OPTIMIZING EFFICIENCIES OF MULTIUNIT HYDRO PLANTS

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ABSTRACT

A technique to optimize the efficiency of any multiunit hydropower plant is described. This simple, easy to use, accurate, versatile, Personal Computer (PC) based technique provides the information for loading of individual units to allow any hydro project to operate at maximum efficiency. This results not only in maximum energy generation which maximizes revenues and/or minimizes water use, but may also result in reduced mechanical wear on the machinery, decreasing Operation and Maintenance (O&M) costs. Since the survivability of downstream migrant fish passing through hydraulic turbines is a function of turbine efficiency, this technique also provides for maximum fish survival.

INTRODUCTION

The economic success of any hydroelectric project depends on two factors: the cost to generate energy and the revenue derived from the sale of that energy. One aspect of maximizing revenue is to maximize energy production by optimizing efficiency. In the development of a project, considerable effort is generally expended to purchase, construct, and install efficient generating equipment. However, it is the optimum use of this equipment that determines the overall efficiency of energy production. Optimizing the efficiency of energy production has a synergistic effect in also lowering the cost to generate energy. First, by

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virtue of reduced vibration, cavitation, etc., the operating life of the equipment tends to be extended. Secondly, the environmental costs of generation are reduced, for the survivability of downstream migrating fish that happen to pass through the turbines is also maximized.

MAXIMIZING REVENUES

Each turbine/generator has a combined, unique, convex efficiency curve in terms of power and head. Consequently, in any multiunit hydro plant there is a unique load or operating point for each unit which maximizes the efficiency of the plant for a given total load. Expressing this operationally, there is a unique wicket gate setting for each unit, even for similar units, which allows the power plant to produce the most energy for a given flow at a given head.

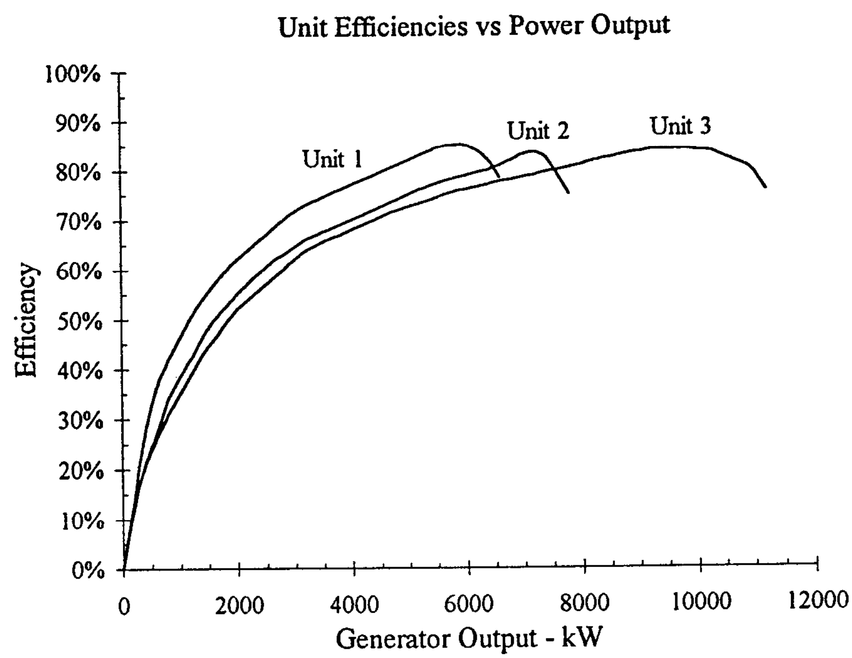

Figure 1 - Graph of 3 Unit Efficiencies

A simple, accurate, easy to use technique was recently developed which allows for the optimization of the generating efficiency of any hydropower plant containing any number and type of units, operating under any conditions. This technique may be used manually, but is readily suited to a Personal Computer (PC) for ease of use and maximum accuracy. In the application described herein, it was adapted to the popular Windows environment and completely programmed to be used at any powerhouse provided that the individual unit efficiency curves are available.

EFFICIENCY CURVES

The efficiency profiles of the individual generating units are required input to this optimization technique. However, they are not part of the technique itself and consequently may be changed at any time such as after each turbine efficiency test. These efficiency profiles may be based on absolute or relative (index) test data and at single or multiple heads. The terms absolute and relative efficiencies denote whether the flow rates were determined in absolute or relative terms. When a flow rate is measured in absolute terms, its volume flow rate is measured in units such as cubic feet per second. Flow is normally the most difficult to measure of the parameters needed to determine efficiency. Consequently, flow is often measured relative to some other parameter such as a pressure differential or a head loss and efficiency is then "indexed" to that relative parameter.

