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SMALL HYDRO AS AN ALTERNATIVE SOURCE OF RENEWABLE ENERGY FOR RURAL DEVELOPMENT

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The purpose of this paper is to propose small-scale hydropower as a viable candidate for renewable energy in rural development. I shall provide a brief overview of the technology, indicate a few of the applications,mention some economic factors, delineate some of the leading issues with respect to developing countries and close with a few recommendations.

TECHNOLOGY OVERVIEW

The objective of hydropower is to convert the kinetic energy of flowing water into mechanical energy via a turbine or wheel and thence into electrical energy via a generator. In our Small Decentralized Hydropower Program, we have concentrated on plant capacities ranging from a few watts to 1,000 kW (1 mw). Plant configurations are of two basic types - impoundment and run-of-river. Impoundment facilities rely on a reservoir of stored water for a power source. The principal advantage of this configuration

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is the availability of a reserve source to protect against low flows. Secondary benefits include flood protection and other uses of the supply, such as domestic consumption and irrigation. Run-of-river facilities are usually cheaper to construct and employ techniques which do not significantly affect the stream flow, such as instream non-impounding dams, used mainly for low-head sites, and diversion configurations, used mainly for high-head sites. System components consist of, for an impoundment facility, the dam, the water intake, penstock, the turbine, the generator, load control equipment, the outlet works or draft tube, the powerhouse which houses as a part of the dam the turbine-generator complex and attendant electrical control equipment. A diversion configuration system is similar. The diversion structure may be a dam or some other technique directing water into a horizontal diversion canal with one or more settling basins which connect with a long vertical penstock down to the streamside powerhouse. There are variations to this general diversion scheme.

Turbines come in two classes - impulse and reaction. Impulse turbines derive their energy from the force of water from one or more nozzle directed toward cups or blades around a rotor. Examples include, Pelton, Banki-Mitchell (Ossberger), and Turgo. Reaction turbines derive their energy from the pressure of water moving over the blades. Examples include Francis and propeller-types such as Kaplan, Straflow, bulb and horizontal axis designs. Generators also come in two basic types - alternating and direct current. AC generators produce power at a frequency coordinated with water flow and require speed control equipment. DC generators produce power which varies with the flow but allows the use of storage batteries for peaking power.

New developments in mini-hydro technology include: 1) new materials - graphite bearings, aluminum and plastic runners; 2) new equipment - electronic (solid state) load control equipment at 1/10th the cost of mechanical governors that can use the grid system for "storage" by automatically feeding power in or drawing it out, dump excess energy as heat (for space heating, water heating or heat storage cookers), and make priority switching as demand approaches capacity; 3) new designs to take advantage of low head sites - bulb and tube turbines and to increase efficiencies - angled blades of the Turgo turbine.

With proper gearing, waterwheels are capable of generating electrical as well as mechanical power. Their advantages are: they can be constructed with locally available materials and labor facilities; they can operate in sites with high flow variability; they require minimal maintenance and repair. Their disadvantages are: lower efficiencies (25%-75%); slow speed; bulkiness; they require large housings and tend to freeze up in cold weather.

POWER CALCULATIONS

The two most important factors in hydropower calculations are head (vertical distance of water) and stream flow (volume).

There are a few rules of thumb to follow in determining power potential at a given site.

a. Minimum energy. Generally the minimum operating head is 10 feet and the minimum flow is 10 gallons per minute (gpm), however, a site with a head of 10 feet and a flow of 10 gpm would not generate useful electric power. A site with a flow of 10 gpm and a head of 100 ft. however will produce 100 W of power, generally - enough to light a 100 W bulb continuously. Conversely, a site with a flow of 100 gpm and a head of 10 ft. also produces 100 W of power.

b. Minimum flow. To determine the minimum flow required, the rule of thumb used by many is mean flow for the site. One manufacturer, to be on the safe side suggests using only 25% of dry season flow for power calculation. Flow data is very important - historic data is best, sampling using a weir system or other means is acceptable and even local interviews can be useful. High variability in flow may favor a DC system with asynchronous generator, whereas a steady, dependable flow may be acceptable for an AC system with synchronous generator. Seasonal variations in flow must be compared with seasonal load projections also.

c. Procedure.

