Micro-Hydropower Schemes in Pakistan

by Allen Inversin

Published by:
Small Decentralized Hydropower Program
International Programs Division
National Rural Electric Cooperative Assn.
1800 Massachusetts Avenue N.W.
Washington D.C. 20036
USA

Available from:

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Small Decentralized Hydropower (SDH) Program

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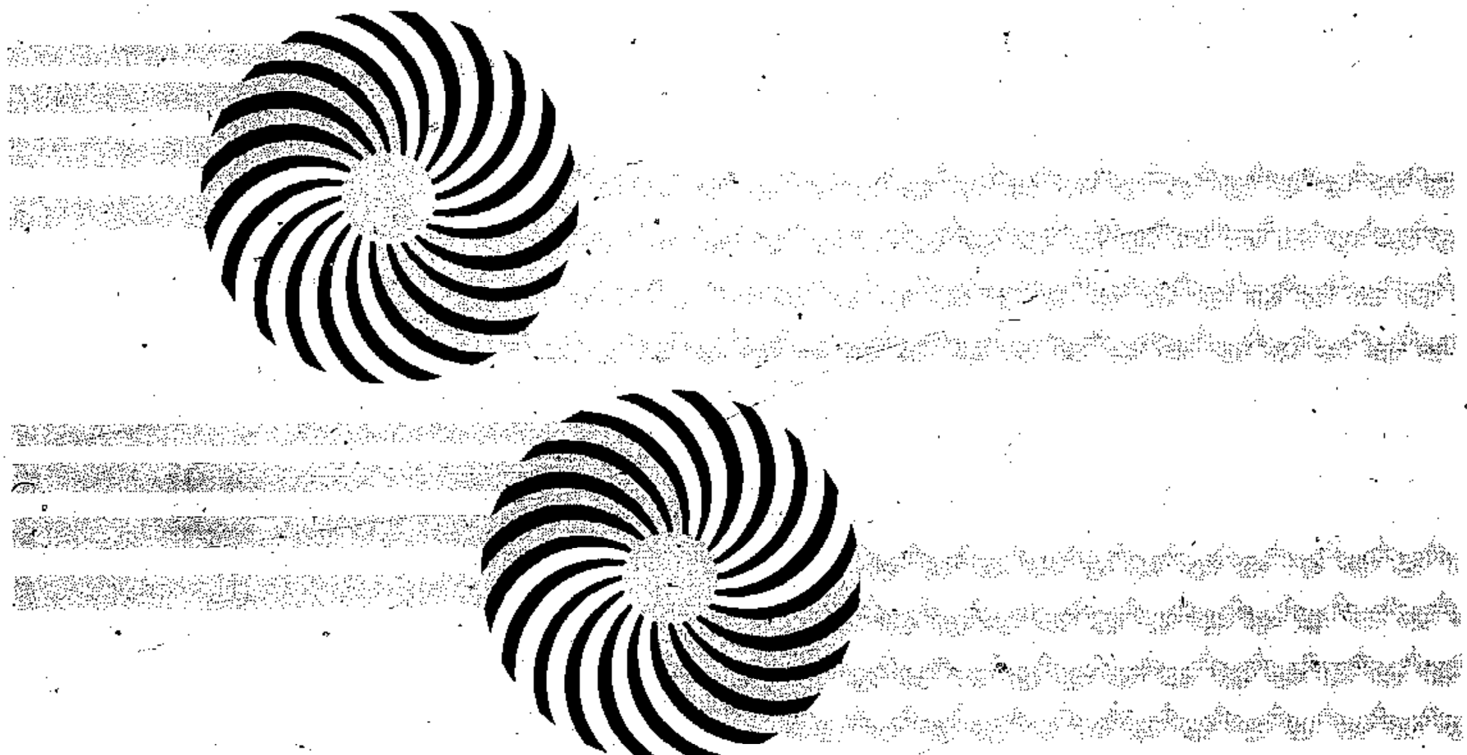

