Canadian Hydraulic Research: Identifying Big Opportunities for Small Hydro

The Canadian federal government is actively sponsoring research in several areas that could substantially reduce costs for small hydro. Results of recently conducted research are available to help developers.

By Tony P. Tung, J.L. Gordon, and Claude Barraud

Traditionally, Canada's hydropower industry, which provides more than 60 percent of the country's electricity, has been dominated by provincially owned utilities and large-scale projects. Private development of small hydro projects—that is, projects having less than about 15 MW capacity—has been almost nonexistent. However, that situation is changing. In recent years, utilities have been implementing policies that are favorable to private power development. Interest in small hydro stems from several factors. Electrical energy has become more valuable than in the past, and is increasingly being recognized for that greater value. Opportunities for development of the very large projects have diminished. And, there is pressure from independent entrepreneurial interests to be allowed to enter the previously government-dominated business of power generation.

In support of private small hydro development, the provincial governments are encouraging utilities to increase power purchase rates, sites are being released for development, banks are establishing loan officers that specialize in small hydro, and insurance companies with money to invest are asking their analysts to look for opportunities. And, entrepreneurs are active, searching for attractive sites.

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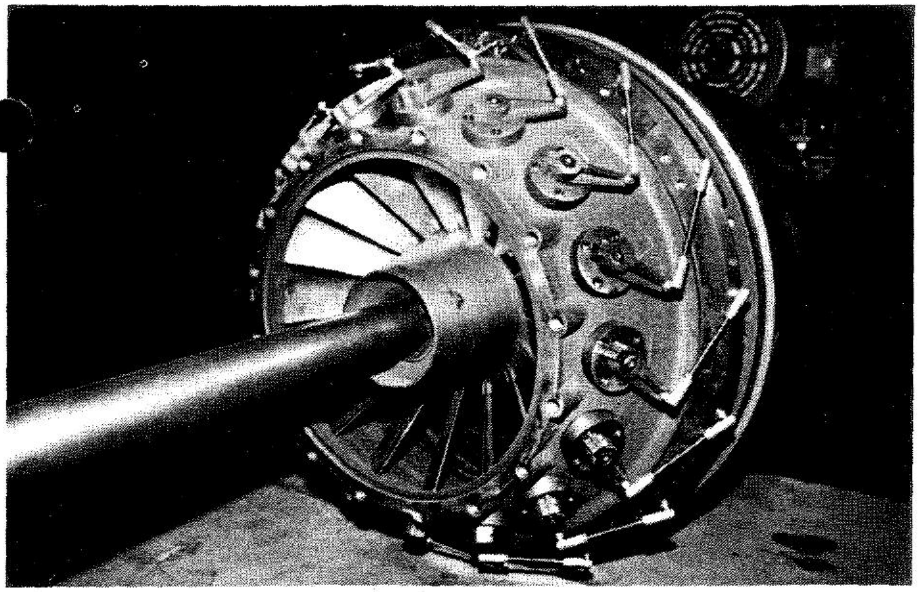
Ottawa University conducted laboratory tests using this rockfill dam model to study the merits of a "leaky" dam. A subsequent study at an existing hydro plant by Acres International Ltd. showed that a leaky rockfill dam would retain floods and reduce spill by 44 percent.

Determining the Potential For Small Hydro Development

The Canadian federal government recently completed a ten-year small hydro inventory study in which more than 3,600 possible sites (all less than 20 MW in capacity) with a total potential of about 7,900 MW were identified. There are, no doubt, more sites yet to be discovered. A report, *Small Hydro Technology and Marketing Assessment in Canada,* outlining the scope and results of the study will soon be available.

Through the study, the federal government discovered that there is a vast difference between the number of sites that are identified, and those that are economically viable at current interest and energy purchase rates. To determine which of the identified sites would be economically viable to develop, the federal government hired Ottawa Engineering Ltd. of Ottawa, Ontario, to conduct an analysis to determine the cost of energy from all of the small hydro sites identified.

Ottawa Engineering entered data gathered during the study into a data-



Canadian Hydro Components is commercially marketing its low-cost cast turbines, which are made from a plastic mold. The plastic molds can be formed at a lower cost than conventional casting methods. The company's work has resulted in the development of low-cost axial flow mini-turbines with outputs of up to about 300 kW from four different sizes of turbines. This photograph shows a wicket gate assembly for one of the turbine's runners.

base, and then used a software program to establish the probable minimum cost of development at these sites. The computer program uses three parameters as a measure of likely construction difficulties: head, capacity, and number of frost free days at each site. Using an interest rate of 12 percent, Ottawa Engineering determined the cost of generating energy at the sites. This cost was then compared with current utility buyback rates to determine whether the sites were viable. This analysis concluded that slightly more than 1,200 MW at 456 sites, about 15 percent of the total available potential, could be developed economically.