The results of this optimization technique can be accurate to any degree specified. However, the resulting optimization can only be as accurate as the accuracy to which the combined turbine/generator efficiency profiles have been determined. Therefore, to be no less accurate than the profiles, the first objective or task of this technique is to accurately enter the efficiency profiles as data. This has two inherent difficulties. First, efficiency profiles can have various erratic, nonuniform shapes that no computer curve fitting program to any nth degree polynomial can exactly replicate. The alternative therefore is to attempt to enter the performance data in tabular form. This may allow a good replication of the shape, but at each tabular point, no matter how graphically accurate it and its adjacent points are read, there is a minute discontinuity of the slope on each side of a point compared to the other.

To use this new optimization technique, these difficulties are overcome by two methods. First, the efficiency profile itself is not entered as data. Instead, the "smooth curves" of power versus wicket gate servo stroke and flow versus wicket gate servo stroke are entered. These are both well behaved curves with continuous positive slopes in which the lower portion is invariably a straight line and in the upper portion the slope decreases with increasing servo stroke. The smooth curves themselves are entered by reading their graphic values at closely spaced intervals, as close as every one percent of servo stroke. Then a series of overlapping, curve fitting polynomials is calculated for each segment of these curves. The overlap is done to achieve a continuity of the slope at the transition between segments. Next, the performance data part of the program interrogates each of these smooth curves at identical values of servo

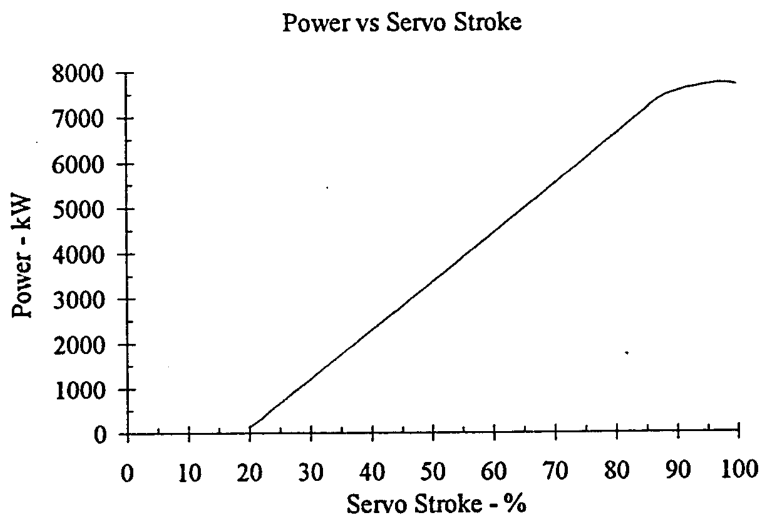

Figure 2 - Graph of Power vs Servo Stroke

stroke and forms the ratio of power to flow, which when multiplied by head and appropriate constants equals efficiency. Finally, the program plots these calculated, smooth, efficiency values against power and also versus flow. The resulting efficiency curves with which the technique now has to work have smooth continuous slopes over their full range and replicate the originals within the accuracy of the original measurements.