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by

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December, 1981

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I. Introduction

In the mid-1970's, the Appropriate Technology Development Organization (ATDO), with the technical consulting services and support of Dr. M. Abdullah of the North West Frontier Province (NWFP) University of Engineering and Technology, Peshawar, launched a program to disseminate small hydro technology and install micro-hydro plants in remote rural villages in northern Pakistan. Their objective has been to create appropriate designs whose technology and cost can be absorbed by the local population. Ranging from about 5 kW to 15 kW, approximately two dozen plants have been installed to date, at a pace quickening with time as news of these installations becomes more widely known. A similar number of plants, ranging in size up to 50 kW, are also under construction. In addition to generating electrical power primarily at night to replace wood or expensive fossil fuels used for lighting, direct shaft power is used to drive a variety of tools and agro-processing equipment at a number of sites during the day.

Beyond the rather impressive accomplishment of implementing a growing number of viable hydropower schemes in remote rural villages, another unique feature of this undertaking has been the unusually low cost per installed kilowatt of these schemes, a cost ranging from about US $350 - $500 / kW (in 1981 dollars). This low cost is primarily attributable to three factors:

- (1) non-conventional use of readily available materials;
- (2) designs more suited to the local realities; and,
- (3) community involvement in the initiation, implementation, management, operation, and maintenance of the hydropower schemes.

At a time when the high cost generally associated with small hydropower schemes is often used as an argument against their appropriateness, the Pakistani exception to the rule prompts a more detailed description of this experience. How were these schemes implemented? What specific approaches were adopted to hold down costs? What constraints exist in applying this approach to other geographical and cultural areas or to larger schemes?

II. Background

In stark contrast to the flat plains which extend over a large portion of Pakistan, the northern part of the country presents physical as well as demographic obstacles to extending roads and electricity grids and developing other physical infrastructures to serve its people. The steep, rugged, stone-studded mountains, rendered even more austere by the dearth of trees, discourage inroads. And among these mountains, villagers in scattered and relatively isolated communities eke out a living off the inhospitable terrain. Greener irrigated plots of land are generally restricted to narrow strips on the slopes bordering perennial streams in the valleys. The areas farther removed, if cultivated at all, must make the most of the low rainfall in the region.

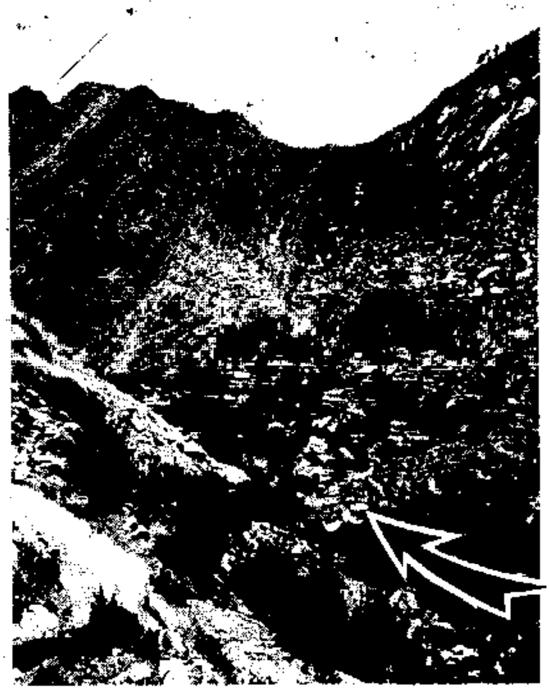

Fig. 1. This view overlooking the Barkalay powerhouse (arrow) shows terrain which is typical of the areas served by ATDO's micro-hydro schemes.

Dr. Abdullah's interest and active involvement in the area of small hydropower was triggered by the concern that grew out of the

1973 oil crisis. As an immediate outgrowth of that crisis, an increasing number of organizations and programs worldwide began to address the problems caused by a dependency on imported oil. However, because of the enormity of the problem, governments in numerous countries generally showed little real concern or capacity for meeting the relatively insignificant energy needs of those in the rural areas, both for replacing costly fuels, especially kerosene and diesel already in use, as well as for providing them with some of the basic amenities already available to those in the urban areas.

