POWER PLANT COOLING WATER TEMPERATURE PREDICTION - SUBJECTIVE VERSUS COMPUTERIZED ANALYSIS TECHNIQUES

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INTRODUCTION

There is a tendency today to overlook the value of subjective, intuitive approximation techniques for the solution of any particular problem. Rather, the tendency is to depend upon computerized analysis techniques for any and all solutions. The following description of a research project, initiated by New England Power Company, demonstrates the value of approximate analysis methods.

THE PROBLEM: POWER PLANTS MUST MEET DISCHARGE TEMPERATURE LIMITS SET BY NATIONAL POLLUTANT DISCHARGE ELIMINATION SYSTEM (NPDES) PERMITS

For power plants with once-through condenser cooling, the problem of maintaining maximum generation levels, while meeting environmental discharge temperature limits, is becoming relatively familar. Generation levels during peak demand periods must often be suddenly reduced to meet these temperature limits. This results in the loss of thousands of dollars. A 24-hour advance prediction of discharge temperatures would help indicate when such reductions in generation levels will occur. Plant reliability could, therefore, be increased. More importantly, this prediction capability could actually save some of the dollars lost due to these generation level reductions. It would indicate when scheduled plant generation levels might be discharge-temperature-limited during peak demand periods on the following day. Knowing this fact, generation levels could instead be reduced during the night off-peak demand hours. This would greatly diminish the magnitude of any generation level reductions during the next day's peak demand periods. In any given instance, implementation of this procedure would cost no more than if the procedure had not been used at all. The procedure is generally applicable at plants located on tidal bays with less than 100% flushing rate.

SOLUTION APPROACH: DEVELOP DISCHARGE TEMPERATURE PREDICTION CAPABILITY

A research project was initiated by the Company to:

1. Determine that 24-hour advance prediction of cooling water discharge temperature is possible.
2. Determine that application of such a prediction system is economically justified.
3. Develop a prediction system.

The Company's Salem Harbor Generating Station, in Salem, Massachusetts, was selected as the study site. Data routinely collected at the plant would be used to develop the discharge temperature prediction system. The plant itself is a 790 megawatt (MW) fossil fuel generating facility, having four generating units (85, 85, 155, and 465 MW capacities). Seawater, taken from Salem Harbor, is used for once through cooling of the generating unit condensers. This cooling water is discharged back into the harbor via a common discharge canal, 1000 feet in length. The flow rate is 420,000 gallons per minute. Under the terms of the plant's National Pollutant Discharge Elimination System Permit, the discharge temperature cannot exceed 90°F at any time. Also, the delta T between intake and discharge temperatures cannot exceed 20°F. The normal delta T of the plant at full capacity is 17 - 19°F. When the intake temperature exceeds 73°F, generation levels must be reduced to keep the discharge temperature below 90°F. This generally occurs early on summer evenings, when the demand for power is at its peak. The plant is located on the northwest shore of Salem Harbor, which is a coastal bay with a Mean High Water volume of 640 million cubic feet. It has a nine foot tide range, an intertidal volume of 338 million cubic feet, and a tidal flushing rate of 50%. This means that 50% of the heated water in the Harbor at any given time will remain there through the next tidal cycle. Heat can, therefore, be withheld from the harbor by reducing generation levels during off peak demand periods. This will cause lower intake temperatures for as much as 18 hours following the reduction, allowing higher generation levels during the next peak demand period.

Work began on the project with an economic justification of discharge temperature prediction capability. This was followed by evaluation of various prediction methods. The first of these was an intuitive approximation approach suggested by a Company employee. Other methods, involving increasing degrees of sophistication, were also studied. The results of the studies to date are presented below, followed by a discussion and enumeration of the obvious conclusions.

RESULTS

Judicious application of a discharge temperature prediction system can save the Company $10,000 per year at Salem Harbor Generating Station.

Table I compares the results of the intuitive approximation, polynomial curve fit, and multiple regression curve fit temperature prediction methods. Both accuracy and development cost comparisons are presented. Where several different computer runs were completed for a particular method, the accuracy shown is the best that was obtained. "Incremental Development Cost" refers to the additional cost over the previous method to achieve the stated results.

DISCUSSION

The value of the intuitive approximation method is immediately obvious from Table I. The most sophisticated method evaluated to date has not yet achieved the accuracy of the approximation method. Yet the development cost has been more than five times that of the approximation method.