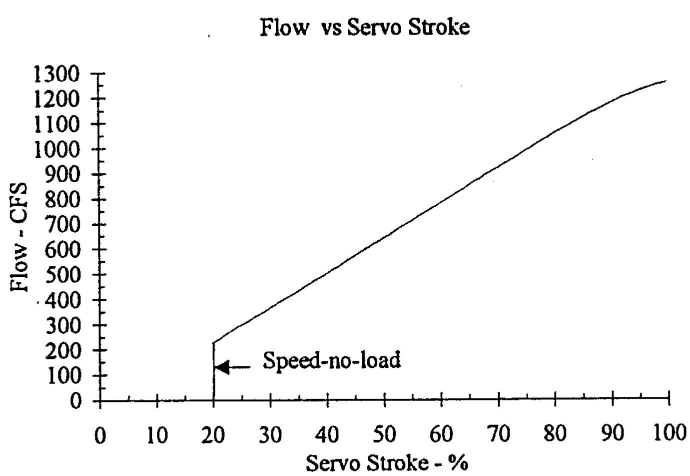

Figure 3 - Graph of Flow vs Servo Stroke

HEAD VARIATIONS

The efficiency profiles are determined on a constant head basis since the smooth curves are all entered on a constant head basis. Where test data is available at more than one head, the performance data part of the program uses interpolative procedures to determine the values at various intermediate heads. When field test data from only one head is available, the program's data routine uses the "affinity laws." These similitude laws predict that for constant servo strokes, flow changes by the square root of the head ratio and that power changes by the head ratio to the 3/2 exponent. The affinity laws are a linear relationship and therefore are valid over only a narrow range of head variation. Their accuracy decreases as the head variation increases, inducing curvilinear relations. Again the technique's optimization can be no more accurate than both the data and extent of actual data coverage with which it has to work.

EXISTING CONDITIONS

The basic program screen in this particular Windows application is divided into two identically formatted regions. One region represents the existing or present condition of each unit and the powerhouse as a whole. First, for bookkeeping purposes, any bypass or diversion flows which do not discharge through a unit are manually entered and any unit may be designated as off-line or shut down by "double-clicking" the unit number. The user may next enter the unit values desired and after checking for errors, the program accepts whatever is entered. A unique, versatile feature of this part of the program is that aside from forebay elevation, which is required, the operator needs to enter only two values for each generating unit. For example, a unit's power output and wicket gate servo stroke need only be entered by the operator. Due to the physical nature of hydraulic machinery, these or any two of the other listed values define a unique, singular operating point for each unit. Consequently, the program will compute and display the corresponding missing values of, for this example, plant tailwater and unit flow and then summarize the values for all units as combined unit flow. After next computing total plant flow by adding bypass flow, the program then computes total plant power output and plant efficiency. The latter is presented in its two usual forms, both as a percentage and as a ratio of power to flow (KW/CFS).

OPTIMIZATION

The other screen region is the heart of this optimization technique. The operator may optimize either the existing condition or any other, future condition. In addition, the optimization may be done for either a specified total plant flow or total plant power output. If the present conditions are to be optimized, the user simply clicks on "Copy Present to

