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INTERMITTENT SOURCES INTO
UTILITY PRODUCTION COSTING MODELS

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PROBLEMS IN THE INTEGRATION OF INTERMITTENT SOURCES
INTO UTILITY PRODUCTION COSTING MODELS

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Abstract - The intermittent generation source, a source over which the utility dispatcher has minimal control with regard to power availability, presents serious problems to the utility planner in terms of reliability, determination of worth, and inclusion in expansion plans. The problems involved with the integration of photovoltaic cells, wind machines, and other renewable sources with limited storage into utility production cost models are unfortunately a function of the different resources.

The problems are differentiated into those dealing with renewable resources which are correlated to the demand and those dealing with renewable resources which appear to act independently of demand. Solutions for the latter situation are given; approaches to solutions for the former are explored as is the practicality of the approaches.

INTRODUCTION

An essential input to any long range expansion plan by an electric utility is the future production costs of a particular expansion schedule with respect to a forecast of demand. The forecast is usually arranged in the form of a load duration curve (LDC) and then generation sources are dispatched against the curve. Conceptually the energy and capacity from the generation sources are modeled in a positive sense; that is, the load is regarded as a given and output from the source is matched against some part of this load. Fundamental to this treatment is the assumption that the generation source and demand are stochastically independent; the assumption implies that demand is not affected by availability of the generation source nor vice versa. That this is not so can be immediately seen in geographical regions in which a source has become unavailable. The Northwest has shown the ability to reduce demand below forecasted levels in periods of drought; likewise the elasticity principle is observable in other systems where fuel adjustment charges have been allowed to compensate for purchased power costs in the event of a prolonged outage of a generating plant. The conclusion is that demand is affected by the availability of the supply. Furthermore the forced outage rates for intermediate and

peaking plants are a function of demand; outage rates are a function of maintenance schedules and these schedules are greatly affected as one moves a plant from a lower usage to a higher usage category. Even the outage rates of baseload plants are greatly affected as maintenance schedules are changed in order to meet periods in which short-fall is expected due to unusual circumstances.

This lack of independence, however, is usually ignored in planning. The underlying philosophy is that an equilibrium exists during the planning period: elasticity affects the forecast only with regard to the expected costs of energy; outage rates for generation sources are assumed to be the average rates, rates which do not reflect unusual stress on machinery. The evidence is that the assumption of stochastic independence works very well in the modeling of conventional demand and conventional resources.

However, with regard to the intermittent source, a source over whose power availability there is little control, one cannot make the assumption of stochastic independence with regard to demand. In a previous paper [1], the authors have pointed out that even in the cases in which there is no deterministic relationship between the resource and the demand, there is still a correlation through time of day which cannot be ignored. For example suppose that for a particular system there is a constant demand of 300 MW uniquely from 3:00 A.M. to 4:00 A.M. and from 3:00 P.M. to 4:00 P.M. Also assume that expected wind resource availability is 5 m/s from 3:00 P.M. to 4:00 P.M. and zero m/s from 3:00 A.M. to 4:00 A.M. Without assuming any causality between the wind resource and the demand, we recognize that 50% of the demand at the 300 MW point of an LDC can at least be partially met by the wind resource and the other 50% will be unaffected. It is also true that the energy available from this 5 m/s wind resource is not transferable to any other point in the LDC without the existence of storage. Therefore the hour-by-hour correlation between the intermittent source and demand must be accounted for. This correlation will be divided into two categories: the correlation which can be regarded as only temporal and the correlation which is both temporal and deterministic.

RESOURCES WHICH ARE ONLY TEMPORALLY CORRELATED WITH DEMAND

In two previous studies [3,4] it was stated that there was no evidence of deterministic correlation between the wind resource and load in the regions studied. Therefore it was assumed that the wind velocity neither increased or decreased demand. There is some disagreement about whether this is a general principle. For a cold climate the increase in heat transfer due to wind velocity would argue against the principle; for a warm climate, the natural ventilation of increased wind velocity would affect at least residential air conditioning demands.