It should be noted that the intuitive approximation method was used to predict plant cooling water intake rather than discharge temperature. This was done because a method already existed to calculate the discharge temperature, once the intake temperature was determined. Also, only the next day's highest or peak intake temperature was predicted. Since the approximation method was a first attempt at prediction, it was felt that off-peak values would only be interpolations from the peak, and therefore, less accurate. Both the peak intake and discharge temperatures were predicted using the computerized polynomial curve fit method. Accuracies of both were low enough that prediction of the hour of peak temperature was not attempted. Only the peak discharge temperature was predicted with the computerized multiple regression analysis. It was felt that all of the variables affecting both intake and discharge temperature could be included simultaneously in this type of analysis.

Economic Justification for Prediction Capability - From January 1 through August 16, 1974, reduced generation levels, due to discharge temperature limits at Salem Harbor Generating Station, cost the Company as much as $129,000. This figure is based on a peak demand period differential replacement power cost of $10.00 per megawatt hour (MWH). Tests at the plant show that a unit #4 generation reduction of 1350 MWH at night (off-peak demand period) will result in at least a 1.0° F intake temperature reduction through the following day. This will allow increased generation of 47 MW during each hour that generation is discharge-temperature-limited. This reasoning was applied to each generation level reduction greater than 47 MW, from January 1 through August 16, 1974. The cost of a 1350 MWH night time generation level reduction was compared to the savings from a 47 MW increase (peak demand period) in generation level for the duration of each reduction incident. Using an off-peak demand period differential power cost of $1.00 per MWH, the Company could therefore have saved $19,000 from January 1 through August 16, 1974. However, differential power costs often are somewhat more and less than $1.00 and $10.00 per MWH, respectively. Therefore, the $19,000 result was generalized to say that prediction capability would allow the Company to save $10,000 per year, at Salem Harbor Generating Station.

Intuitive Approximation Method - As described previously, Salem Harbor is a coastal bay with tidal flushing rate of 50%. The plant cooling water intake temperature at any given time is dependent upon a number of factors: solar radiation, tidal stage, plant generation level, wind speed, and wind direction. The values of all of these factors for some hours prior to the time of intake temperature observation are of chief importance. The discharge temperature is then a function of intake temperature, generation level, and amount of cooling water flow at the time of observation. This can be calculated with excellent accuracy by any number of methods. Consequently, the approximation method was developed to predict the plant intake temperature. Also, for reasons described previously, only the next day's peak intake temperature was predicted by this method.

In general, the next day's peak intake temperature is obtained by starting with the present day's peak. Increments of temperature are then added to or subtracted from this value, for each of the factors which effect the intake temperature. These increments are obtained in the following manner:

TABLE I: PREDICTION METHOD ACCURACIES AND DEVELOPMENT COSTS

METHOD	PREDICTED VARIABLE	ACCURACY RANGE	PREDICTIONS WITHIN RANGE	INCREMENTAL DEVELOPMENT COST
INTUITIVE APPROXIMATION	Peak Intake Temperature	± 1.0° F	43%	$1,000
	Hour of Peak Intake Temperature	± 1.0 hour	75%	Developed in Conjunction With Above
POLYNOMIAL CURVE FIT	Peak Intake Temperature	± 1.0° F	11%	$3,000
	Peak Discharge Temperature	± 1.0° F	33%	Developed in Conjunction With Above
MULTIPLE REGRESSION	Peak Discharge Temperature	± 1.0° F	34%	$1,500
	Hour of Peak Discharge Temperature	± 1.0 hour	60%	Developed in Conjunction With Above

1. Solar Radiation
   If the next day will be mostly sunny (greater than 6 hours of sunlight) add 1.5° F.
   If the next day will be mostly cloudy (especially after 12:00 noon) subtract 0.5° F.
   If the next day will be mostly cloudy and rainy, subtract 0.7 to 1.0° F.
2. Tidal Stage
   If the next day's peak intake temperature will occur during ebb tide, add 0.1 to 0.2° F.
   If the next day's peak intake temperature will occur during flood tide, subtract 0.1 to 0.2° F.