1.) Measure water flow

2.) Determine usable flow

3.) Measure gross head

4.) Determine net head (multiply gross head by friction factor and other losses)

5.) Calculate theoretical power (P_{th})

$$P_{th} = \frac{Q \times h}{709} = \text{Kilowatts}$$

Q= useable flow in ft^3/min
h= net head in feet

6.) Multiply P_{th} by the efficiency of each piece of machinery, for example:

Turbines	60% - 85%
Belt drives	95% - 97% per belt
Gear boxes	95% +
Generators	80%

POWER GENERATION AND STORAGE

Two types of power systems are available with mini-hydro systems - AC and DC.

a. AC. This system requires a synchronous or induction generator producing 60 or 50 cycles per second, it requires a control system for water flow and system speed and a speed increaser may be required between the turbine and generator. The control system, generally a mechanical governor, can cost as much as the turbine (see new developments).

b. DC. This system uses an asynchronous generator and can be used for very small (< 5 kW) systems. An inverter can be used to convert DC to AC power. A voltage control system is generally required.

The DC system can be used with storage batteries to provide peaking power and to improve system reliability. A hydropower system using storage batteries is continously cycling power with the system thus avoiding deep discharge. Battery systems are usually under 6 kW, and the batteries are costly and unwieldy.

ECONOMICS

Compared with conventional thermal technologies, the economic characteristics of mini-hydro involve a relatively high initial capital expenditure and almost nil operating and maintenance costs. The most commonly used figures for installed costs in U.S. dollars per kW range from $750 to $1500. However, it is interesting to note that the Small Decentralized Hydropower Program at NRECA is currently assisting USAID/Panama in the installation of turbines at two sites. In this instance, the equipment costs for one of the sites with a 50 kW unit is approximately US $17,000. If civil works for this site are 40% of the equipment costs, the installed cost per kW will be around US $480.

True life cycle costing for mini-hydro plants typically uses a time frame of generally between 40 and 50 years. For conventional diesel plants, 10-20 years is more common. This means not only that replacement costs for conventional diesel plants are incurred at least twice as often , i.e., over a 40 year period one 50 kW hydro plant would be expected to last longer than two 50 kW diesel plants, but also that there is a substantial savings with mini-hydro in operation and maintenance costs, i.e., fuel costs. OPEC prices for a barrel of oil in 1976 were roughly US $12 and they will soon reach US $40.

Capital costs of mini-hydro can be lowered substantially by integrating the civil works with other development systems such as irrigation or domestic water supply - both of which offer potential for mini-hydro development. Civil works costs have been further decreased in projects utilizing free or low cost labor of village volunteers or university students such as those in Tanzania, Nepal and Peru.

Operation and maintenance costs are kept low because the technology is relatively simple and easy to understand and by the fact that parts can often be fabricated or duplicated by a local blacksmith, welder or bodyshop mechanic. Pelton wheels have been duplicated by a small machine shop in Ibarra, Ecuador for many sites in northern Ecuador. New technological developments are also helping bring down capital costs as mentioned earlier.

Sources of financing for mini-hydro development range from international banks, such as the World Bank and the Asian Development Bank, technical assistance agencies such as USAID and the UN, to private and public funds, foundations, commercial banks and credit cooperatives. The source of funding depends to a large extent on the scope of the development, that is,(whether it's a countrywide program, a regional effort or a single site) and the associated risk, or the social and economic costs as well as the benefits.

