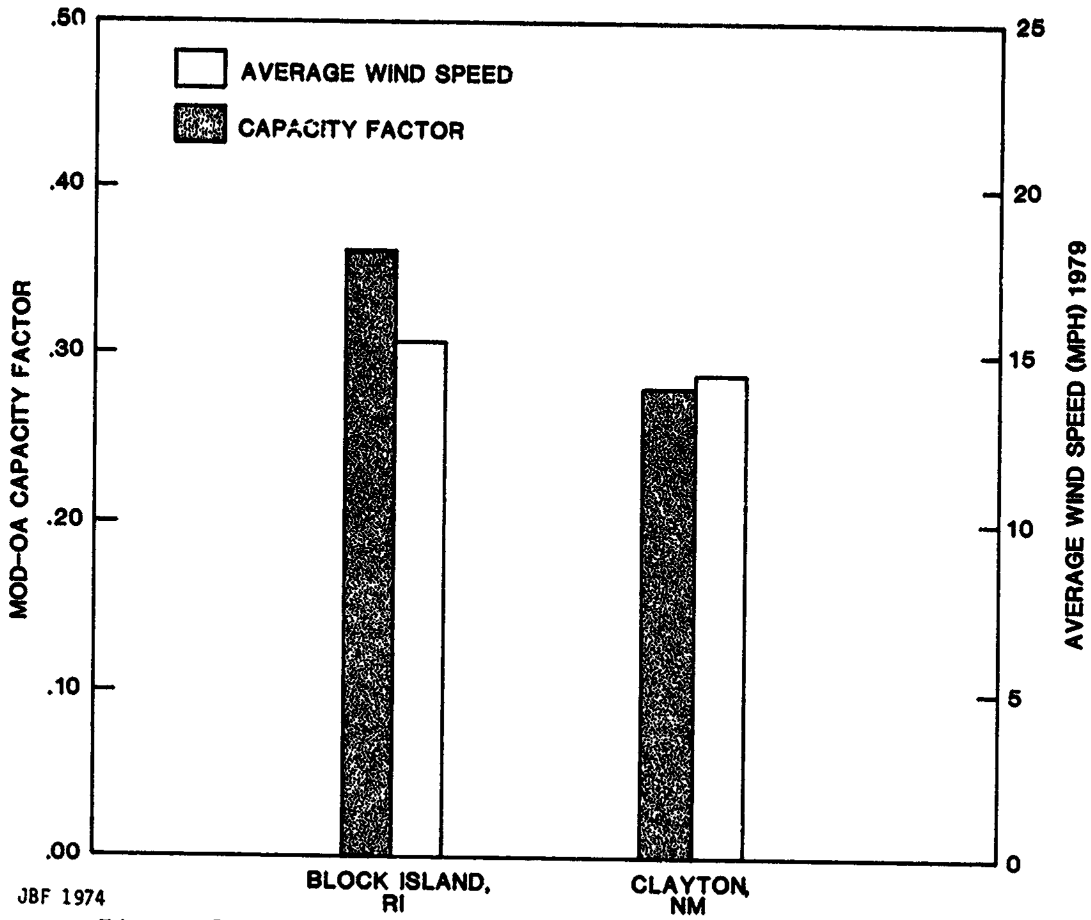

Figure 2. Wind Speed and MOD-OA Wind Turbine Performance

The MOD-2 machine is simulated in the appropriate wind resource to determine the energy available to each of the other utilities.

As the analysis for both Southern California Edison Company and Los Angeles Department of Water and Power used the San Gorgonio resource, only four sets of results are presented in Figure 3. Of the six sites presented, the poorest average wind speed was at Clayton, New Mexico whereas the poorest capacity factor was for the MOD-2 at Point Arena, California.

A significant part of the characterization of a utility for the purpose of establishing the economic value of wind energy includes a description of the mix of generating sources by fuel type and efficiency.

The mix of generating sources for a given utility is a reflection of size, regional fuel supply consideration, the financial structure, and load of the utility. These mixes have evolved over the years based upon a series of generation expansion evaluation efforts to identify the least costly means of producing energy to supply the utility load.

