Small Hydro as Green Power

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***Abstract* – This paper addresses the issue of small hydro as green power, discusses the fundamental differences between small and large-scale hydro, and investigates small hydro implementation from the standpoint of its development philosophy, operational principles, construction features, the small hydro resource, and equipment maintenance and scheduling. General advantages and disadvantages of small hydro plants are reviewed, and the case for environmentally sensitive small hydro is made. Case studies of four small hydro installations are presented with an analysis of site-specific engineering details, constraints and environmental enhancements achieved .**

I. INTRODUCTION

What is it that makes the movement toward "green" power so important? Is it that the product (green electricity) contributes both to social and environmental justice? Is it that the consequences of the varying types of electric production have such different impacts on the environment that it really does matter? Is it that the style of development (distributed generation versus central plants) has very different economic consequences at the community level that is important? And in the final analysis, does it really matter what technology we use? This article claims it does, and attempts to review the benefits of small hydro as a distributed resource.

A small hydropower generating unit is identified as a power supply that feeds a distant or a local load from a small hydroelectric source, which could either be run-of river, or have a small impoundment. Small hydro installations are designed for capacity ranges between 500kW and 30 MW. Mini hydro is sometimes designated as ranging from 100kW to 500kW. Micro hydro units are between 10kW to 100kW. Below 10kW capacity can also be labeled as micro hydro (Pico hydro has also been used). This paper however utilizes "small hydro" as an encompassing term for representing micro, mini, and small hydro units.

An Example of a micro hydropower design is depicted in figure 1. Such types of micro hydro units are currently installed in hunting and fishing camps and at remote cabins located across northern Canada. They successfully make enough energy for the lighting, water pumps, radios and televisions, and various communications devices needed to make such locations operate smoothly. And when the alternative is noisy, dirty, diesel engines burning fossil fuels in pristine environments, there is no contest between styles of generation.

Figure 2 is a photo of Laurentian Lodge, in Northern Ontario. In operation for 20 years, the lodge actually has two specially designed turbines, uniquely crafted to match environmental circumstances, with turbines that are adjustable to stream flow. The first of these turbines, a 27 kW unit manufactured by Rapid-Eau Technologies of Galt, Ontario, was installed in the mid 1980's, when, in Canada, small hydro demonstrations were being supported by the Ontario and Federal Governments (it should be noted here that the Ontario Ministry of Natural Resources has just recently announced a policy of the release of small hydro sites for development).

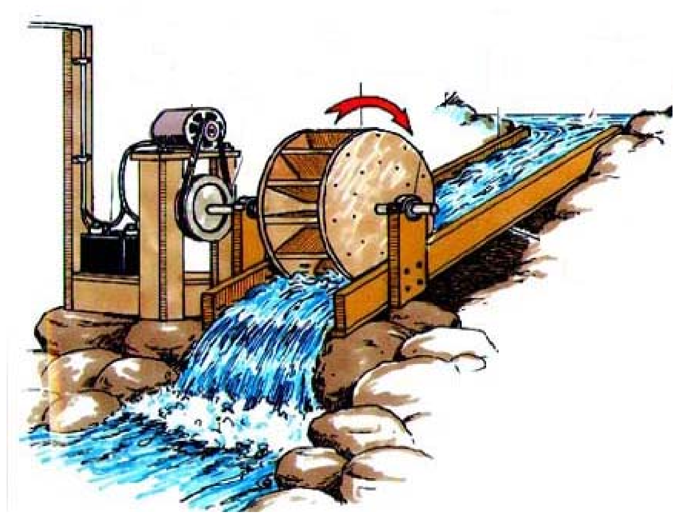

Fig. 1. Schematic of a micro-hydro plant

Fig. 2. Laurentian Lodge in Northern Ontario

The site engineering involved a unique design developed to avoid potential icing problems associated with small units in cold climates where if a unit trips off and a bypass valve sticks, you are left with a column of ice in a

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penstock until you can heat it up (very hard to do in minus 30 degree temperatures). So in this case, the team designing the installation decided to use a different approach, dropping the unit several feet under the water level in the headpond in a watertight container, with an intake to the unit and a long draft tube down to the tailrace (see Fig. 3). Ice and snow build up over the unit, insulating it from the extremes of the winter. If the unit trips off, the draft tube voids itself by gravity, without the need for valves or pumping. And the energy produced is the same.