Ottawa Engineering's study indicated that two major impediments to development of identified potential small hydro sites are lack of access to the site and distance to the nearest transmission line. The firm conducted various sensitivity analyses, and discovered that the number of sites economical to develop increased two and half times when: interest was decreased to 10 percent, buyback rates were increased by 15 percent, and development costs in the region were reduced 16 to 19 percent (depending on whether or not the site was at an existing dam).

The sensitivity analyses indicated—as expected—that reducing costs greatly influences site economics. For this reason, the federal government has been actively sponsoring research to study cost-effective equipment for hydro sites and design-cost methodologies.

Hydro Research Looks into Cutting Small Hydro Costs

Since 1980, the federal government has sponsored more than 20 small hydro demonstration projects. In the 1990s, funding is being directed almost entirely toward research and the dissemination of information on small hydro. Examples of research include development of: a "flow-through" dam design; turbine flow analysis software; a syphon intake design; innovative design concepts that are simple and inexpensive; software for estimating small hydro costs; and new designs for turbines and induction generators. Reports of the results of much of this research and the software that has been developed are available. The accompanying box on page 42 gives information about the reports and software and how to order them.

Ottawa University Develops Design for a "Leaky Dam"

Most of northern Canada lacks impervious materials for use in the core of an earthen rockfill dam. However, there is typically an abundance of rock and gravel in this region. A dam could be built with rock and gravel, but would require importation of cement and/or steel to form the impervious barrier. A dam built only of rock and gravel will leak, which is traditionally considered a design problem. However, leakage can be advantageous since most dams need to pass some water to maintain minimum flow. Designing a "leaky" dam, though, is difficult—stability is affected by the size of the rock and the slope of the dam's downstream face. The dam engineering community has also expressed some concern about the growth of ice within the dam shell.

Energy, Mines and Resources Canada awarded a research contract to the University of Ottawa in Ottawa, Ontario, to conduct hydraulic model tests to measure forces on a dam and develop design parameters. (The work included tests in a cold atmosphere laboratory where temperatures were –10°C.) Results from the work are featured in a detailed design report with extensive and highly complex equations for stability and flow through the dam.

In the cold tests, researchers experienced considerable difficulty with the instrumentation due to the glycol (an alcohol) freezing in the piezometer tubes. However, the concern about ice forming an impermeable barrier in the dam, which could result in failure due to overtopping, proved to be groundless since the water managed to maintain flow within the relatively warm interior of the dam. This discovery confirms the experience at Nonacho Dam in the Northwest Territories, where an 8-meter-high flow-through rockfill dam has been in place since the mid-1960s. Snow cover provides sufficient insulation to maintain the flow through the dam.

With the dam design criteria established, Acres International Ltd. undertook a dam reliability study upstream of Newfoundland and Labrador Hydro's 8-MW Paradise River hydro plant. Acres found that a leaky rockfill dam, built with rock excavated from an abutment spillway channel and equipped with an ungated culvert pipe, would retain floods and reduce spill at the downstream plant by 44 percent.

Calculating Flow through a Turbine on a Computer

Although hydraulic scale models of turbines are typically used in the hydro industry to predict performance characteristics, in many cases the computer has taken over the task of

Ordering Reports and Software

If you would like to obtain copies of the software or reports on specific research projects discussed in the accompanying article, use the following contact information:

Software:

SHYDRO Verson 3.2. The SHYDRO 3.2 package, which includes software and a user's guide, costs $50 (Canadian) and $50 (U.S.). It can be ordered from ShawMont Newfoundland Ltd., P.O. Box 9600, St. John's, Newfoundland A1A 3C1; (709) 754-0250.

The Fluid Flow Simulation software, developed by the University of Montreal, is not available for commercial use.

Reports:

Copies of the reports mentioned in the accompanying article may be obtained for a nominal fee by contacting Tony Tung at Energy, Mines and Resources Canada/CANMET, 580 Booth Street, 7th Floor, Ottawa, Ontario, Canada K1A 0E4; (613) 996-6119; Facsimile: (613) 996-9416. When ordering, refer to these reports:

Design Concepts for Low-Head Small Hydro for Community Supply, prepared by ShawMont Newfoundland Ltd. for the Canadian Electrical Association and Energy, Mines and Resources Canada, CEA Project No. 832 G 685, April 1990.