In Pakistan, two alternatives for providing electrical energy to the remote areas, without relying on imported fossil fuels, were apparent. To the extent that the national grid relied on large hydropower generation of electricity, grid extension to these areas provided one such alternative. But the annual development plan of the Water and Power Development Authority (WAPDA), the agency responsible for electricity generation, transmission, and distribution in Pakistan, envisions rural electrification proceeding at the rate of about 1,000 villages annually. With three-quarters of the country's 43,000 villages still not electrified, it may well take decades to provide electricity to most of these villages. The remoteness of the villages, the small population in each village, and the lack of income-generating enterprises all contribute to making rural electrification by extending the grid uneconomical. Under the present system, the average cost of electrifying a village, even one only several kilometers from the main grid, approaches Rs. 500,000*. This figure covers only the cost of distribution, not transmission.

Another alternative for providing electricity to the rural areas was the on-site autogeneration of power. In the early 1970's, the Ministry of Water and Power installed

* Rs. 1 = US $0.10

several small hydropower plants along conventional lines but, at US $5,000 - $6,000/kW, this alternative proved equally as uneconomical.

Consequently, both the high costs implicit in pursuing either of these alternatives, grid extension or autogeneration, as well as the logistical and organizational difficulties involved seemed to preclude the possibility of providing electrical energy to the rural areas. If this end was to be achieved, it appeared necessary to develop a new approach, one designed to more appropriately address the specific realities and problems encountered in rural electrification in remote areas.

Given their desire to make power available to those in the rural areas, the ATDO, under the Ministry of Science and Technology, initiated a program to develop a more viable approach. Though hydropower resources could be found in a number of villages in the mountainous regions of the country, one factor which contributed to the high cost of autogeneration was a reliance on commercial equipment and conventional designs. Also implicit in this was a need for skilled expertise to install and to maintain systems on a continuing basis. Consequently, the ATDO focused on developing equipment designs suitable for local manufacture, designs more appropriate from the fabrication, installation, maintenance, operation,

Fig. 2. An example of a simple design used by the ATDO. The steel penstock into the Barkalay powerhouse terminates with a rectangular nozzle. The shaft with cross-flow turbine is supported by bearings on a small concrete base and wooden slats prevent water from spraying out.

and cost points of view. After several attempts, the ATDO adopted the cross-flow turbine design fabricated of steel as the one most suited to local realities. Its design provided ease of fabrication, useful efficiencies, and seemed suited to the head and flow conditions most frequently found in the area. Since new generators were unavailable in Pakistan, the ATDO also attempted to use reconditioned generators to couple to the turbine. At that time, generators were only being imported as part of a generating set, a complete package of generator and diesel prime mover, and not separately. Though these attempts at reconditioning generators were not successful, suitable Chinese generators later appeared on the local market.

The ATDO also developed new designs for the civil works as well as a new approach toward implementation. It adopted designs which stressed the use of local materials rather than those imported into the area and the use of locally available manual labor rather than machinery.

And finally, the ATDO sought to devise an administrative and management structure less costly to maintain and one more responsive to the needs of small scattered

ATDO

Fig. 3. Simple earth headrace (canal) conveying water to the Eillonai (1) powerhouse.

communities. A structure evolved which minimized the need to rely on a central and remote administration. The communities are each responsible for all aspects of their own schemes. Decisions on such questions as tariffs, hours of operation, and distribution of power are all made locally as the need arises.

Initially, in order to get the technology out into the field, several individuals supported by the ATDO held discussions in villages where some water power potential was readily apparent. They informed the villagers of the possibilities for tapping this power and gauged their interest in undertaking such a project. Some villages dismissed the idea while others took it up and made a nominal contribution of labor and cash. These latter eventually served as demonstration sites, as examples to other villages of what they could accomplish if they have the necessary interest and resolve.

