A REPORT ON THE SURVEY OF SOFTWARE PROGRAMS TO OPTIMIZE HYDROPOWER GENERATION

Prepared for the Bonneville Power Administration

By

ENRON Corporation
Houston, Texas

May 10, 2000

EXECUTIVE SUMMARY

As specified in the Work Scope of the contract from the Bonneville Power Administration (BPA), a survey was made of the software to optimize hydropower generation. This survey was of the commercially available Type 1 and Type 2 optimization software programs. Type 1 denotes the optimization of a single generating unit, such as the automatic "indexing' of a Kaplan turbine to determine the optimum blade to gate relation or cam curve. Type 2 denotes the optimization of a multiunit generating plant, such as the optimum manner in which to share or apportion load among the different units.

The survey was conducted for the Type 2 programs by first creating a spreadsheet to list the features and attributes of such programs and an accompanying explanatory write-up. Then, each known vendor was contacted by telephone or e-mail and provided a copy of the spreadsheet to complete for the particular software program. The responses were entered on a master spreadsheet and with the write-up, form the first part of this report. Type 1 programs are restricted to either the few turbine or governor manufacturers. Since there are only a couple of such programs, a narrative history of their development to date is provided in the second part of this report.

A total of thirteen (13) software developers responded to the survey describing a total of fourteen (14) Type 2 optimization programs. However, although contacted more than once, responses were not received from the following firms:

Type 2:

- Facet Decision Systems
- Henwood Associates
- Quebec Hydro
- California Powel
- Hydropower Technologies

Type 1:

- VA TECH VOEST MCE

Lee H. Sheldon, PE
Senior Hydropower
Engineer

Mr. Walt Pollock
Portland General Electric
1 World Trade Center
1 WTC - 17
121 SW Salmon Street
Portland, Oregon 97204

Dear Walt:

The enclosed is a letter from one of my staff engineers that I wish to bring to your personal attention. It is being sent to Portland General Operations by our Hydro Modernization group as a proposal for PGO's action. Their intent is to develop optimization as one of the ENRON products that the HMOD program offers.

The technology is apparently now available. Therefore it would appear to be in ENRON's interest to use this technology to become an industry leader in the field of optimizing hydroelectric power generation.

Sincerely,

Dennis J. Alexander, P.E.
Vice President, Engineering

Encl w/attachments

Mr. Thomas Murphy
Bonneville Power Administration
911 NE 11th Street
Portland, Oregon 97232

Subject: Hydropower Optimization Software Survey

Dear Sir:

In accordance with your work scope, contained in enclosure (1) for record purposes, the survey of software to optimize hydropower generation is contained in enclosure (2). This study is in two parts, with a spreadsheet contained in the first part. Some of the survey respondents consider their answers to be proprietary. Therefore, only one copy of the survey is enclosed to each addressee. It was a pleasure to work with you on this survey and if I can be of further assistance, please let me know.

Sincerely,

Lee H. Sheldon, PE
Senior Hydropower
Engineer

Encl.

cc w/encl.
Mr. Paul Willis
US Army Corps of Engineers
220 NW 8th Street
Portland, Oregon 97209

Mr. James Hughes
nLink Corporation
2022 NE 15th Avenue
Portland, Oregon 97201

Mr. Rick Whitaker
Director, HMOD Company
ENRON Corporation

Bill Fox
Director, Mechanical Group
ENRON Corporation

cc wo/encl.
Dennis Alexander
Vice President, Engineering
ENRON Corporation

File: AbvOptiStdy.doc
Feb 00

PROPOSAL FOR ABREVIATED HYDROELECTRIC GENERATION OPTIMIZATION STUDY

Statement of Work

The purpose of this proposal is to conduct a survey of all available unit and powerhouse optimization systems/programs for hydropower generation. The optimization systems to be evaluated are those designed for use on a generating unit and within a single powerhouse. Other optimization programs designed for use on river basins or watersheds, hydrology models, rainfall and runoff prediction models, reservoir operations models, and load prediction and marketing models are not included. However, if a unit and powerhouse optimization program is a part of one of these other types of optimization programs, it should be included, if appropriate.