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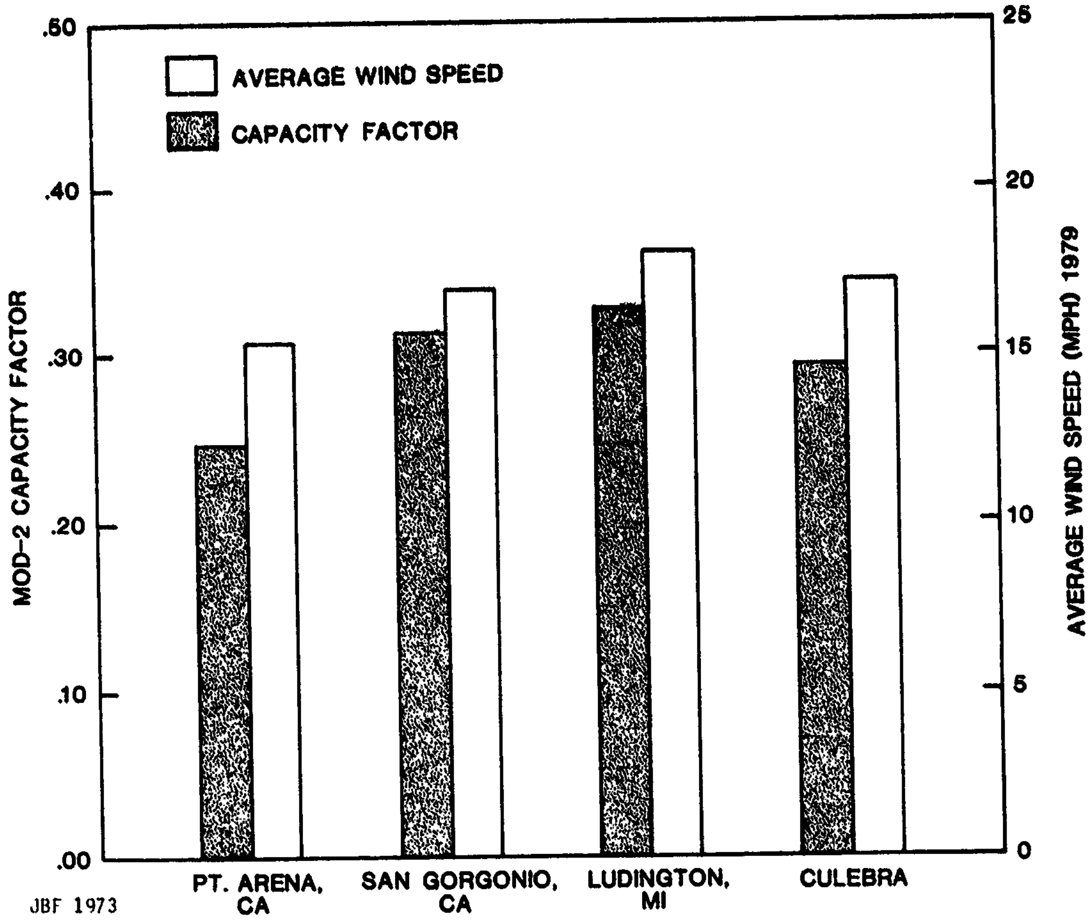

Figure 3. Wind Speed and MOD-2 Wind Turbine Performance

The next three graphs present comparisons which directly relate to generation mix impact upon the derivation of the value of wind systems to the utility. They are the utility capacity projections for each of the years of analysis by fuel type, the generation projected from that capacity for 1985, and finally, the generation displaced by the wind systems for 1985 for both the 5 percent and 10 percent penetration levels.

Figure 4 contains the capacity projections for each of the six utilities. The relative mix by fuel type, the change in this mix, and the relative growth in installed capacity can be seen from this graph.

The capacity is economically dispatched to meet the utility load. It is therefore useful to show the projected generation by fuel type. Figure 5 provides this breakdown for each of the six utilities as projected for 1985.

The hourly dispatch of generation combined with the hourly displacement of energy by the wind systems result in a displacement of fuel by wind energy. The breakdown of this displacement by fuel type for the six utilities is shown in Figure 6. This clearly shows that