The idea caught on. Initially, the ATDO envisioned that a team organized and supported by it would have to install each scheme. But it soon became apparent that, because of the enthusiasm of the villagers and their ability to learn quickly the skills necessary to install these schemes, this responsibility could easily be shared with them. The ATDO has also been able to decrease its financial contribution toward these schemes in line with its mandate of only providing financial support for the initial development and dissemination of appropriate technologies. Interest is snowballing -- about two dozen schemes have been installed and more than three dozen new sites are being considered or under construction. Lillonai, the village where the first scheme was installed, now has four micro-hydro schemes while in the area around Bishband, there are three schemes in the same small valley. All the plants installed to date continue to operate properly, proving the effectiveness of the ATDO's approach to implementing these micro-hydro schemes.

The team to coordinate the implementation of these schemes includes a full-time technician and a field officer who serves as an administrative assistant and maintains contact with the villagers. Both of these individuals are assigned by the ATDO to work with Dr. Abdullah under his direction. In addition, two colleagues from the university, one civil and one electrical engineer, assist with site inspections and implementation. Personnel from either the university workshop or a private workshop fabricate the turbine according to specifications prepared by Dr. Abdullah.

Given their very limited staffing and resources, the ATDO has installed hydropower schemes in villages in a fairly large geographical area in the mountainous regions of northern Pakistan, in the Swat, Dir, and Kaghan districts in the NWFP and in Gilgit in the Northern Areas. These villages, which generally include several hundred inhabitants, are far from the electrical grid. Whereas some may be situated by a dirt road, others may be half a day's walk away. Agriculture on irrigated or rainfed terraces provides employment and a meager cash income for most.

III. Implementation and Operation

The ATDO adheres to no rigid strategy in implementing their rural micro-hydro schemes. Their approach can be considered unique only in that it is flexible. Just as a turbine is designed for specific site conditions, so the approach taken in implementing these schemes caters to the social and economic circumstances existing at the site.

In considering the possibility of a micro-hydro project which potentially could affect an entire village, it would be naive to overlook the often intricate interrelationships and implicit constraints to action inherent in a traditional village setting and to assume that the "village" will request assistance in exploiting its hydropower resources. The issue is further complicated by the fact that implementing such a project requires access and rights to water, to a suitable site for the powerhouse, and to land through which water is to be conveyed, usually in an open canal, from the river to the powerhouse. Consequently, it is an individual or a small group who takes the initiative, those who, partly because of their economic and/or social position, retain the respect and trust of the villagers. They may be traditional village leaders, local entrepreneurs, the manager of a local cooperative, or a resident landlord. The group may also include the owner of the land on which the hydropower plant is to be built. This naturally simplifies implementing any potential scheme. Generally this venture is not formalized although the villagers are encouraged to register with the cooperatives department of the provincial government to avoid any future problems as well as to have access to benefits, especially loans, available through this department.

Already operating schemes provide the impetus for a growing awareness of the benefits which result from developing a village's hydropower potential and for subsequent requests to the ATDO for assistance. After a specific request for assistance has been received from the villagers, the ATDO first ascertains whether the national grid is to be extented into the area in the foreseeable future. If no extension is planned, then one or more members of the ATDO team visits the village to assess its potential for hydropower development, to inquire into the villagers' objectives, and to advise them about possible implications of their decisions and of costs, monetary and otherwise, that would be involved. All stages of the work, from the construction of the civil works through to household wiring, are explained. The ATDO only approves the project if, after discussions with the villagers, it is satisfied that the entire community will share in the accrued benefits. If it is apparent that this point is in question, the ATDO delays or withholds any potential assistance. This measure indirectly tends to nudge the community into fruitful cooperation.