Fig. 4 shows the larger (150 kW) of the two turbines in its small powerhouse. Again, this turbine, of the SBR variety [20] was, designed, manufactured, and installed by Rapid-Eau Technologies in the spring of 1999. Fig. 5 shows the draft tube at Laurentian Lodge. Fig. 6 depicts an existing 9.948MW hydroplant on the Mohawk River. Also, Fig. 7 shows an example of a pico hydro unit financed by the World Bank ESMAP, which aims to pave the way for micro hydro to become accessible to low-income households in Ecuador, with the view to replicating the process in other developing countries [2].

Fig. 3. Smaller of the two turbines at Laurentian Lodge

Fig. 4. Larger of the two turbines

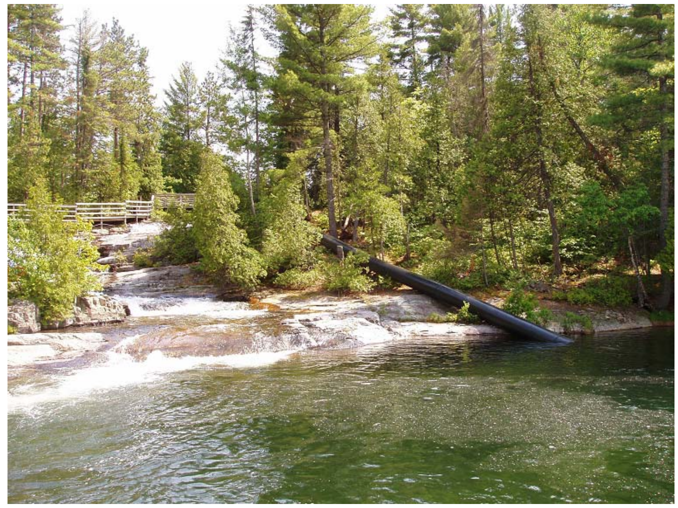

Fig. 5. Draft tube at Laurentian Lodge

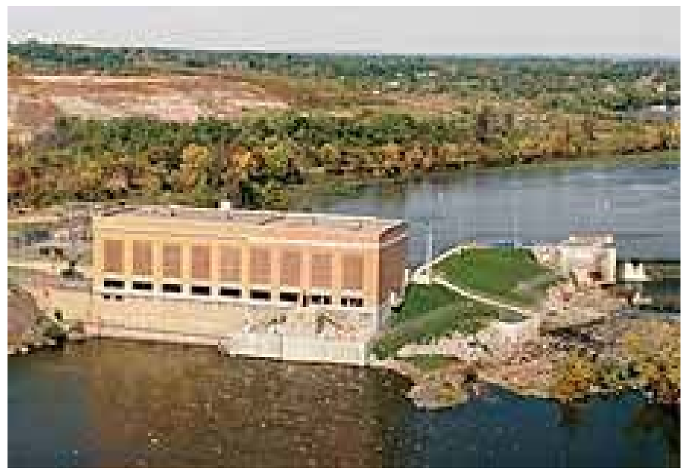

Fig. 6. Crescent small hydro plant on the Mohawk River

Fig. 7. Pico hydro unit in Ecuador

Today, small hydro is a proven technology which provides reliable renewable electrical power. Small hydropower generation has gained immense popularity not only as a renewable energy source that can provide independent (off-grid) power to remote locations, but also because of its ability to act as an effective distributed generation source to augment grid-power. Small hydro units have the unique advantage over large hydro units of short paybacks and acting as an economical power supply owing to their low capital investment and relatively minor maintenance requirements.

Technological advancements in mechanical, structural, and electrical engineering have in turn contributed to advancements in small hydro technology such as that used at Laurentian Lodge. In general, the importance of small hydro is realized when it is seen as:

1. Decentralized power generation that supplies power to rural communities and small industries.
2. An effective network-connected source that offers immediate and distributed voltage support to local loads.
3. Individually owned generation units, which, along with storage, can offer flexibility in meeting dynamic load demands.
4. Generating facilities that have minimal civil works and simple equipment thereby requiring minimal maintenance and operation.

II. PROSPECTS FOR SMALL HYDRO GENERATION AS RENEWABLE SOURCE

Hydroelectricity provides 19% of the world's energy production. The installed global capacity of small hydro was around 19.5GW in the year 1990, which amounted to about 80TWh/year [11]. Countries like Brazil, Canada, Norway, and the United States have produced a significant amount of their electricity consumption from large hydroelectric facilities. In 1924, around 7000 small hydropower stations were in use in Switzerland. More recently, it is estimated that there have been around 76,000 small hydro stations built in China between 1970 and 1985, which contribute more than 19,000MW of power [16].