Design of Low-Cost Flowthrough Rockfill Dams and Spillways, prepared by the University of Ottawa for the Hydraulic Energy Research and Development Program at Energy, Mines and Resources, Serial No. 23283-7-6138/01-SZ, April 30, 1990.

Development of a Stand-Alone Induction Generator for Low Cost Micro-Hydro Systems, prepared by Thomson and Howe Energy Systems for Energy, Mines and Resources Canada, 1989.

Laboratory Investigation of Syphon Intake Geometry, prepared by Acres International Ltd. for Energy, Mines and Resources Canada, 1990.

Selection of Economic Structure Types to Provide Upstream Regulation and Reduce Spill During Small Flood Events in Remote Locations, prepared by Acres International Ltd. for the Canadian Electrical Association and Energy, Mines and Resources Canada, CEA Project No. 939 G 776, March 1991.

Canadian Hydro Components' report on low-cost cast turbines and the *Small Hydro Technology and Market Assessment in Canada* report are not yet available. Both of these reports should be available later this year. Contact Tony Tung at the above address for more information.

testing alternative designs and optimizing blade shapes. As a result, several major turbine manufacturers have developed proprietary software to simulate flow through the turbine casing, runner, and draft tube.

To assist small turbine manufacturers, EMR awarded a research contract to the University of Montreal to develop fluid flow simulation software suitable for a personal computer or a workstation. Three programs have been developed, focusing on, respectively, the casing, the runner, and the draft tube. The software programs are primarily intended for investigation of alternative shapes and configurations of the turbine. For the three turbine components, they also include solutions of the 3D Navier-Stoke equations (flow continuity equations) to obtain the flow pattern. However, due to the number of iterations required, this task may take several hours, even on a high-speed (over 25 mega-Hertz), large memory workstation. The fluid flow simulation software is not available for commercial use.

The software is user-friendly, and includes the following modules:

—MARS 2D for turbine configuration and preliminary analysis;

—CAD-model, an input tool to assist the engineer in describing the turbine shape components such as the spiral casing, runner, and draft tube. Three-dimensional surfaces can be developed from line equations, and blended shapes can be generated at discontinuities; and

—VENUS 3D post-processor used in conjunction with the computer aided design (CAD) program to display the flow field using velocity vector and pressure plot in the turbine components.

All displays can be enlarged, rotated, and viewed from any angle. The programs are particularly suited to the investigation of alternative turbine layouts at existing power plants.

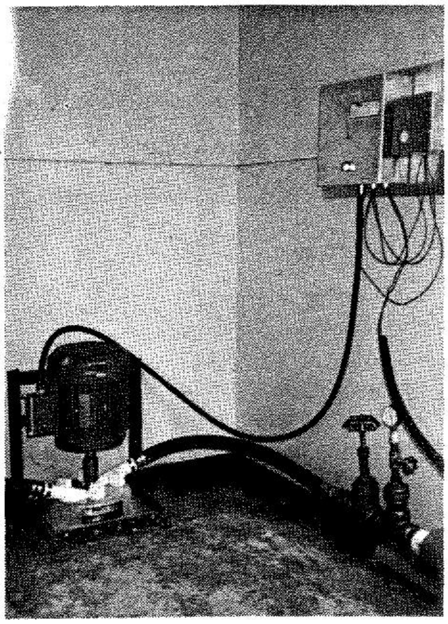
Identifying Parameters for Effective Syphon Intake Design

Where there is an existing dam with a reasonably constant upstream water surface, designers sometimes incorporate syphon-type penstocks. These penstocks, which lift water over structures to power plants downstream, are often used for low-head hydro sites at existing dams because they reduce the need for dam modifications. From a hydraulic standpoint, there is a lack of information on syphon performance, particularly in the area of vortex formation. Accordingly, EMR awarded a contract to Acres International Ltd. to use its hydraulic laboratory to undertake a three-phase study, including: a literature search to identify problems; a preliminary model study to determine design parameters; and a detailed model study to quantify the design parameters.

The final report, which includes comprehensive design data, points out several problems with syphon intakes as reported by operators. These problems include air entrainment by vortices (which reduces power output) and the formation of a bubble at the top of the syphon. One surprising finding from the study was that submergence of the syphon, to avoid vortices, is a function of the syphon inlet shape (rectangular or round), as well as the inclination of the pipe, geometry of the adjacent surfaces, and the water velocity within the intake pipe. Other factors being equal, Acres found that, compared to a circular intake, a square intake required 30 percent more submergence and a rectangular intake 45 percent less submergence for vortex-free operation.