If villager interest appears well founded and genuine, the ATDO discusses the roles of each of the parties concerned. The civil works which will have to be built are also discussed with the villagers who, in turn, will undertake the construction by both purchasing the necessary materials (possibly cement, timber, and/or wire) and providing the necessary labor. Designs for the civil works are discussed. The ATDO does not prepare engineering drawings since villagers cannot understand them. Instead, small wooden models are used on occasion to convey the design of some of the components of the civil works. A model of a forebay, for example, might be presented since this is an unfamiliar component to most. On the other hand, headraces are familiar, having been a component of their irrigation systems for centuries. Since there are no critical aspects in the construction of the civil works, the villagers undertake this work themselves under the direction of the initiators of the scheme. Whereas masons and carpenters are often found in the villages, an electrician to undertake the household wiring might only be found in the larger towns. The villagers are responsible to locate an electrician who, in turn, might pass the necessary skills on to resident villagers. The villagers themselves install the distribution lines. Depending on the circumstances, if the initiators of the scheme have more immediate access to cash, they might provide the necessary materials and the remainder of the villagers might provide the labor. The ATDO determines the portion of the total cash outlay to be covered by the villagers based on

Fig. 4. A temporary structure across the river diverts a portion of the water into an irrigation canal at the right. Similar structures are used with hydropower schemes.

their financial resources. To avoid any possible misunderstandings, it is ATDO's policy to avoid handling any cash contributions made by the villagers. With the monies they have collected, the villagers themselves purchase whatever materials are necessary.

During the course of the site work, the ATDO provides the villagers with technical guidance when necessary. At the same time, the university workshop or a private workshop in Peshawar fabricate the turbine. Because of its simple design, a village-level technician with experience in sheet metal work and welding could fabricate the turbine in several days. But with limited staff, no effort has yet been made to train local technicians. Generators are purchased and stocked in sufficient numbers so that they are available when required. When the villagers complete the site works, the ATDO team provides guidance in installing the turbogenerating equipment. From the time that a framework for the implementation of the project has been worked out and any disputes, such as those concerning land or water rights or accessibility to future electrical power, have been resolved, the entire project can be completed in 3-4 months.

A villager designated by the community operates and maintains the plant. For a few days after completion of the installation, the local operator runs the plant with assistance from the ATDO staff, learning the various tasks necessary for proper operation of the plant. Since no governor is incorporated in the system, a principal task of the operator is manually regulating the equipment through the night. Though the lights around the village are generally provided with a switch, this lighting load, which provides the principal load on the generator, does not vary markedly. The operator, therefore, is not required to continually adjust the water into the turbine to keep pace with changes in the electrical load. After early evening when most of the lights are on, the only major change occurs several hours later as the villagers prepare to retire for the evening. Thereafter, the load is maintained at a fairly constant, low level and the plant is shut down at or before daybreak.

The initiators of the project often also manage the system, undertaking operational decisions, including setting a tariff, in league with the affected villagers, although this is generally not formalized. Equitable operation under these circumstances depends on a mutual trust which has evolved over the years. In cases where the same canal serves for both irrigation and power generation (Fig. 5), power generation is relegated a subordinate position and, during the irrigations periods, the plant is either shut down during critical hours or days or else operated at reduced power. Whenever required, the villagers contribute their services and carry out the necessary maintenance work on the civil works without waiting for external assistance. The ATDO, through its staff which makes occasional visits and shares experiences, maintains a strong link with the local communities.

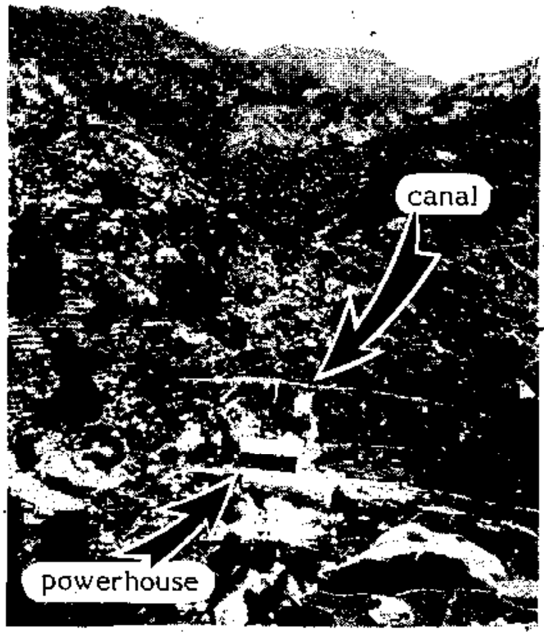

Fig. 5. The Barkalay powerhouse utilizes excess water available from an irrigation canal which cuts across the terrain a short distance uphill.