Fig. 8 shows the breakdown in terms of worldwide small hydro capacity [11]. At present, small hydro accounts for about 4% of the world's total hydro capacity and the percentage is bound to increase at a fast rate due to the restructuring of electricity, higher fossil fuel costs, and the move toward renewable energy sources. The World Energy Council has indicated (see Fig. 9) that there would be a potential for approximately 210-310TWh/year energy production by the year 2020 for small hydro resources in regions like North America, China and Western Europe [11].

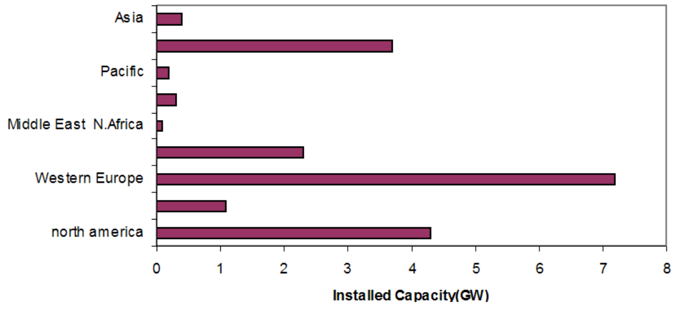

Fig. 8. Small hydro capacity in 1990

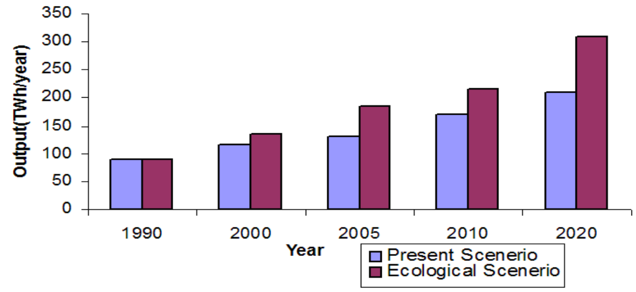

Fig. 9. Global potential for small hydro

For the period 2000-2009, USDOE has identified 12 mini hydro sites in the U.S. with a combined capacity of 70,190kW. This represents an additional contribution of 307.43GWh to the existing energy mix and will displace an equivalent of 0.53 million barrels of fuel oil equivalent (MMBFOE). By the end of 2009, the total mini hydro capacity is expected to reach 159.26MW, producing average energy generation of 557.43GWh. The 70.19MW capacity additions during the period 2000-2009 will form part of the 368.77MW mini hydro capacity identified for implementation by 2025. At the end of this period, the total mini hydro capacity should be about 457.84MW representing 40.43% of the total identified mini hydro resource potential with an estimated average energy generation of 2,005.34GWh/year [3].

In Canada, hundreds of megawatts of small hydro sites are identified and being developed. As an indication of the potential for small hydro in Canada, a recent (11-18-04) article in Elsevier's Refocus, the International Renewable Energy Magazine, quotes Pollution Probe as saying that green power could become a significant source of clean energy across Canada, and that small hydro could contribute significantly in the power mix of new green projects.

III. ATTRIBUTES OF SMALL HYDRO UNITS

Potential benefits of small hydro units are listed as follows:

1. Small hydro is a reliable source of energy with a very long life-cycle (usually 50-75 years).
2. Small hydro energy is more predictable when compared to other renewable forms of energy such as photovoltaics and wind energy. The available energy of small hydro can be predicted quite accurately to meet the load demand.
3. The limited impact of small hydro to a river's ecosystem is often offset by its pollution-free and environmentally benign attributes.
4. The technology is manufactured to last 50 or more years.
5. Small hydro is an inflation-proof source of energy that requires minimal maintenance. This factor makes small hydro an economically attractive renewable source.
6. Small hydro systems operated in parallel with the utility grid can serve as reliable back-up power.
7. Micro, mini, and small hydro plants typically have short construction schedules and are easily built compared to other forms of energy.