However, if one can assume correlation only through time of day, modeling difficulties are greatly reduced. The authors have suggested that the variability in intermittent source availability be accounted for within the hour; they have shown that appropriate LDC's can easily be constructed [1,2]. Distributions for this variation can be constructed from one of the following: adequate data if it is available, techniques used by Lindley and Melton [4], Rayleigh and Weibull distribution theory as discussed by Justus [5] in the case of wind, and yet-to-be-determined distributions in the case of other intermittent resources. In most cases of solar electric and solar thermal sources the relationship between demand and source will not just be temporal.

In order to make the calculations easy, the continuous distribution over wind velocity should probably be discretized into no more than 10 levels or bins. Power output as a function of the wind velocity level is calculated and the output is treated as negative load; that is, the output as a function of velocity, machine characteristics, and penetration is subtracted from the hourly demand. The probability of the velocity is multiplied by the uniform density over hourly demand and becomes the basis for the LDC. This procedure is summarized below.

$$\tilde{L}_A(h,1) = \tilde{L}_0(h) - f(\tilde{w}(h,1)) \quad (1)$$

$$\Pr[\tilde{L}_A(h,1)] = 1/n \Pr(\tilde{w}(h,1)) \quad (2)$$

$$\Pr[\tilde{L}_A = j] = \sum_{h=1}^n \Pr(\tilde{L}_A(h,1) = j) \quad (3)$$

where

$\tilde{L}_A()$ = the forecasted hourly load adjusted for the output from the intermittent source

$\tilde{L}_0()$ = the forecasted hourly load (although a mean value is usually given instead of a distribution)

$\tilde{w}()$ = the resource random variable as a function of the hour and discretized into levels

$f[]$ = the output as a function of the resource, technology and penetration

h = the hour

i = the discretized levels for the variation in output from source

$\Pr$ = Probability

n = the number of hours being considered

j = the common levels for the adjusted load

The increased computer time for the temporally correlated case is not very great. If one uses a maximum of 10 levels or bins and if one ignores the number of operations in calculating $f[\tilde{w}(h,1)]$, Equations (1) - (3) should increase the number of operations by $(3.0 \times 10^1)n$ where n is the number of hours in the period to be studied. The number of values which must be ranked in order to form an LDC are of course increased. We would suggest Equation (3) be ignored and the ranking done first. Then depending upon the mesh size needed in the computer routine to form the LDC, summation would take place after the ranking in order to approximate the LDC (i.e., if the mesh size is 1 percentile, the probabilities of the ranked points would be summed; as each percentage point is exceeded, the corresponding percentile point is determined from the L_A so that the LDC can be approximated).

In a previous paper [2], the authors have presented a Lemma which implies that uncertainty in the forecast is a matter of concern only in limited neighborhoods around the minimum and maximum values of the LDC. Essential to the result is that a straight line through the inflection point of the LDC gives a reasonable fit except for the upper and lower neighborhoods. (See Fig. 1). Assuming that only the upper and lower deciles are affected and that a 3σ error band around forecasted values is used, the uncertainty in demand would require $(3.2 \times 10^1)n$ additional operations plus another ranking of the upper and lower 10 percent of the LDC values. The conclusion is that the consideration of the variation in output from the intermittent source increases the number of computational operations by less than $(3.5 \times 10^1)n$ operations and the number of values to be ranked by $(1.2 \times 10^1)n$ (where n is the number of hours). The computer requirements receive a minimal increase.

RESOURCES WHICH ARE DETERMINISTICALLY CORRELATED WITH DEMAND

With solar electric and solar thermal generation sources, one must recognize that not only does the output from the intermittent source

Figure 1. Region in which variation in demand can be ignored

change with respect to insolation but so might the demand. Since one of the factors which affect temperature is insolation, demand may reflect increased air-conditioning usage or decreased heating requirements depending on the season and the locale. Functional relationships between temperature and load have been studied and are usually incorporated in forecasting models [6,7].