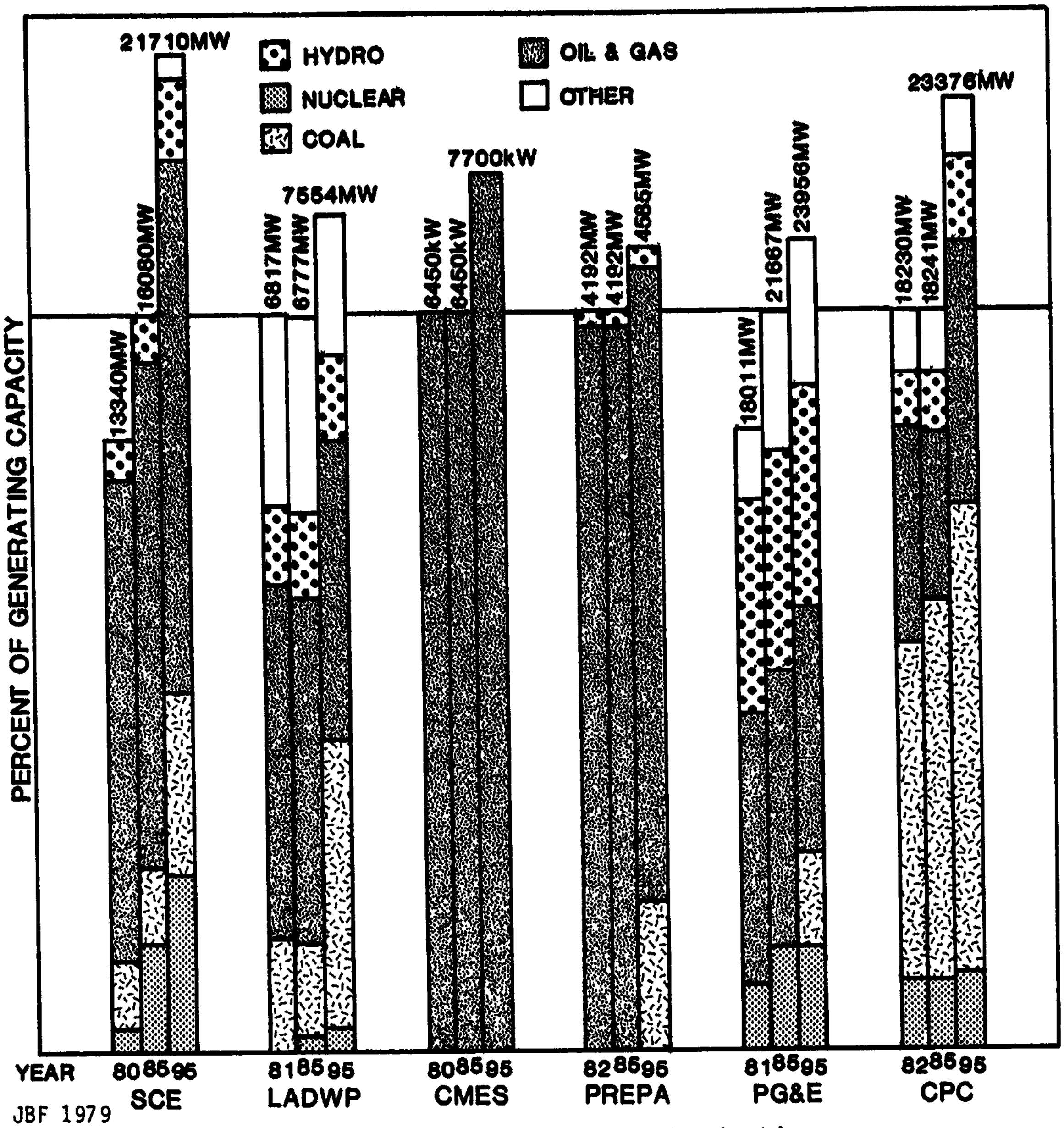

Figure 4. Utility Capacity Projections

except for Consumers Power Company, which has little oil generation, essentially all the value for wind energy from these utilities is derived from displacing oil.

Conversion of the displaced fuel into dollars and dividing by the installed capacity of wind systems for each penetration and utility provides a useful comparison among the utilities. These results are shown in Figure 7. On this graph the annual savings range from under $100 per kW for Consumers Power Company with its lower cost fuels to a savings in excess of $260 per kW for Southern California Edison Company with its 100% oil displacement.

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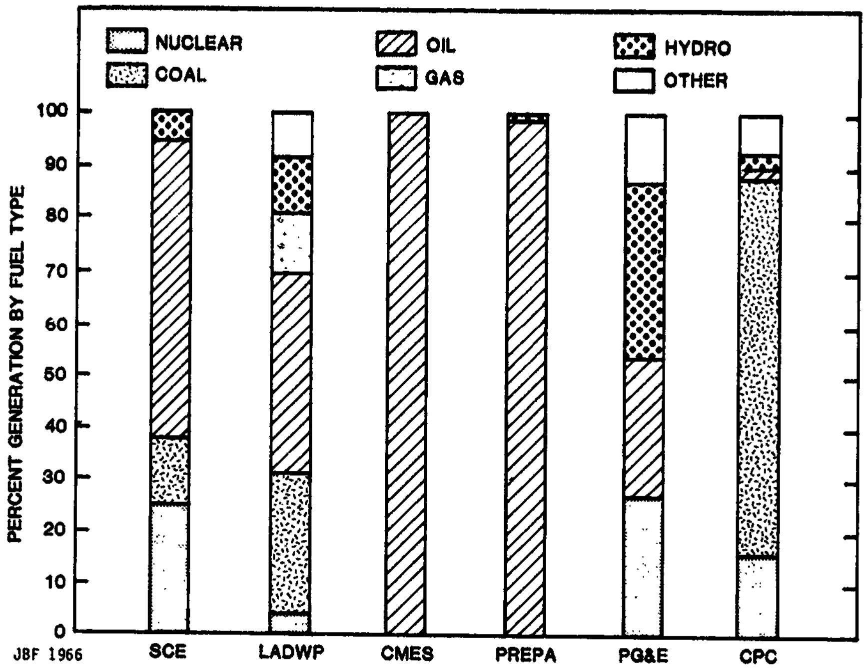