Challenges of small hydro units:

1. Small hydropower units using run-of-river as a method of generating cannot always meet the required load demand due to the seasonal water flow variations.
2. Floods during rainy seasons may cause break down of the small hydro system.
3. Small hydro can only be sited where the potential exists.
4. Expansion of a small hydro unit to serve additional load is frequently limited by available flow.
5. The impact of variable water flow reduces the average power output of a small hydro plant as compared to its peak generating capacity.
6. Provision of preventive measures for fish migration is an economic imperative for operating small hydro units.
7. Technically experienced on-call engineers may be required to ensure safe and reliable operation of the hydro systems, although remote operation of these systems is becoming standard practice in the industry.
8. Trash racks protecting the intakes require periodic inspections and cleaning, (self-cleaning trash racks do exist), which may increase the maintenance cost of these units.

IV. COMPONENTS OF A SMALL HYDRO PLANT

Hydro flow rate is usually measured in liters per second or in cubic meters per second. Head is the vertical height in meters from the point where the water enters the penstock, (which is the inlet), to the turbine. The available power (P) which is proportional to the product of the head (H) and the flow (Q) is given as $P = H \times Q \times c$ where c is a constant denoting the acceleration due to gravity (g) and density of water (ρ). The power P is measured in Watts, Q in cubic meters per second, head in meters and g is $9.81 m/s^2$ and the density of water is 1000 Kg per cubic meters. Therefore, power is given as P = 1000 x 9.81 x H x Q (Watt). The above equation holds good for a system of about 50% efficiency.

Major features of small hydro installations include a weir, small dam, or small water intake structure, penstock, powerhouse, and draft tube. Water from the dam or intake structure is directed into a passageway that can include a canal, penstock, or the turbine inlet. It is a common practice to use a penstock as a water carrier to the turbine. The potential energy of water is converted into mechanical power at the turbine when water strikes the turbine blades with high pressure. Unlike conventional hydropower plants that use water available from large dams, which involve a high investment cost, the small hydro plants use water either from a low dam or sometimes a diversion weir.

The water passage of a small hydro installation consists of an intake comprised of trash-racks, a gate, and an entrance to a canal or a penstock. Water is carried through a passageway to the powerhouse located at a distance downstream from the intake. The entrance and the exit of the turbine include the necessary valves and gates for shutdown and maintenance of the turbine (and usually a bypass to pass water in the event of a shutdown. The tailrace carries water from the draft tube back to the river.

The powerhouse holds most of the mechanical and electrical equipment and is usually stationed downstream at a lower altitude, although in the case of one of the two installations at Laurentian Lodge, the unit is sunk in the headpond, with a draft tube down to the bottom of the flow. (This is to avoid icing problems in the winter.) Powerhouses are generally built of concrete with adequate foundation strength, and easy access for maintenance and safety. Simplicity and ease of civil construction is of primary concern for a small hydro unit to maintain low cost.

Electrical and Mechanical Equipment:

The primary mechanical and electrical components of small hydro are turbines and generators.

Turbines: The choice of a particular turbine depends on the available pressure head and the design flow. Depending on the availability of head, turbines are broadly classified into low, medium, and high head turbines. Based on the water flow, turbines are classified into two categories as impulse and reaction turbines.

- Impulse turbines convert the kinetic energy of a jet of water in air into mechanical energy. These turbines are driven by a high-speed jet of water and are generally used for high-head applications.
- Reaction turbines are used for low and medium-head applications. The blades of a reaction turbine are completely immersed in water and the linear and angular momentum of water is converted into shaft power.

Generators: In small hydro, the generator is connected to the turbine so that the mechanical output from the turbine is fed into the generator to produce electrical energy. Both the synchronous and induction type generators are used by small hydro developers. A synchronous generator can be operated autonomously and is therefore used for off-grid applications. Induction generators (less costly than synchronous) are best suited for on-grid applications. The output from the generators is utilized in supplying power in two ways. .. Battery-based systems are inexpensive and generally serve average loads. These systems store excess power during low demand and supply this power as needed by the consumer and thus help in meeting the load demand during peak periods. The generator can be maintained with battery in operation without interrupting the power supply. Depending on the transmission distance, the voltage for a battery-based system varies from 12-48 volts DC. Electric power can also be supplied to utilities by AC systems which do not employ battery storage and the generator must meet the necessary instantaneous and peak demand. These systems employ an electronic load controller to maintain the voltage and the frequency of the system within permissible limits. The load controller behaves as an automatic switch and maintains constant speed and load on the AC generator by diverting excess power to the shunt loads. Inverters control the loads from shutting down from the batteries during the periods of low-voltage [5].