Scope

In the scope of this proposal the general tasks are as follows:

1. Identify and locate all single generating unit and single powerhouse optimization programs/systems. This will be done by a world-wide industry survey. It is the intent of this survey to determine the salient characteristics, methodology and operational techniques of each optimization program/system, as well as hardware and software proprietarity; and required input and output data.

2. The general and detailed characteristics/criteria, and miscellaneous information listed below should be determined/obtained for each program/system.

a. High level overview, "block diagram," of program

b. System platform, i.e., operating system and hardware associated with the program

c. Programming language

d. Source code availability, such that COE can modify code

- Software development environment used, i.e., Usual Basic by Microsoft or Rose by Rational, etc.

- If source code is not available for every component, what parts are proprietary?

e. Electronic documentation availability, such that COE can modify code

- What is format, i.e., Word, PDF, HTML, or ?

f. Proprietary hardware

- List if any

g. How are customer data tables or curves input, modified, refined and used? Are inputs changeable and how?

- Generator curves

- Turbine curves

h. List real time system data input quantities and how they are obtained

- Data quality required of real time inputs

i. Are there any other inputs required other than those listed in "g" and "h" above? If so list them.

j. What input data accuracy is required for what output data accuracy?

k. Are software of hardware filters available for real time inputs? If so, what are they.

l. What is the method used for turbine flow determination and what is it's accuracy?

m. Describe the turbine/unit efficiency calculations concept.

n. Frequency of data and calculation update

o. What type of feedback loop or error checking mechanism is implemented to assure correct system functionality and accuracy?

p. If an individual machine has been index tested and is operating on the appropriate cam, what improvement can be expected on a unit and powerhouse basis, if your optimization program is used?

q. Determination of unit start-stop

r. Program cost....basic, plus each additional unit. Separate out installation costs.

c. Web address for additional product information

5. There will be no funds for travel in this work. Information should be obtained via telephone, e-mail, fax, etc.

The survey findings should be summarized in a matrix of "program/system" vs. "characteristic/attribute." This summary should be in spreadsheet form. It should be prepared using Microsoft Excel, unless otherwise approved. The spreadsheet template should be submitted for approval prior to inputting the data. The document for approval can be submitted via e-mail.

A one to two page more detailed presentation of findings should be prepared, using Microsoft Word, unless otherwise approved, for each program/system. The general format of this one page document should be submitted for approval prior to writing all finding documents. The document for approval can be submitted via e-mail.

An "Executive Summary" coversheet shall be prepared, in Microsoft Word and furnished with each of the six document sets.

A formal presentation of findings will be made at either the Portland office of BPA or COE upon conclusion of the study. A pamphlet/booklet will be prepared as a handout which will encompass all activities and findings.

6. <u>Deliverables:</u>

a. Excel spreadsheet providing the summary of survey findings, Task 4.

b. A one to two page Word document detailing findings for each program, Task 5.

c. An "Executive Summary" Word document of the work and finds associated with this work scope.

g. Six hardcopies of each document prepared, as requested above, and one 3 ½ disk, containing all documents, shall be furnished at the end of this work. Documents should be collated into six pamphlets.

Schedule

PURPOSE

The purpose of this study is to survey the currently available software for use in optimizing hydroelectric generation. This survey is to concentrate on "Type 2" software; that is software specifically intended to optimize the load sharing or load apportionment among the various generating units in a given powerhouse. In particular, the attributes and features of the different software programs are to be delineated such that the Corps of Engineers (Corps) and Bonneville Power Administration (BPA) may select the program(s) most suited to their needs.

INTRODUCTION

In general, optimization of hydroelectric generation means maximizing efficiency. However, there are a number of different efficiencies that may be maximized. As defined in reference (1), there are three (3) basic "Types" of optimization. Type (1) refers to optimization of an individual generating unit. A classic example is index testing a Kaplan turbine to determine the optimum blade-to-gate cam curve to input to the governor. Type (2) optimization, as mentioned above, is devoted to optimizing the efficiency of any given power plant. This means internally maximizing the generation of the combination of units for whatever hydraulic or hydrologic conditions, such as head, are imposed externally on a given plant. Type (3) refers to optimizing the generation from a river basin containing multiple power plants. This later type involves such considerations as rainfall run off, flood storage, and the hydraulic travel time between projects.