A tariff for the consumption of electricity by the villagers, which is amenable to all, is generally set to cover some of the general recurring costs. In one instance, the landlord who initiated the scheme provides free power to those who provided labor toward its construction. Commonly, however, a fixed monthly rate per bulb (generally Rs. 4.) is set and villagers are asked to use bulbs in the range of 40 W to 60 W. Most homes have three to four incandescent bulbs. No current limiting devices are used. The villagers involved in the first project implemented with ATDO assistance (about a 10 kW unit at Lillonai) decided to install individual energy meters (at a cost of Rs. 180 to each of the eighty consumers) simply because that was the conventional approach used in urban areas. In this case, the tariff is set at Rs 1.00/kWh and the total monthly revenue collected from the villagers is about Rs. 900. With initial guidance from the ATDO staff, the manager of each scheme maintains an up-to-date register of all accounts. Non-payment of the tariff can result in disconnection of power. Government agencies do not collect any revenue or levy any taxes on these installations.

Lighting is the principal end-use of the electrical power generated although some appliances, such as fans, irons, arc-welders, drills, and televisions, are used occasionally. At one site, an electrically driven wheat thresher/corn sheller is operated in the field. It is moved to convenient locations around the village and electricity is tapped from a nearby distribution pole. The ATDO encourages other income-generating end-uses and provides information on availability and cost of industrial and/or processing equipment of suitable capacity.

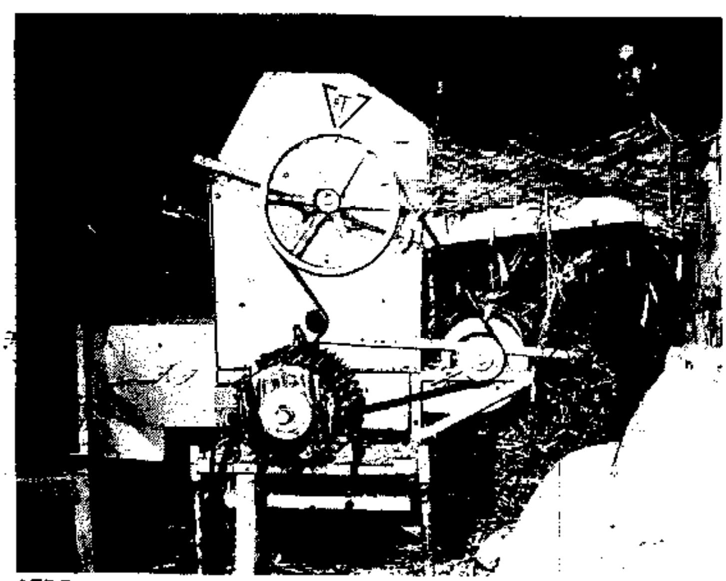

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Fig. 6. An electric motor-driven wheat thresher drawing its power from the Barkana hydropower scheme.

Fig. 7. In addition to generating electricity, a belt-drive from the turbine (below floor level) drives numerous tools at Lillonai (1).

At a number of sites, cottage industries have been established which utilize direct mechanical power from the turbine to drive a variety of tools. These include flour mills, rice hullers/polishers, band saws, rock-salt grinders, wood lathes, cotton gins, and workshop grinders. These are generally used during the day when electricity is not generated. At some sites, the owner of the land on which the powerhouse is located purchases his own equipment. In cases where a cooperative undertakes a micro-hydro scheme, the provincial Department of Agriculture and Cooperatives provides loans for end-use equipment. A number of banks in Pakistan have introduced schemes to advance loans to farmers for agro-processing equipment powered by micro-hydro plants.

Fig. 8. A band saw in operation at the Bishband powerhouse/ workshop is coupled by a flat belt to the turbine.