Electrical switchgear, electrical protection and control system, backup power supply (batteries), fire and security alarm systems, water shut-off valves for the turbine, hydraulic control system, transformers for power transmission, cooling and lubrication, ventilation, etc. form the remainder of the electrical and mechanical equipment of small hydro [7].

V. CASE STUDIES FOR HYDRO INSTALLATIONS

Small hydro continues to gain popularity as a benign source that is environmentally friendly and an effective distributed power generation source that supplies reliable and economical power to remote and grid-connected load centers. It is of prime importance to thoroughly analyze various small hydro installations and carefully learn the advantages and the disadvantages of individual development philosophies and hydro schemes.

In search of excellence in this field, our journey takes us to Toronto to interview a company that has been gaining a reputation for excellence in the field. Before making this judgment we decided to call some old acquaintances in government and in the private sector to verify. Our journey led us to Bruce Sampson, VP of Sustainability for BC Hydro, and Ian Crawford, Manager of Hydropower for the Ontario Ministry of Natural Resources, and to two Canadian First Nation communities, one in northern Ontario, and the other three thousand miles away in British Columbia.

What was the common denominator? Our quest for the best has led us to David Carter, Vice-President of Regional Power and a visionary in the field of green small hydro development. "Because our development philosophy is so environmentally based, we walk away from many of the potential developments we see," says Carter. "The only ones we do are where we can enhance some aspect of the environment. Talk to Byron Le Clair, Economic Development Officer of the Ojibways of the Pic River First Nation in Northwestern Ontario, and to Sid Quinn, Manager of Fisheries for the Sechelt Indian Band in British Columbia. In both these cases we were able to enhance the fishery; in one case we were even able to re-establish salmon runs that had been seriously depleted for decades. And in the case of the Ojibways of the Pic River First Nation, the installation of 13 MW of small hydro (Fig. 10) on the Black River, (just east of Thunder Bay), and giving them a role in the development and operation of the plant has completely turned around the financial well-being and economic status of the band and its members."

Byron Le Clair, Economic Development Officer of the Pic River First Nation, said in a recent communication to another First Nations community, "The power plant created the greatest turning point in the modern history of our community. The monies provided to the community allowed us to reinvest without having to ask government for a handout…Today we have used the funds we received…to reinvest in many diverse economic activities within the community without government approval. Pic River First Nations now runs its own cable television network and high-speed internet service. We operate a successful forestry operation and we are looking forward to develop new hydroelectric projects. Pic River First Nations has also invested in a women's crisis center, youth center and a recreation center."

At Sechelt Creek, just north of Vancouver in British Columbia, there are thousands of salmon back in the Creek where, for years, they had been absent. This is because Regional Power was able to work with the band to recreate the fishery, not simply do a green power project (Fig. 11).

Fig. 10. Wawatay generating station (13 MW, Black River, Ontario, Canada)

Fig. 11. Reestablished salmon run in Sechelt Creek, British Columbia, Canada

PICO HYDRO PROJECT: KUSHADEVI, NEPAL

This third case study was installed for community power in rural Kushadevi, close to Kathmandu, the capital city of Nepal [9]. A summary description is given in Table 1.

Description of the project: The purpose of this project was to provide power to a community with 88 households. A careful survey was first made to estimate aggregated household power consumption. The potential for hydro power generation during the dry season when the water flow is minimal was estimated to be around 5kW. Since the primary load was for lighting, an allocation of approximately 40W was made for each of the households, thereby leading to a total desired capacity of 4 kW.

Table 1. Technical description of the project

Maximum Head	72 meters
Maximum Flow through the turbine	0.6 cu.m/sec
Average river flow	0.53 cu.m/sec
Total Rating	380 kW
Units	1*380 kW
Transmission	Direct coupling
Turbine used	Francis
Turbine type	Horizontal shaft
Design Type	Atleast 20 years
Maximum Power	380 kW at 0.6 cu.m/sec
Generator	Synchronous, brushless, self-excited, self-regulated, two-bearing
Rating	550 kVA, 400 kW
Voltage	415 V
Speed	1000 rpm
Supply frequency	50 Hz
Runner diameter	550 mm
Penstock length	1.4 Km