OPTIMIZATION

The basic definition of fluid power is that the volumetric flow rate, Q, in cfs, times the specific weight of water, γ, in lbs./cuft, times the head in ft., times the conversion efficiency, E, divided by 550 ft-lbs./sec/HP is equal to the mechanical horsepower output, $HP \equiv Q\gamma HE/550$. At a given flow rate and efficiency, power is increased by increasing head. However, maximizing head falls under the Type (3) optimization. Therefore, for this purpose of Type 2 optimization the power plant internal efficiency is to be optimized for whatever external head conditions are prevailing. Within that restricted degree of freedom, at any given head, efficiency is proportional to power divided by flow rate, $E \propto HP/Q$. Therefore maximizing efficiency at any given head means to maximize power for a given flow OR to minimize flow for a given power. The later is of importance wherever the saved flow may be stored for use in generation later.

TYPE 2 OPTIMIZATION

There are several different activities that may be done to optimize the generation within any given powerhouse. Reducing station service loads, such as lighting and heating and cooling is one such activity. However, of recent, it has become recognized that there are significant gains in power generation to be made by the optimum apportionment of load among the various generating units.

As a simplistic example, assume a powerhouse consists of two identical units, and one is operated at its very peak efficiency and the other one is at a different load and wicket gate setting. This is NOT the most efficient manner to operate the two units together. One only has to picture a small load change on the peak efficiency unit in which the drop in efficiency is not great near the rounded top. However, the opposite load change on the other unit, such that the same total power is produced by both units, could allow the operating point on that second unit to clime a steeper slope on the efficiency curve. The end result would by that the combined efficiency of the two units would be increased while they are producing the same total power. This example may be applied to maximizing efficiency from the two units for the same total flow rate.

If a power plant consists of a large number of units, units of different sizes, or aged units whose efficiency profiles differ, the same principle still applies. However, the number of possible combinations or different ways to share a given load has increased astronomically. It is the basic purpose of any load sharing algorithm to determine the one, unique, optimum manner in which to share a given load or flow set point among the generating units.

PROGRAM FEATURES

Hydraulic Connection

There are two basic methods of developing algorithms for Type 2 optimization. The first involves actually measuring the volumetric flow rate and continually computing efficiency. Then by small load shifts, the combined efficiency of the generating units is systematically improved until the maximum combined efficiency is achieved. This is referred to as "on-line," which means that hydraulically, it is measuring flow in real time. The second method utilizes stored data on the efficiency profiles and is therefore "off-line." Each method has its own advantages and disadvantages. In the on-line method, the efficiencies used are the actual efficiencies as they exist in real time. However, absolute volumetric flow rates are sometimes difficult to impossible to measure at some power plants. In the second method the efficiencies may no longer be precisely accurate due to equipment degradation, but this method does allow simulations and studies of future events such as a preplanned schedule of how to share load when a change in reservoir inflow occurs. Consequently, the first category to classify optimization software is whether hydraulically, it is on- or off-line.

Maximize Power or Minimize Flow

The second feature of optimization software is whether it can maximize power for a given flow as well as minimize flow for a given power. As mentioned above, both are ways to maximize efficiency. Where a project has virtually no storage and its generation is based on river flows, maximizing power for a given flow may be important. On the other hand, where a project has storage and is controlled by a power dispatcher, minimizing flow for a given power may be important.

Output

A third feature is whether the software output is information only or whether it is capable of actually controlling the generation of the units. For some projects, their control systems or SCADA may not be capable of automatic optimization control, at least not without significant upgrade. Also, for some projects, having an operator in-between the optimization software and actual generation control may be important. On the other hand, if a plant is run remotely, then having the optimization software actually controlling generation locally may be important. Generation control may be further divided into two categories. The first is generation control or control of the power output of units that are already on-line. The second is termed "full automation" and means the software is preprogrammed to be able to independently start and stop units and to even control the sequence with which units are brought on- or taken off-line.