Identifying Innovative Concepts For Simple Design, Low Cost

In Canada hydroelectricity was first generated in 1881, when the Ottawa Electric Light Company built a small water wheel to power a local lighting system. Design procedures are now well known. However, for small hydro, design innovation is often required to



Thomson and Howe Energy Systems, a small manufacturer of hydro electronic load and frequency controllers in western Canada, developed a stand-alone induction generator for micro-hydro plants of less than 10-kW output.

cut costs, particularly for the site work (civil structures, powerhouse, etc.). This site work typically comprises between one-half and two-thirds of the total cost for a small hydro project. In order to determine whether new design concepts are being used, or can be used, the Canadian federal government co-funded a research project with the Canadian Electrical Association. ShawMont Newfoundland, Ltd. undertook the project, and divided the work into three phases: a literature review; concept development; and application of the concepts to three sites.

The literature review resulted in a bibliography of 130 useful design manuals and papers, along with ShawMont's staff comments. The work on concept development, the second phase, produced alternative low-cost designs for dams, spillways, intakes, penstocks, and powerhouses along with comments on the influence of equipment on powerhouse design. The contractor engineer on ShawMont's project team contributed ideas on access, construction, equipment, manpower, methods, and materials.

During the last phase of the research project, ShawMont applied the innovative concepts that were developed in the second phase at three hydro sites in case study situations to identify the most optimal designs. These sites represent a range of access situations and topography. At the Forteau Brook site in Labrador, a steel "A" frame dam, fiberglass penstock, and an axial flow tube turbine of 1-MW capacity proved to be the most attractive layout. At the Torrent River site on the west coast of the Great Northern Peninsula in Newfoundland, a natural waterfall favored a no-dam design with a syphon intake, fiberglass penstock, and a Banki turbine of 600-kW output. At the Great Rattling Brook site in central Newfoundland, an existing dam and fishway resulted in a layout with a diversion to a short canal, intake, and twin penstocks to two 250-kW "L" turbines. Concrete was the favored construction material due to the project's location, which was within access to concrete materials.

A report that summarizes the findings of this study concludes with a section on how to approach the design and development of a small hydro site, which should be of particular use to entrepreneurs. The report shows how to keep designs simple and how structures can be built at minimum cost.

Software for Estimating Small Hydro Costs

A comprehensive software package for the design and costing of small hydro sites has been developed by ShawMont Newfoundland Ltd. with funding from Energy, Mines and Resources Canada.

The software, known as SHYDRO, is a user-friendly computer program that will determine the cost of all the components of a small hydro site, including access and transmission. Its prime function is to determine the least cost site from a number of alternative sites being considered for development. The software was developed in 1984, and has undergone extensive modification to add more functions and make it easier to use. It is now available in version 3.2 released in 1991, and is designed for use with IBM and IBM-compatible computers.

Most of the required input data can be obtained from large-scale topographic maps, but a site visit is recommended. Required parameters are: head, average annual flow, penstock length, access road length, and transmission line length. Other parameters include: dam height and length, reservoir drawdown, canal length, canal mean transverse slope, canal depth of overburden, and flood flow. Other necessary parameters are number of units, fishway requirements, tailwater elevation, distance to the nearest town, and distance to the nearest concrete plant. The last two parameters are used to determine whether a site construction camp is required, and whether the contractor will need to install a concrete plant.

With this data, the program will estimate quantities and costs for the dam, spillway, fishway, control structure to the canal, power canal, intake, penstock, powerhouse, substation, transmission line, and access road.

Developing New Designs For Turbines and Generators

Developers welcome innovations in equipment that will make operations easier and/or save money—either in capital outlay or maintenance costs. Two new equipment design advances involve turbines and stand-alone induction generators.

Low-Cost Cast Turbine: About 30 years ago, most turbine parts were made from castings. This method is labor intensive, particularly the fabrication of wood molds. Modern turbines are usually built from fabricated cut and welded steel plates. By using a three-axis computer-controlled milling machine, Canadian Hydro Components, Ltd. of Almonte, Ontario, a small turbine manufacturer, realized that a plastic mold could be formed at a lower cost compared to the conventional way. EMR provided funds to pursue the work, which has resulted in the development of low-cost axial flow mini-turbines with outputs of up to about 300 kW from four different sizes of turbines.