Figure 5. Projected Utility Generation by Fuel Type for 1985

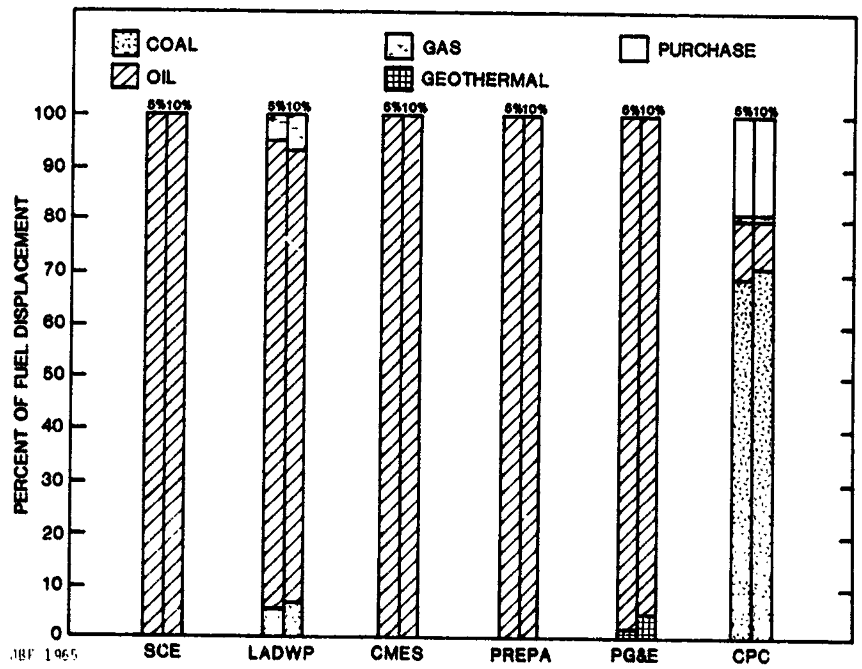

Figure 6. Projected Utility Fuel Displacement by Wind Systems for 1985

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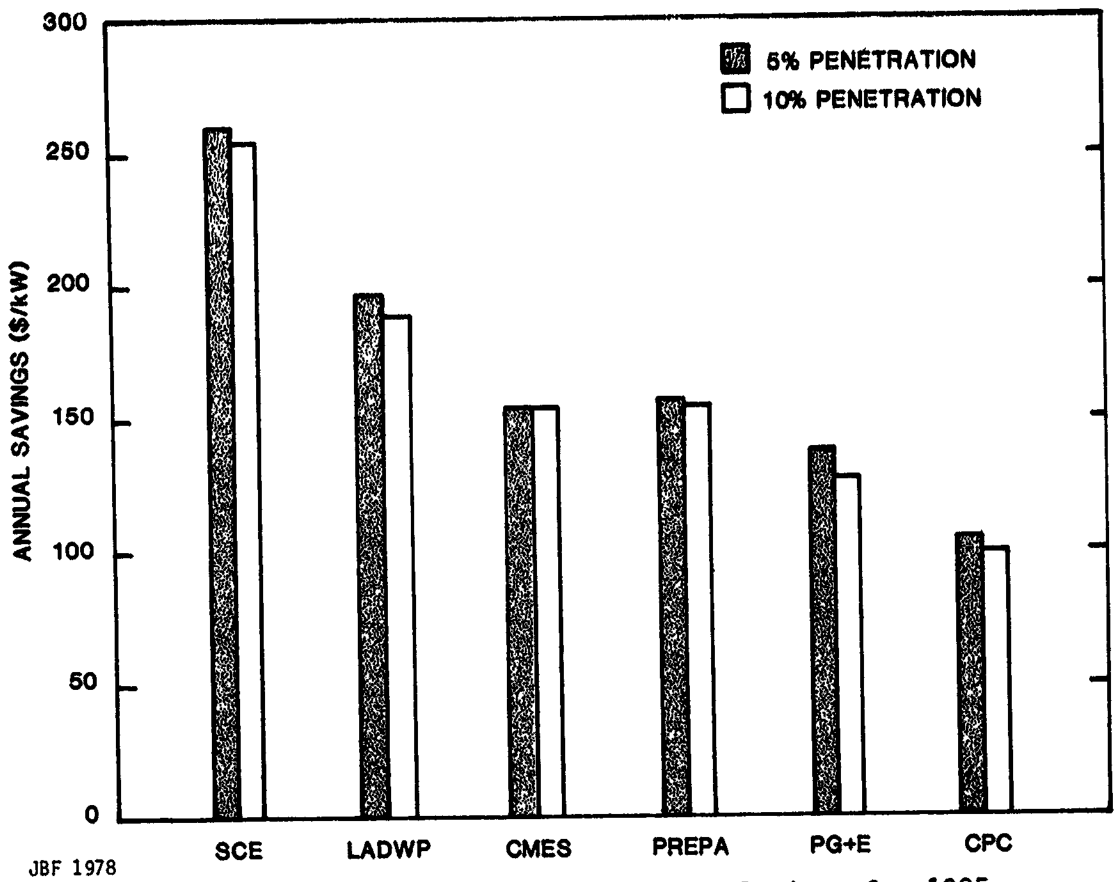