Display

A fourth feature, which is an adjunct to the third feature, is whether the optimization information is capable of being displayed remotely, as well locally to a plant operator. For projects which are either operated remotely or dispatched remotely, the local information on the optimum generation may be important at a remote location.

Net Head Determination

A fifth feature is whether the optimization analog is capable of determining the net head on each individual hydraulic turbine. Upstream, this includes whether the program is capable of solving the optimization problem if there is a common penstock. On many hydro plants there is a common penstock (or tunnel) from the forebay to the powerhouse which then bifurcates or trifurcates to supply two or three separate hydraulic turbines. Thus, the head loss that an individual turbine incurs is the sum of the losses in its own penstock, the common upstream penstock, and the junction or branch connection losses. Consequently, a load change on any one unit, which changes the flow and therefore the velocity, changes the head loss in the common penstock. Thus, for a given gross head, a change on one unit results in a change on the others. This is known as "the common penstock problem" and, of course, increases the complexity of the solution algorithm in any optimization software. A second upstream aspect of determining an individual net head is whether the software can detect a trash rack(s) that needs cleaning. Partially plugged trash racks are an almost universal problem with hydropower plants. Knowing when they need to be cleaned to minimize head loss can result in a significant increase in generating efficiency. A third aspect of determining an individual net head is the variations in tailwater elevation that can occur across the length of a powerhouse. Often, when adjacent units are at full discharge, the tailwater on a middle unit is higher than a tailwater gage at the other end of the powerhouse would indicate. In such situations tailwater sensors at each unit may be needed and the optimization program needs to be able to compute individual tailwater elevations for each unit.

Environmental Constraints

A sixth feature is whether the program is equipped to handle environmental constraints or overrides. Many hydro plants operate under a number of different environmental restrictions. Some plants must operate so as to best aspirate or draw atmospheric air into the turbine discharge if the BDO (Biological Dissolved Oxygen) in the tailrace drops below a minimum value.

Some plants must operate their turbines within 1% of peak efficiency during periods of downstream migration to minimize the mortality of fish passing through the turbines. For such plants, the solution algorithm should be able to optimize efficiency within these environmental constraints and restrictions.

Aside from these basic features, there are a number of ancillary features that may add to the value of a particular Type 2 optimization software. These include:

- Historical Trending
  Whether the software can provide historical trending. This means whether the software is capable of comparing an individual unit's generating efficiency against a historical benchmark of that unit's efficiency. Such a program feature can detect a unit's degradation and annunciate an alarm indicating the need for a unit inspection.
- Operating Condition Alarms
  Whether the software is capable of annunciating an alarm if certain operational conditions are encountered or exceeded. There is a multitude of conditions for which it is convenient to have a software program keep track of and display an advisory alarm if they are encountered. Operating experience may have shown there are certain zones of rough operation due to hydraulic, mechanical or electrical resonances that it is preferred to avoid. There may be certain procurement contract provisions that must be observed, such as not operating more than so many hours beyond specific cavitation limits.
- Revenue Calculations
  Whether the software provides a revenue calculation as to the monetary value of optimizing operations over whatever revenue is being earned from the present conditions of operation. A monetary display of the incremental value of optimization has been found to be an excellent incentive to maintaining optimum generation efficiency. Whether the software provides a revenue calculation as to the monetary cost of certain operation and maintenance practices. There are numerous O&M practices that incur a cost rather than producing an optimum benefit. There may be a power demand that requires operating a turbine in its known cavitation zone. The resulting cavitation damage, that will have to be repaired in the future, is an incurred cost for that operational response.
- Help Menu
  Whether the software provides a help menu or an on screen explanation for the new user. The more user friendly the software program, the more likely it is to be used to optimize generation efficiency.
- Graphical Displays
  Whether the software provides graphs of the efficiency profiles and optimum solutions as well as numerical displays. Graphical displays aid the user in understanding the process of optimization.
- Protections

Whether the various software programs have one or more of the different degrees of intellectual protection. These protections include patents, copyrights, and trademarks. The extent of these protections has an effect on the accessibility of the source codes for modifications.

Required Hardware

Finally, what type of hardware is required to run the optimization program?