APPLICATIONS

There are a number of both conventional and non-conventional applications of mini-hydropower today.

a. Conventional. This technology is a "tried and true" one and is being used world-wide in many areas. These uses include: electricity for pumping of water for irrigation systems, for stock watering ponds and for domestic water supplies; electricity for domestic consumption (community uses in churches, schools, homes) for cottage industries (lighting and power for wood working, weaving, tinsmithing, glassblowing, pottery, and for commerical purposes (sawmills, kilns, food processing and storage).

b. Non-conventional. As a technology whose time has come again, the re-emergence of small hydro has produced some new and innovative uses, such as: 1) the use of electricity to produce nitrogen fertilizer with a special hydrolysis reactor, 2) the production of hydrogen through electrolysis, 3) the use of mechanical energy from the turbine for operating such equipment as a grain mill, a rice huller or an oil expeller and electrical energy from the same turbine for lighting and cooking and 4) the development of hybrid systems using mini-hydro and other energy sources both conventional, such as diesel power, and non-conventional, such as solar energy.

ISSUES

A number of issues connected with small decentralized hydropower systems are common to most small rural energy systems.

. End Uses. What are the criteria for use of the developed energy, who determines these criteria and how, should the emphasis of SDH systems development be on enhancing existing cultures, businesses, enterprises, etc. or developing new industries and lifestyles?

- Finance. Who should finance rural small-scale energy systems, what should be the public and the private responsibilities, and what are some creative options open to financial institutions?
- Management. How should isolated small-scale energy systems be managed - from a central institution or a decentralized local organization - what are the advantages, disadvantages, costs, labor considerations, levels of social acceptance and political feasibilities of each?
- Priorities. In developing a national mini-hydro program which of the following options should take procedence and why: 1) developing systems only in remote communities; 2) developing systems as an integral part of larger development plans - water supply, irrigation or hybrid with other renewable energy technologies; 3) developing systems that can be tied into an existing grid system, what are cost considerations of these options, what impact would the developing state-of-the-art of other energy technologies have on mini-hydro power?
- Development. Should mini-hydro be developed (i.e. financed, constructed, operated and maintained) by the private or public sector, do countries need

legislation to develop an effective energy policy, should incentives for private investment be provided, how important is the private sector in mini-hydro development?

. <u>Manufacture</u>. What are the needs and opportunities for mini-hydro manufacture in developing countries, what are the constraints, what are the opportunities for standardization on a national, regional or continental basis, what are the pro's and con's of industrial vs. village manufacture from materials, labor, cost, marketing, and management viewpoints?

. <u>Assistance</u>. In the particular case of developing a manufacturing program, which technique is most effective - government-to-government, government-to-industry, industry -to-government or industry-to-industry, to what degree should research to support industry be encouraged, should industrial cooperatives be developed?

. <u>Subsidy</u>. To what extent should the government subsidize energy production, likewise for consumption, what are the key social, political and technical problems with subsidies, what are the important similarities and differences in subsidies in developing and developed countries.

Methodologies. How well are analytical techniques developed for determining the feasibility of small-scale remote energy systems, how important is the aspect of social feasibility, how important is the ability to evaluate the long and short term impacts of rural small energy systems.

RECOMMENDATIONS

In response to the preceding issues, I presented the following recommendations at a recent workshop on small decentralized hydropower that we sponsored in Quito, Ecuador in August, 1980. They seem appropriate for the purposes of this panel discussion as well.

a. Reconvene in two years to again exchange information and ideas and to assess the status of mini-hydro plans and programs.

   Goal: Keep the momentum for these small scale, isolated energy systems moving.

b. Evaluate the potential for innovative financial assistance programs by developing criteria and other guidelines for "soft" (or non-repaying or partially-repaying) loan programs.

   Goal: Financial support of small-scale decentralized energy systems.

c. Develop a multidisciplinary approach to the development of mini-hydropower through the inclusion of a wide range of fields in, not only the physical sciences and engineering, but also the social sciences, such as anthropology and environmental sciences and socio-economics.

Goal: Regional development which has a multiple-use or balanced-use theme as its objective.

d. Improve analytical techniques through such activities as the adjustment of methodologies to better analyze particular circumstances in various countries.

Goal: Develop better decision-making tools.

e. Develop improved means of institutional cooperation through such techniques as cooperative agreements and regional planning.

Goal: Successful implementation of a national mini-hydro program.

f. Continue to develop and improve education and training programs, through exchange programs, seminars, lectures, curricular development, and other techniques.

Goal: Develop capability and know-how independent of outside (foreign) assistance.