Figure 7. Projected Annual Utility Savings for 1985

In the section in which the method for determining economic value was discussed, it was pointed out that the value is determined by extrapolating the annual savings for the first year to an annual savings for each year of the life and, by the use of normal present worth techniques, converting them to an equivalent first year investment. This investment is equal to the value of the wind system. This process involves a series of calculations utilizing certain economic parameters relative to the particular utility and reflective of its financial structure and its projections of the future economic climate. A composite economic parameter which is used in these computations is the fixed charge rate. The fixed charge rate is essentially the projected equivalent uniform annual carrying costs of a similar plant investment made by that utility divided by the initial cost of the investment. Figure 8 is a graphical presentation of the fixed charge rates for each of the utilities in order of increasing rates. As might be expected, the two municipally owned utilities exhibit the lowest rates which is consistent with their ability to raise capital through borrowing at lower interest rates. Investor-owned utility systems must divide their capital requirements between borrowing and the higher cost process of issuing additional equity.

Indicative of these economic parameters, including the utility financial structure and fuel escalation rate projections and their use in

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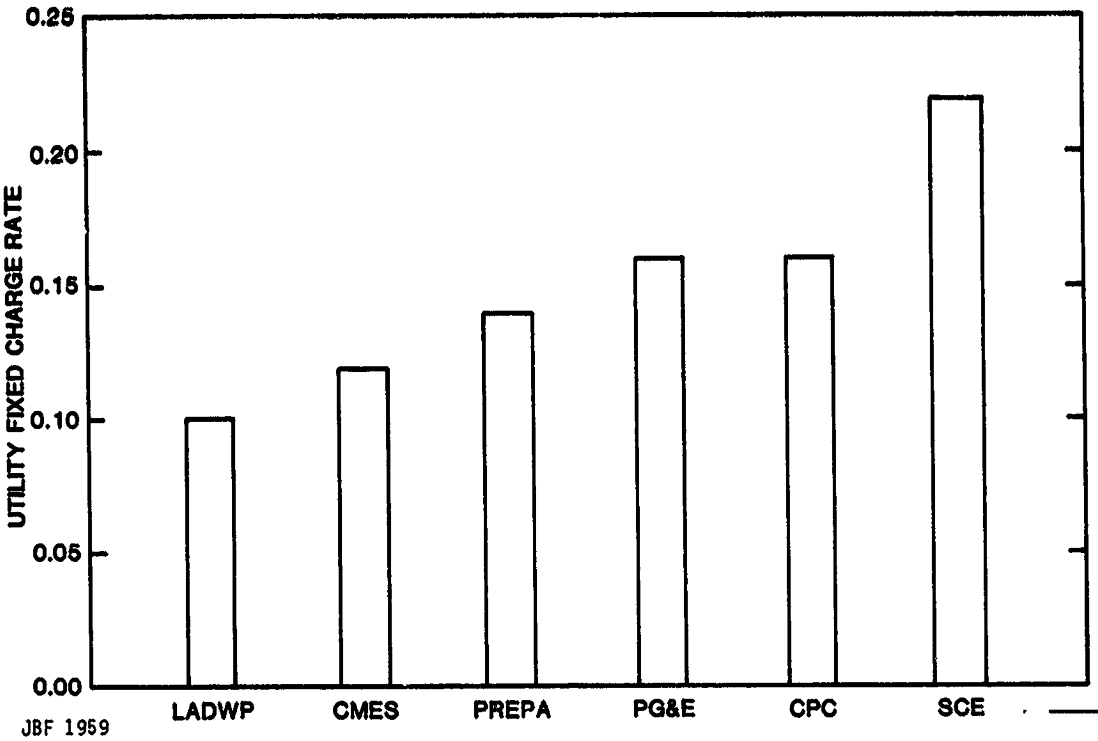

Figure 8. Utility Fixed Charge Rates

this process to determine the economic value of wind systems to a utility, is the value to savings ratio. The value to savings ratios are provided in Figure 9 in the same sequence as were the fixed charge rates. The inverse relationship does not hold true primarily due to the impact on the value determination of fuel escalation rates as used by the utility. Figure 10 provides a representative period of average annual fuel escalation rates by fuel type. It must be remembered that, with the exception of Consumers Power Company, most of the savings were produced by displacing oil generation, hence a comparison of the oil price escalation projections is most significant. Based upon the fixed charge rates alone, it could be expected that Southern California Edison would have the lowest value to savings ratio, and indeed that is the case. However, by similar logic one might expect that the Los Angeles Department of Water and Power would have the highest value to savings ratio, and that is not the case. A review of both their projected oil escalation rate and the Clayton Municipal Electric System projected oil escalation rate shows why they did not have the highest value to savings ratio.