3. Plant Generation Level
   The relationship between plant generation level and intake temperature is quite complex. In general, a drastic change in generation level, lasting for at least three to four days, will affect the intake temperature by as much as 2.0 to 3.0° F. It has been definitely determined, however, that the next day's peak intake temperature can be reduced by at least 1.0° F. This is accomplished by a 1350 MWH reduction in the plant's #4 unit generation level the night before.
4. Wind Speed and Direction
   If the 24-hour average wind speed prior to the next day's peak intake temperature is expected to be less than 11 MPH, wind effect can be ignored.
   If the 24-hour average wind speed prior to the next day's peak intake temperature is expected to be between 11 and 14 MPH, with the average direction from the southeast, add 0.5 to 1.0° F.
   Same conditions as above, but average speed greater than 14 MPH, add 1.0° F.
   If the 24-hour average wind speed prior to the Next day's peak intake temperature is expected to be between 11 and 14 MPH, with average direction other than from the southeast, subtract 0.5° F.
   Same conditions as above, but average speed greater than 14 MPH, subtract 0.5 to 1.0° F.
5. Hour of Peak Intake Temperature
   Add 1.0 hour to the present day's peak hour.
   If the present day's peak occurs at each of two non-consecutive hours after 12:00 noon, use the earlier hour.
   If the present day's peak occurs between 1:00 AM and 12:00 noon, use the next highest peak hour after 12:00 noon.
   As a check on the above, if a high or low tide will occur between 3:00 and 6:00 PM the next day, the peak temperature will usually occur at 6:00 PM or slightly earlier; if a tide will occur between 7:00 and 9:00 PM the next day, the peak Temperature will also usually occur between those hours.

It can be seen from the ranges of incremental values above that experience is a factor in applying this method. Nevertheless, the method was used to make daily predictions of plant intake temperature from June 1 through July 31, 1974. The accuracy of these predictions provided the values shown in Table I. It should also be noted that the incremental temperature values were developed during the summer months. These would be slightly different during other seasons, due to the difference in solar radiation levels.

Polynomial Curve Fit Method - The possibility existed that either the intake or discharge temperature depends primarily on a single factor. Consequently, a number of runs were made using a computerized polynomial curve fit technique. This computer program uses the least-squares method to fit observations of a single dependent variable to corresponding observations of a single independent variable. Both intake and discharge temperature (for the period from August 12, 1973, to August 12, 1974) were separately included as the dependent variable in this analysis. The following factors were individually considered as the independent variable: solar radiation, wind speed and direction, plant generation level, and the previous day's peak discharge temperature.

The best accuracy with this method was achieved by the fit of peak discharge temperature to the previous day's peak discharge temperature. This is to be expected, since the peak discharge temperature generally varies by only 2.0 to 3.0° F from day to day.

Multiple Regression Analysis - The various factors affecting plant intake and discharge temperature were next incorporated in a computerized, linear multiple regression analysis. This computer program uses linear regression methods to fit observations of a single dependent variable to corresponding simultaneous observations of multiple independent variables. The study considered peak discharge temperature as the dependent variables. The independent variables from the polynomial curve fit runs were added one at a time to sequential runs of the multiple regression program. The order of inclusion was based on the degree of accuracy achieved for each independent variable in the polynomial curve fit runs. Some additional factors, such as tidal stage, daily cooling water volume through the plant, and the previous day's peak discharge temperature, were also considered as independent variables.

The best accuracy using this method was achieved with the fit of peak discharge temperature to the following independent variables: solar radiation, plant generation level, wind speed and direction, daily cooling water volume through the plant, previous day's peak discharge temperature, time of the peak discharge temperature after high tide, and time of peak discharge temperature after low tide.

Work in Progress - An accuracy of ± 1.0° F, at least 90% of the time, is believed necessary to control generation at Salem Harbor Generating Station, using the discharge temperautre prediction system. It is felt that a complex, hybrid multiple regression/hydrological analysis computer model is required to achieve this accuracy. Consequently, a $15,000 contract has been awarded to consultants to provide such a model.

CONCLUSIONS

1. An intuitive approximation method, for 24-hour advance prediction of power plant cooling water discharge temperature, has achieved ±1.0° F

accuracy almost 50% of the time.

2. More sophisticated, computerized methods have not yet achieved the accuracy of the approximate method.
3. The approximate method was developed at less than one-fifth the cost-to-date for development of the more sophisticated methods.
4. It has been demonstrated that 24-hour advance prediction of power plant cooling water discharge temperature is possible.
5. At New England Power Company's Salem Harbor Generating Station, 24-hour advance prediction of cooling water discharge temperature can save up to $10,000 per year.