ATDO

IV. Technical Design

Appropriate designs of both the components and the entire system account for the relatively very low costs incurred in implementing the ATDO micro-hydro schemes as well as for the possibility of using the villagers themselves to install, operate, and maintain the schemes with the minimum of outside assistance.

A. Civil Works

One area in which the use of local materials is maximized is in the construction of the civil works. Not only does this noticeably reduce costs, but it permits the use of materials and construction techniques with which the villagers are already familiar. Once involved in the construction, the villagers are then more aware of the operation of the various components of the system and are in a better position to maintain the civil works in working order.

1. Intake Area

A temporary diversion structure, a low wall of stones across the stream, directs a portion of the flow into the intake. A major advantage of this temporary diversion is that, during periods of heavy rains and flooding, it easily washes away, no longer restricting the flow of the stream nor focusing it into the intake. The floodwaters, along with potentially destructive boulders and debris carried down the river, continue downstream unhindered. The villagers can then easily reconstruct the diversion after the flood waters have subsided. And if possible, the actual intake itself is placed so that the natural contour of the land, rock outcroppings, or large boulders protect it from flood waters and water-borne debris. In this manner, an intake for a micro-hydro plant is similar to any one of the innumerable intakes to irrigation canals which have been dotting the local streams for generations (Fig. 4). No new skills have to be brought in from outside the community. Permanent dams or diversion structures used elsewhere require high-cost materials (concrete and steel) which must be purchased outside, new areas of expertise which must be introduced into the area, and proper engineering studies which must be carried out.

2. Headrace

At the majority of sites, the headrace closely parallels the river. It is similar to the traditional irrigation canals used in the region except that, in order to convey the larger flow that is usually required for power generation at low head, it may be of slightly larger cross-sectional dimensions. It is generally an

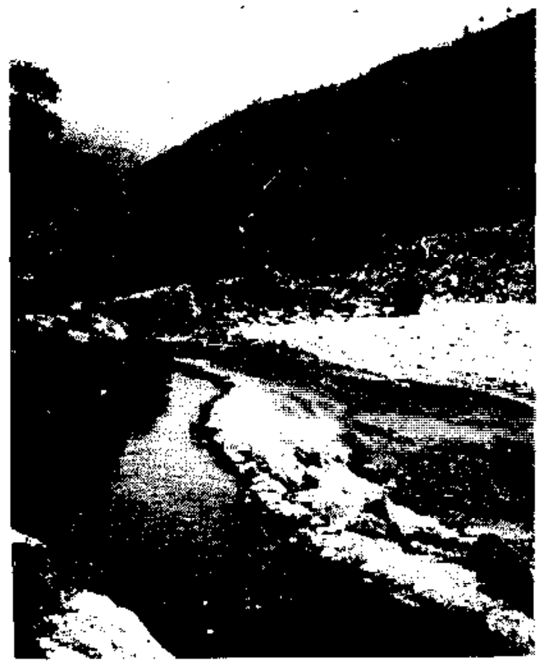

Fig. 9. An earth headrace conveying water to the Alpuri powerhouse.

Fig. 10. A portion of the headrace constructed of concrete and supported by masonry pillars, leading to the powerhouse (behind the trees) at Bunji.

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unlined earth canal. Occasionally, when a portion of the headrace is built above the original terrain or goes through soils which are porous, that portion may be lined of concrete or constructed of masonry (Fig. 10). There are no settling ponds; instead, any settling which occurs does so in the headrace itself. Consequently, depending on the site, a headrace may have to be cleaned out on a monthly basis using village labor and this may take a few days. Probably the only kind of settling area which might be included in the scheme in order to save on these labor inputs would be a structure lined of concrete and properly designed, but this would involve increased cost. In selecting an appropriate design, the tradeoff between cost and labor must be considered. The approach actually adopted in Pakistan suits local realities well. Labor is generally more readily available than capital and, in any case, the lay of the land often precludes finding sufficient land for an adequate settling area.