Earlier it was indicated that three factors influence the economic value of wind systems to utilities. In the preceding paragraphs a comparison among the six utilities for each of the three factors has been presented. These factors combine to provide the economic value of wind system to the utilities. In Figure 11 the marginal value of wind systems for each of the utilities for 1985 is presented. Marginal value is defined as the value derived from adding one addition-

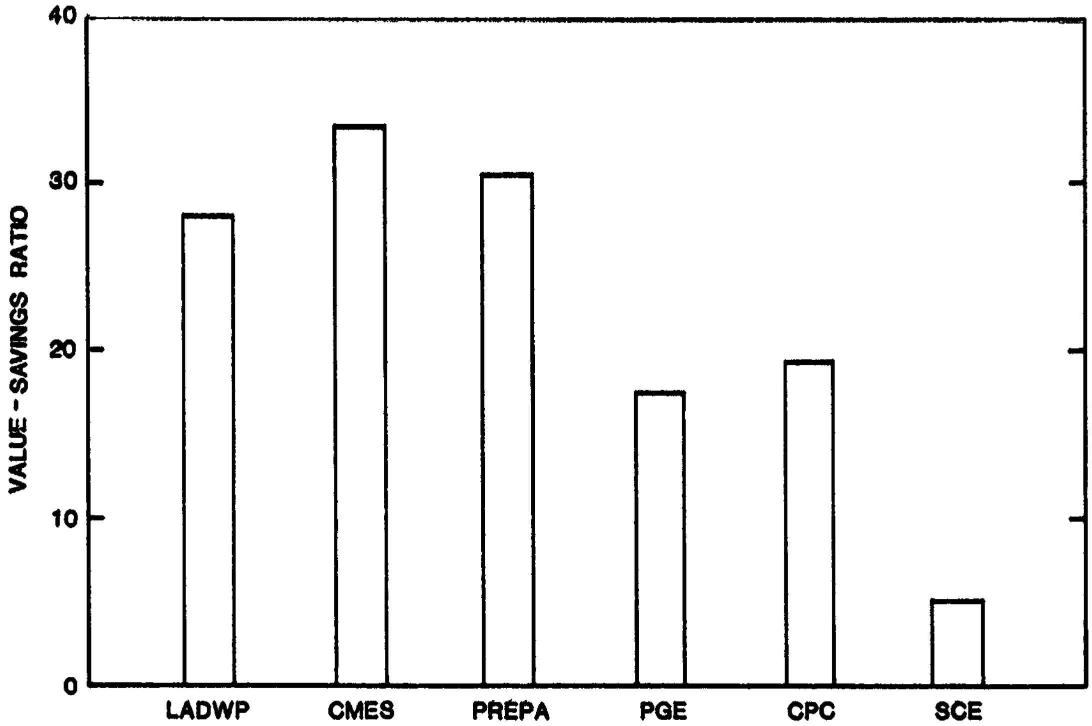

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Figure 9. Utility Value to Savings Ratios