The forecast is partially based on the mean temperature forecast for the period. To the degree that a resource like insolation affects the load forecast, we propose to adjust this hourly forecast to reflect both the functional change in demand as a result of resource variation and the amount of demand which will be supplied by the varying levels of output from the intermittent source. These adjustments are summarized below:

$$\tilde{L}_A = L_0 + f(\tilde{I} - \mu_I) - g(\tilde{I}) + \tilde{\epsilon}_0 \quad (4)$$

where

$\tilde{L}_A$ = is the adjusted hourly random variable for the demand

L_0 = is the original hourly forecast

$\tilde{I}$ = the random variable for the resource over the hour (e.g. insolation)

μ_I = the hourly mean of the resource

$f(\)$ = the functional relationship between the intermittent resource and demand; $f(\)$ is defined so that when $\tilde{I} = \mu_I$, $f(\) = 0$

$g(\)$ = the functional relationship between the intermittent resource and the power output from the generation

source; the relationship is a function of both technology and penetration

$\tilde{\epsilon}_0$ = the random variable for error

Equation (4) states that there are two adjustments needed for the deterministically correlated situation: the native demand must be adjusted for both the resource change over the hour and the energy supplied by the intermittent source. The L_0 in Equation (4) is really the mean value for the load for the hour. The reality of the situation is that this demand is really a random variable and can be written as a function of the resource under consideration and other parameters:

$$\tilde{L}_0 = h(\tilde{I} - \mu_I, \tilde{X} - \mu_X) + L_0 + \tilde{\epsilon}_1 \quad (5)$$

where

$\tilde{L}_0$ = the random variable for load

$\tilde{X}$ = the vector of random variables other than the resource under consideration upon which forecasts are made

$h(\)$: the functional relationship for the forecast;

$$h(\) = 0 \text{ when } \tilde{I} = \mu_I \text{ and } \tilde{X} = \mu_X$$

Since $h(\)$ is assumed to be symmetrically distributed around zero, it has been ignored in most approaches to production costing; in fact the mean value is most often used. However, the assumption of a deterministic relationship between load and resource implies that systematic error is introduced by only considering adjustment for the output from the source. Therefore the assumption is made that the effects of the resource I and the other parameters are independent and additive. Equation (5) then is rewritten as

$$\tilde{L}_0 = f(\tilde{I} - \mu_I) + v(\tilde{X} - \mu_X) + L_0 + \tilde{\epsilon}_1 \quad (6)$$

The second and fourth terms become the $\tilde{\epsilon}_0$ of Equation (4):

$$\tilde{\epsilon}_0 = v(\tilde{X} - \mu_X) + \tilde{\epsilon}_1 \quad (7)$$

and the assumption is made that the distribution for $\tilde{\epsilon}$ retains symmetry (The stronger assumption used in forecasting is of course normality).

The problems which one faces in evaluating Equation (4) are numerous. Solutions to some of them are close to being formalized; others are still awaiting the necessary data acquisition. We will enumerate some of the problems.

a) The distributions for $\tilde{I}$. Although previous studies have not discovered any deterministic

relationship in the case of the wind resource, there are locales where this relationship may show up. As pointed out earlier there is good resource data at certain sites for the wind resource. For others the analyst is dependent upon Rayleigh or Weibull distribution theory. For insolation there is very little data for distributions over an hour. The SOLMET data is an hourly average and in many cases twenty-two years of data exists. One could build an approximating distribution over an hour using the twenty-two years of data. If one were prepared to assume that for a week at a specific hour, the random variable for insolation was identically distributed and independent, then one could increase the data base as was done by Lindley and Melton with wind data [4]. It seems apparent that this distribution built on hourly averages would lack the extrema of variation that actually occurs. The Energy Resource Assessment Branch at SERI has been studying the distribution over the hour through direct measurement. The preliminary findings seem to point to a truncated Weibull distribution. In those areas and during those seasons in which puff-type clouds are common, strictly theoretical considerations would point to insolation shading from a puff cloud as a Poisson event and the waiting time for cloud passage as being distributed according to a Gamma distribution.