Allowing for a safety margin of 10%, the generator capacity was chosen to be 4.4kW. The safety margin included considerations for errors in the measurement of head, and system efficiencies that would prove lower than expected. The selection of the location for the powerhouse was based on the optimal solution that served the dual requirement of having a less costly penstock and a suitable point from where electricity distribution and transmission could be easy. The turbine and the generator efficiencies were assumed to be 65% and 75% respectively. The net head required to generate a power of 4.4kW taking the flow to be 0.0135 m^3/sec was calculated as:

$$\text{Net Head, H} = \frac{P}{\eta_{generator} * \eta_{turbine} * flow * 9.81}$$

$$= \frac{4.4 * 1000}{0.75 * 0.65 * 13.5 * 9.81} = 68 \text{ meters}$$

which indicates that the choice of the intake and powerhouse where there is a 15% head loss of the available head of 80m (i.e., 12m) is reasonable and acceptable to produce the desired 4.4kW.

Since the available head of 80m was quite high, a horizontal-shaft Pelton turbine was chosen with a 65% efficiency. The generator employed here was an induction motor that was operated at 5% speed above the synchronous speed thereby generating power at 50Hz. This induction motor was connected to the Pelton turbine via direct coupling. The induction motor was chosen to be 4-pole motor that had a nominal speed rated at 1575rpm. The pitch circle diameter of the Pelton runner is calculated as:

$$D_{runner} = \frac{38 * \sqrt{H}}{speed(rpm)} = \frac{38 * \sqrt{71.3}}{1575} = 0.203 \text{ m}$$

where 71.3m is the net head that is taken after accounting the actual head loss that was found out be 8.73m. The maximum flow rate available in liters per second is calculated as:

$$Q_{max} = 1000 * \frac{(0.11 * D_{runner})^2 * \pi}{4} * \sqrt{2 * g * H_{net}} = 14.2 \text{ l/sec}$$

which clearly indicates that the required flow rate could be met with a 4-pole generator. The motor capacity was chosen to be 7.5kW allowing de-rating in excess of 20% for the heat generated at the high-speed operation of the machine and the possibility of a slight increase in the power compared to the design power. The 20uF/kW capacitor was used to excite the generator for single-phase operation. Current limiting devices often prove to be extremely useful in small hydro schemes as these devices are the only means which can prevent excessive withdrawal of load by consumers. Current limiters are used to limit the amount of current drawn by the consumer by automatically disconnecting the supply when a consumer load exceeds the rated and allowable limit.

Economics of the proposed scheme: A figure of $2000/kW is used as the nominal cost of this project. This figure excludes the cost of the lighting equipment used for the households and also other end-uses. The cost per household was calculated to be $104 if all households were connected. Table 2 shows the itemized expenses for the project.

Table 2. Itemized expenses

Expenditure type	*Cost in USD*
Civil works including penstock layout	**4,052**
The commercial power pack implemented	**2,194**
Induction generator controller	**657**
Distribution	**1,982**
Load-limiters	**448**
Low-power consumption lighting equipment	**430**
Total	**9,763**

AFON IWRCH MINI HYDRO PROJECT, WALES, U.K.

The fourth case study is that of the Afon Iwrch small scale hydro project at Wales, U.K.[6] that won a 15-year power purchase agreement to supply electricity to the utility network. The overall technical description of the project is shown in Table 3.

Table 3. Technical description of the project

Maximum Head	72 meters
Maximum Flow through the turbine	0.6 cu.m/sec
Average river flow	0.53 cu.m/sec
Total Rating	380 kW
Units	1*380 kW
Transmission	Direct coupling
Turbine used	Francis
Turbine type	Horizontal shaft
Design Type	Atleast 20 years
Maximum Power	380 kW at 0.6 cu.m/sec
Generator	Synchronous, brushless, self-excited, self-regulated, two-bearing
Rating	550 kVA, 400 kW
Voltage	415 V
Speed	1000 rpm
Supply frequency	50 Hz
Runner diameter	550 mm
Penstock length	1.4 Km

Description of the project: This 380 kW project is run-of-the-river style construction that was commissioned in the year 2000 with an anticipated annual production of 1.26 million kWh of electricity which would be sufficient to meet the electricity demands of about 330 homes. The project site was once again carefully chosen bearing in mind that the water is based on the annual rainfall that is collected in the available catchment area of 17.7 sq.km which was sufficient for the commercial exploitation of a mini hydro project.