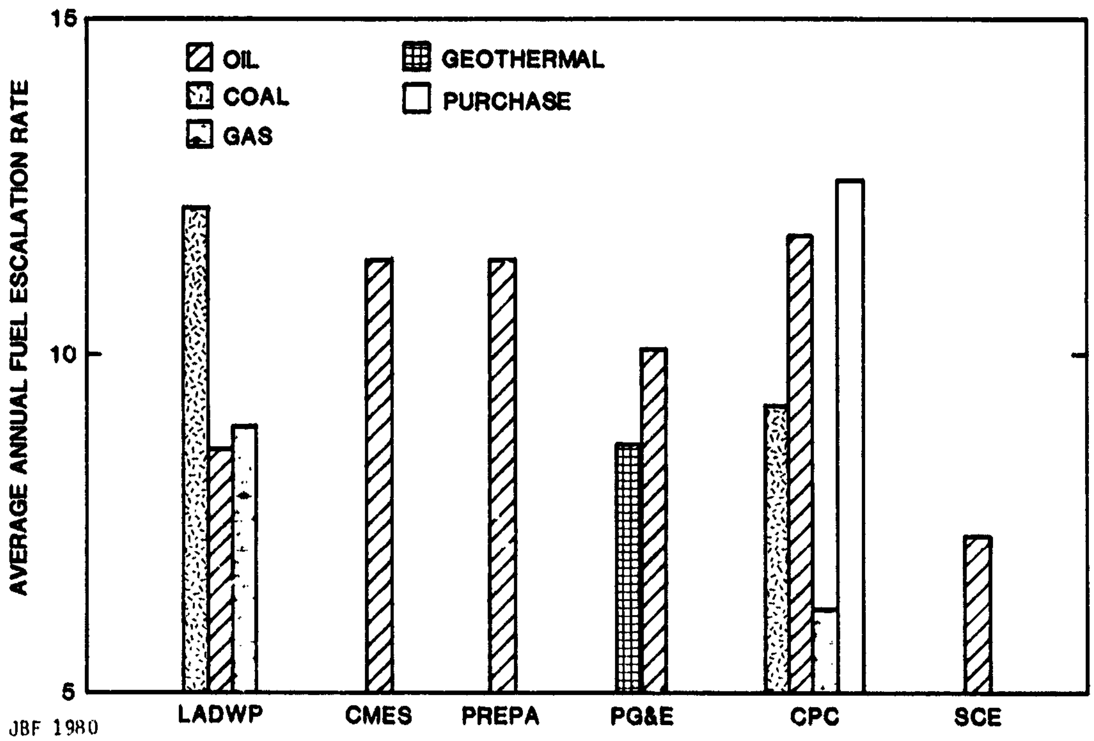

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Figure 10. Average Annual Utility Fuel Escalation Rates from 1985 to 1995

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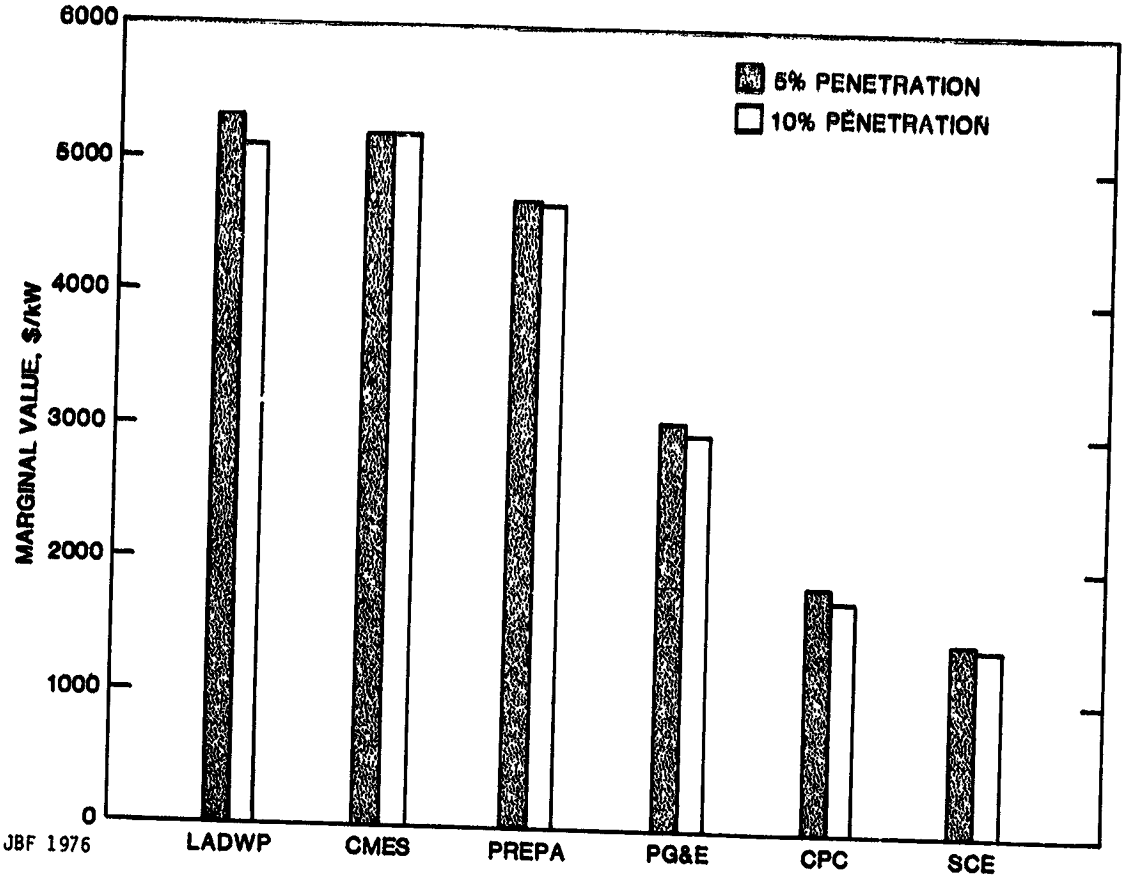

Figure 11. Marginal Value of Wind Systems for 1985

al wind unit to the penetration level for which it is expressed. The marginal value is provided for both the 5 and 10 percent penetration levels for 1985. These marginal values range from a high of over $5200 per kW for the Los Angeles Department of Water and Power at the 5 percent penetration level to a low of almost $1400 per kW for its neighboring utility system, Southern California Edison Company at the 10% penetration level.