All parts of the turbine are formed from low-cost steel castings. For example, the levers on the ends of the wicket gates, connecting to the operating ring rods, cost less than $3 each. To date, two prototype propeller turbines have been operating successfully for more than a year at a project in Waba, Ontario. Both have four blades and a throat diameter of 630 millimeters. One produces 115 kW at [illegible] meters of head, and the other 225 kW at 12.8 meters of head. Three vertical units are now under installation at another site in Douglas, Ontario.

The original prototype units are manual Kaplans, which require 90 minutes to open the draft tube, change the blade angle, close up, and re-synchronize. Designs are now underway for full double-regulated Kaplan units. Canadian Hydro Components also owns a mini hydro plant, which is used as a full-scale test stand for new fabrication designs.

Stand-Alone Induction Generator: Many small hydro plants use induction generators that draw their excitation from the connected transmission line. They do not require governors on the turbine and do not contribute to frequency stability. For these reasons, it would appear theoretically impossible to have a stand-alone induction generating system. However, induction generators have major cost advantages over synchronous generators for low power outputs. This factor, coupled with the low costs of electronic controls, persuaded Thomson and Howe Energy Systems, a small manufacturer of hydro electronic load and frequency controllers based in Kimberley, British Columbia, to experiment with the development of stand-alone induction generators for micro-hydro plants of less than 10-kW output.

The Canadian federal government awarded a research contract to Thomson and Howe to pursue the idea. The first experimental installation comprised two battery charging systems of about 440-watt capacity. Both used centrifugal pumps-as-turbines of 38-mm inlet diameter, running at 2,500 revolutions per minute (rpm) at 15 meters of head. One system was a single-phase AC to DC battery charger, and the other was a three-phase AC to DC battery. The generator efficiency was found to be surprisingly high at 95 percent. Of the two, the single-phase system proved to be the most economic, and could be used in homesteads currently equipped with wind-powered battery systems.

The main thrust of the research work was to develop a synchronous system. Thomson and Howe built four prototypes. All systems use a 100-mm plastic Turgo wheel, supplied by Energy Systems and Design of Sussex, New Brunswick, as the turbine. The power output varies between 600 to 2,200 watts, depending on the head. Single-phase power is produced from a three-phase induction generator, using one of the phases to provide excitation and current balance.

With the success of these systems, Thomson and Howe then went on to develop larger AC induction systems using pumps-as-turbines coupled to generators with three-phase outputs of up to 8 kW. The practical experience gained with these systems has shown that they have distinct cost advantages and that with rugged construction, the turbine-generator can withstand 100 percent overspeed. The power output is a good sinusoidal wave form with low harmonics, which provides a consistent flow.

Canadian Research Highlights Hydro Opportunities

Although budget cutbacks in the federal government have reduced the number and amount of research grants, money is still available. Funding requests are reviewed by a committee of experts from government, industry, and the hydro consultant market. Work is continuing on:

—flow analysis;

—development of a hydraulic laboratory for testing mini and micro hydroturbines in association with Laval University in Quebec;

—development of a geographic information system (GIS) to extract physiographic parameters directly from digitized map information, for use in hydrologic modeling, design, and testing of a single vane control to replace wicket gates;

—testing of an "L" turbine wherein water approaching an axial flow runner is given an initial whirl by entering at an angle to the axis; and

—testing of alternative configuration for a simplified small hydro intake.

Research work that EMR's advisory committee considers worth pursuing in the future includes:

—optimization of small hydro operation;

—guides for safety assessment of small dams;

—study of low cost controls;

—comparison of synchronous and induction small generators; and

—fish passage and mortality mitigation.

With more than a century of experience, hydro is an established technology. Turbine and generator efficiencies now approach 95 and 98 percent respectively. However, technology for peripheral equipment and controls in hydro plants is far from established. Who would have predicted 15 years ago that computers would replace governors, and that stand-alone induction generation was possible? There are now moves to dispense entirely with oil pressure systems for wicket gate control, and use instead electric motor positioners on each wicket gate. All these changes are being made in the interest of reducing cost. It is only through research, though, that such advances can be made.

What about the future? Current technology allows developers to use satellites for mapping potential hydro sites. The developer can take the mapping information and feed it into a software program that will generate flow patterns from that mapping. Further, developers can take the flow pattern information and run it through design/cost programs such as the SHYDRO software. In the future, engineers will be able to walk through a hydro site with a hand-held satellite-based position locator (where the sphere of error is rapidly diminishing in size) and quickly determine exact locations for all structures. With such technology, the cost of assessing and designing a potential hydro site could be greatly reduced, possibly allowing more small hydro sites to be developed economically. □

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