We would like to point out that the occurrence of an insolation level above or below the mean value can be of very different types depending upon duration. As will be pointed out later, a brief decrease in insolation level has an entirely different effect on the heating requirements of a building than the same decrease over an hour's duration.

b) The relationship between the resource and the demand.

- 1) Data concerning the actual relationship are almost non-existent for some of the re-sources. In the case of insolation, temperature is a function of insolation but it is also a function of a great many of other parameters. For some systems the relationship between demand and temperature is well-known. However, we are unaware of any work in the area of insolation and load. SOLMET data could be used to determine this but at present all we are able to say is the effect of insolation variation should be less than that for temperature. Since variation from the forecast is partially due to temperature excursions, the following holds:

$$\sigma_f^2 = \alpha \sigma_L^2 \quad 0 < \alpha < 1$$

where

σ_L^2 = the variation for the forecast

σ_f^2 = the variation due to insolation

The use of a linear equation to express the change in load due to resource variation might be adequate for the present purposes. The heuristic argument that demand response to temperature is asymptotic due to limitations on heating and cooling machinery would imply that the fit would be poor if the region of response is not closely bounded.

- ii) It is quite possible that for some re-sources this change in load due to change in resource level can be treated as a second order effect and hence, be ignored. This seems to be the situation with increasing penetrations. The problem is that we lack evidence for most resources to support the contention.

For the insolation case we have already noted that its effect is less than that of temperature. We also note that there are two entirely different occurrences which make up a drop in insolation level during a day: prolonged cloud cover and transient shading due to cloud movement. Load response due to heating requirements in the former case is quite likely; in the latter case, the inertia in air mass of a large building would make immediate response improbable. If one has to account for a lag variable for this case, the difficulty in modeling escalates considerably. The point to be made is that $f(\cdot)$ in Equation (4) does not behave like a mathematical function but rather as a relation for the insolation resource: the same level gets mapped into two different demand responses.

- iii) The final difficulty which we wish to point out is that in studies whose purpose is to compare expansion plans, the base case and the intermittent resource cases will have to reflect the deterministic relationship of demand and resource. For comparative value analyses failure to include the relationship in the base case would bias the comparison.

With regard to increase in computer usage the deterministically correlated case increases computation in the production cost routine minimally. The actual increase is, of course, dependent on the form of $f(\cdot)$ in Equation (4), but a linear relationship would increase operations by $(2 \times 10^4)n$ over the temporally correlated case. The real increase in computer usage comes from the processing of data to determine the form of $f(\cdot)$.

Finally, assuming that the error term in Equation (4) is symmetric allows the consideration of the variation in forecast after the LDC has been formed. As in the temporally correlated case, if the shape of the LDC allows a fairly good fit as a straight line through the point of inflection only the extrema of the LDC must be adjusted for variation in demand.

CONCLUSIONS

Due to the intermittency of power output, many of the renewable resource technologies do not lend themselves to the modeling assumptions of conventional production cost models. Presently, most studies have ignored the variation due to intermittency and have opted for hourly average values as an approximative. However, the conceptual framework of load duration curves (LDC) allows for the handling of variation of output without any changes in the conventional models. By adjusting the hourly demand values with a distribution over the power output, an LDC can be formed in much the same way as is presently done with hourly averages. The practical problems concern the availability of data and distribution theory for the resource itself. The situation in which there is a deterministic relationship between resource and demand presents the special problem of determining a mathematical form for this relationship. The increase in computation steps for the adjustment to the load is small when compared to the number of steps used in most production cost models.

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