Although both extremes present good values for wind systems, they provide an interesting case inasmuch as the analysis for each utilized the wind data from the San Gorgonio site and a simulation of the MOD-2 wind turbine, hence neither the wind resource nor the wind turbine contributed to the difference.

Figure 12 presents the marginal value of wind systems at the 5 percent penetration level for each utility for each of the three projected years of installation. The contribution of each of the three factors has been presented in the previous material for 1985. The analysis performed in the study provided the results seen in Figure 12. Not only have the marginal values changed for 1995 installations, but the different rates at which they have changed results in a different ranking among the six utilities for 1995.

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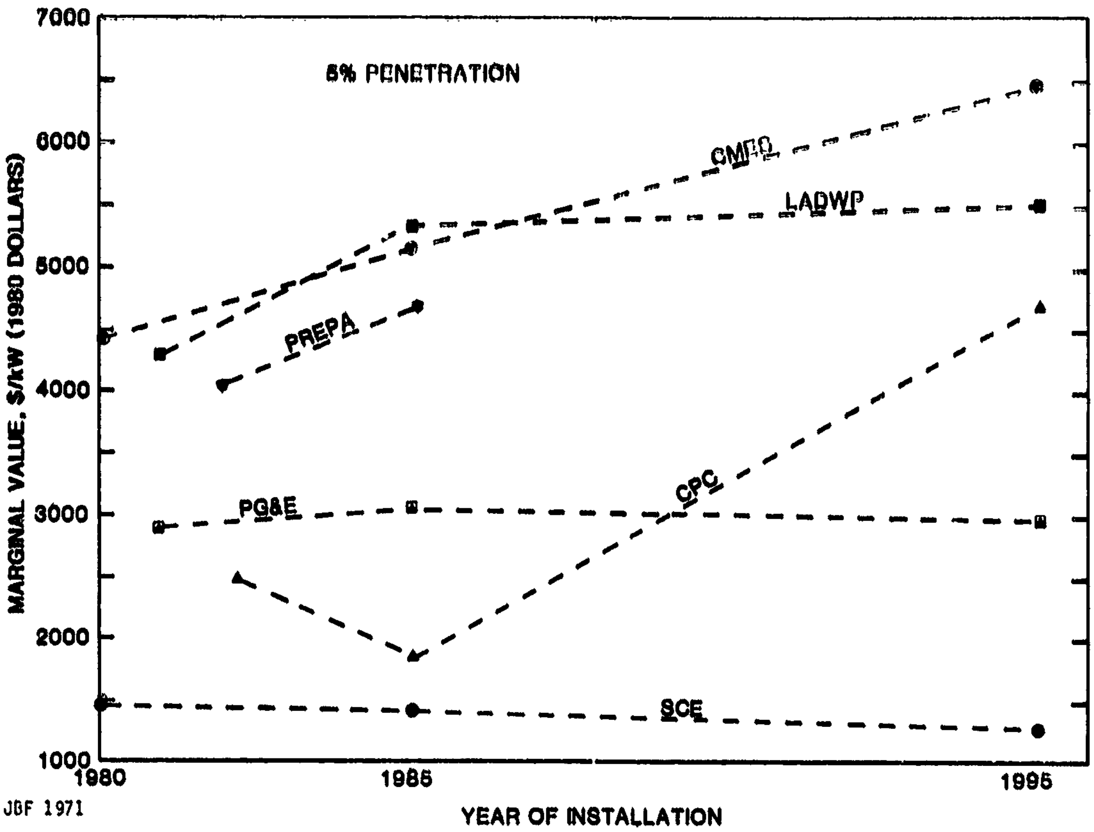

Figure 12. Marginal Value of Wind Systems vs. Year of Installation

There are several observations worthy of note that can be made relative to these results. It is normally expected that the economic value of wind systems to the utility will increase over time. The results for Southern Caifornia Edison run contrary to that expectation. Two factors that we have previously discussed explain this result. Southern California Edison is shifting away from oil in its projected generation mix and, therefore, some of the displacement in later years may be of fuels other than oil. Secondly, the fuel escalation rates that they provided were the lowest of the six utilities. The results for Consumers Power Company show a drop in value from 1982 to 1985 and then a substantial increase in value to 1995. The drop from 1982 to 1985 reflects an increase in the amount of coal generation displacement whereas the 1995 results reflect displacement of peaking oil units.

This paper has presented some of the preliminary results on the economics of wind energy for certain utilities. In addition, it has attempted to provide some insight into those factors which can contribute to the value of the wind systems to the utilities.