In this scheme water is taken from two low-head weirs. The main lower-level weir was constructed across the river to form a small pond. At the intake chamber, where the inlet pipe is run to the turbine, a screened mesh is installed that helps in screening out river debris and coarse sediments. The length of the penstock used here was 1.4 km and the outer diameter of the penstock was 0.6 m. Head at the site (the distance of waterfall along the penstock from the water inlet to the Francis turbine) is 72 m.

A horizontal shaft Francis turbine was selected, directly coupled to a 415 volt, 3-phase synchronous generator. Electric power generated by the synchronous generator is fed into the utility's distribution network through a buried cable. The output passes through an existing 11 kV transformer and standard protective switchgear to an existing 11 kV distribution power line.

The operating life period of the mini hydro scheme is estimated to be at least 20 years. The project requires periodic maintenance to help guarantee the reliability of mechanical and electrical components. Sufficient water resource is estimated to be available for about 80% of the time despite the natural variability of river flow. The load factor for the scheme was predicted to be around 45%, which results in about 1.26 million kWh/year of electricity that could supply 330 homes.

The total cost of the scheme was $750,000 which indicated an approximate figure of $1975/kW that is typical for mini hydro schemes. The power is sold at approximately 7 cents/kWh to the utility grid. Based on the predicted load factor, the annual income for the sale of electricity is about $9,105,750. Considering the operating and the maintenance costs are to be minimal, this figure can be used to calculate a simple payback period of 8.3 years which is an acceptable payback period if the life expectancy of the hydro project of 20 years or more is valid.

Advantages of the project:

1. When compared with an equivalent coal-fired power station output, this mini hydro system saves around 950 tones of CO_2, 12 tones of SO_X, and 5 tones of NO_X.
2. The calculated payback period of the scheme is reasonable considering the estimated life expectancy of the power plant.
3. Lower operation and maintenance costs are expected owing to fewer and less complicated electrical and mechanical equipment in the powerhouse.
4. This scheme is an easy and reliable solution to tackle federal policies like Non-Fossil Fuel Obligation (NFFO)
5. The design can be implemented with minimal visual impact on the environment and be in harmony with the unique nature of rural communities.

Disadvantages of the project:

1. Sensing equipment is needed to detect any build-up of material on the screened mesh at the intake chamber, and timely cleaning of the screen is required to maintain optimum flow to the turbine. This is routine maintenance.
2. Telemetry linked to the power station is required to ensure reliable monitoring of critical hydro parameters.
3. Although operating and maintenance costs are minimal periodic checks are required. If these checks are overlooked, sudden failure of the hydro system can result.

VI. ENVIRONMENTAL ISSUES OF SMALL HYDRO

The most significant environmental impact of small hydro development is positive in that that small hydro plants generate electricity without the type of emissions associated with conventional power stations. (As with any technology, there are emissions connected with the manufacturing and construction of small hydro components) [11].

Small hydro projects, however, risk being judged unacceptable from an environmental point of view. The main impacts of small hydro developments are summarized as follows:

1. Emission of dust and materials into water from construction activity could result in the short-term increase of suspended particles in the water thereby affecting the aquatic species and reducing the natural attractiveness of the river to the public during construction.
2. Construction equipment used at the site also releases pollutants temporarily, although the total amount is very small.
3. Small hydro impact from any development is site specific, and most impacts can be mediated.
4. Small hydro schemes, if not carefully engineered, may also change the level of suspended solids in the water thereby affecting the erosion and siltation of the river. This might can effect natural flow patterns of the river which could impact activities downstream.
5. The use of biocides and anti fouling preparations for the cleaning of pipes can pollute the discharge water. However, good operating practices minimize the use of such chemicals.

The overall impact of small-scale hydro schemes on the environment is likely to be extremely small and heavily localized. However, it is important to understand and be aware of such impacts (as above mentioned) so that the impact can be easily reduced by good engineering and sound practices. Rather than dwell on "impacts" however, we would like to bring the reader's attention to the benefits that environmentally-sensitive small hydro offer, like the enhancement of fisheries, and sustainable local economic development.

VII. CONCLUSIONS

This paper has addressed various issues related to small hydro that can help in appreciating this continually developing technology as an effective means of generating reliable power to remotely located loads as well as to load centers with highly congested transmission systems. A brief yet comprehensive description of the equipment in a small hydro powerhouse has been offered. Four examples of small hydro installations have been described and the case-dependant factors have been analyzed for estimating the payback as well as the advantages and constraints of each site. Environmental issues associated with small hydro have also been explored.

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BIOGRAPHIES

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