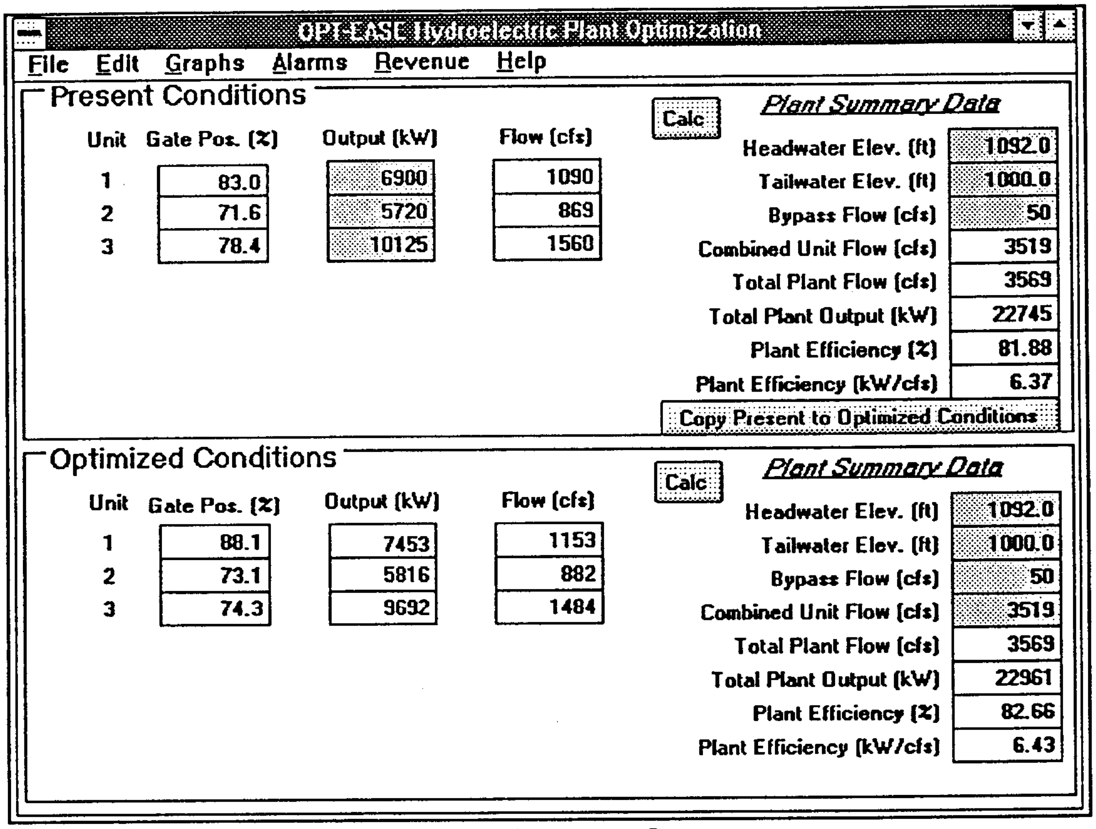

Figure 4 - Program Screen

Optimized Conditions", enters either the existing total power output or total flow on the lower half of the screen, and clicks on the "Calc" button. The program assumes the same forebay and tailwater elevations exist and provides the individual unit loadings to optimize the total plant output. This optimum solution may even include taking additional units off-line, but will not include restarting units the user has already specified as shut down. Again, the user may designate a particular unit or units as shut down (not available for operation) by "double-clicking" the unit number.

In hydropower plant scheduling knowledge of future conditions is often desired. For example, in a typical scenario in a few hours it is known that a downstream project is going to curtail generation to store water which will increase our project's tailwater elevation. The user need simply input the new tailwater elevation and the desired total powerhouse flow or power output and click on "Calc." Again, the program provides the individual unit loadings to achieve the optimum powerhouse efficiency for this new specified future condition.

The actual optimization technique is simply one of repetitive comparisons and eliminations. The heart of the technique is a matrix composed of the individual generating units initially available to enter the optimization procedure. The starting point for each unit in this matrix is derived proportionally so that each is as relatively close to its individual peak efficiency as every other. Then, an incremental increase and decrease in either power or flow is made for each unit and then the pair of units with the best combined increase in efficiency, but the same total power or flow, is selected. These new power or flow values are substituted into the matrix and the process is repeated. This optimization continues until no further improvement is available, depending on the size of the user specified solution increment. One of the several advantages of this particular optimization technique is that it uses only the magnitude of efficiency values at the various points, not slopes or derivatives of the curves. This not only allows for a very high degree of solution accuracy, but largely eliminates the possibility of false solutions.

ANCILLARY FEATURES

To provide a continuous reference to the value of powerhouse efficiency optimization, the screen can display the equivalent annual dollar revenue increase for each optimization calculation. This value is based on the plant factor and energy value which are input by the user. This can also serve as a motivational tool to encourage operators to improve plant efficiency. The revenue screen can also show potential loss or gain for any proposed optimized scenario with changed circumstances, such as a reduction in head. There are appropriate error checks and diagnostics to prevent individual unit or powerhouse capacities from being exceeded. There are also a wide variety of internal alarms that may be programmed on a customized basis such as whenever a unit is in a cavitation or other rough operating zone or if minimum required stream flows are not being maintained. A HELP menu is provided so this simple technique may be used without any tutorial and the individual unit's performance graphs may be displayed showing the location of both the existing and optimum points of operation. A chart of efficiency versus output or versus flow as well as the "smooth" curves discussed earlier may be selected and displayed.

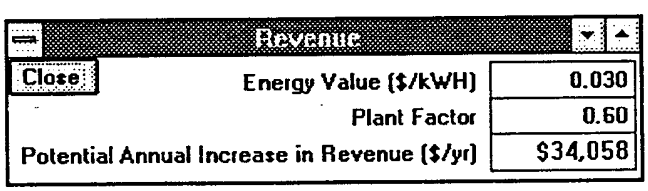

Figure 5 - Revenue Subscreen

CONCLUSION

A simple, easy to use PC Windows based technique is now available to optimize the efficiency of multiunit hydro plants. The internal model is customized for each specific plant. All that is needed is the efficiency profiles on the individual turbine/generator units. The program provides information of the loadings to set each individual unit so that the output of the powerhouse may be at optimum efficiency. This optimization may be done in terms of total powerhouse flow or total powerhouse output. Benefits resulting from such optimization include increased generation, increased revenues, decreased water use, decreased O&M costs, and increased survival of downstream migrating fish.

10 key words:

Efficiency
Energy
Fish
Flow
Generation
Head
Optimization
Power
Revenue
Turbine