3. Forebay

The headrace terminates in a forebay which is the only structure using a relatively substantial quantity of concrete. Even so, the actual portion of the forebay conveying the water is small, often with approximately the same cross-

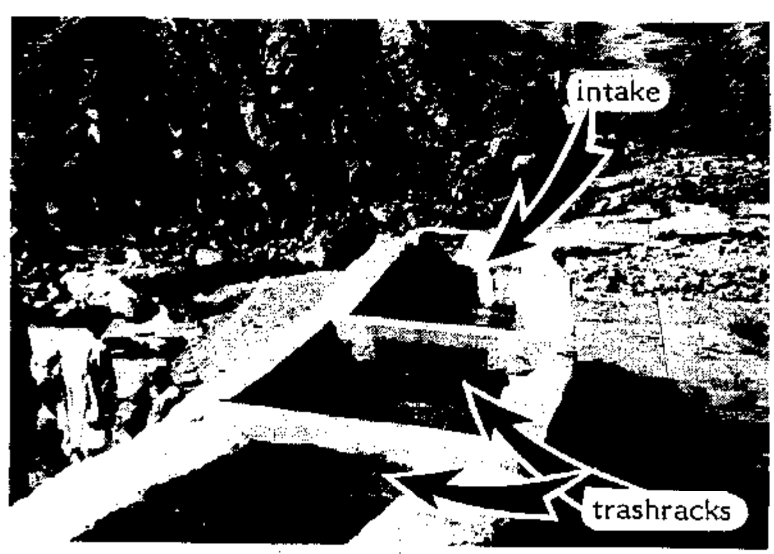

Fig. 11. Trashracks just before the intake to the oil-drum penstock at Alpuri.

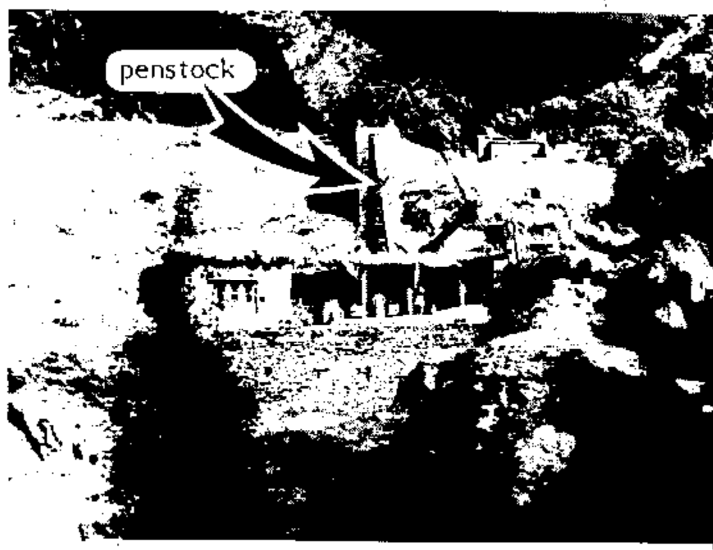

Fig. 12. A nearly vertical wooden penstock leads to the turbine in the Bishband powerhouse.

section as the headrace itself (Fig. 11), and it is only on this immediate portion that concrete is used. The forebay used serves neither to store water nor to permit substantial settling to take place. A spillway is provided either before the water actually enters the forebay or as part of that structure. Also included as part of the forebay is a manually operated, wooden sluice gate which is used either to completely shut off the flow into the penstock or to control the flow of water. To eliminate bends in the penstock and to minimize its length, the forebay is often placed as close to overhead of the powerhouse as practical (Fig. 12). Accordingly, the foundation for the forebay is often built up above the natural terrain. To minimize use of concrete, this foundation is often constructed of dry-rubble masonry (Fig. 13). Generally it is only on the upper portion of the forebay structure, that portion that actually contains the water, that concrete is used.

4. Penstock

A range of materials is used in the construction of the penstock. Sites with heads exceeding about six meters usually use a conventional, relatively costly, steel penstock pipes which are fabricated in town. The flanged pipe sections

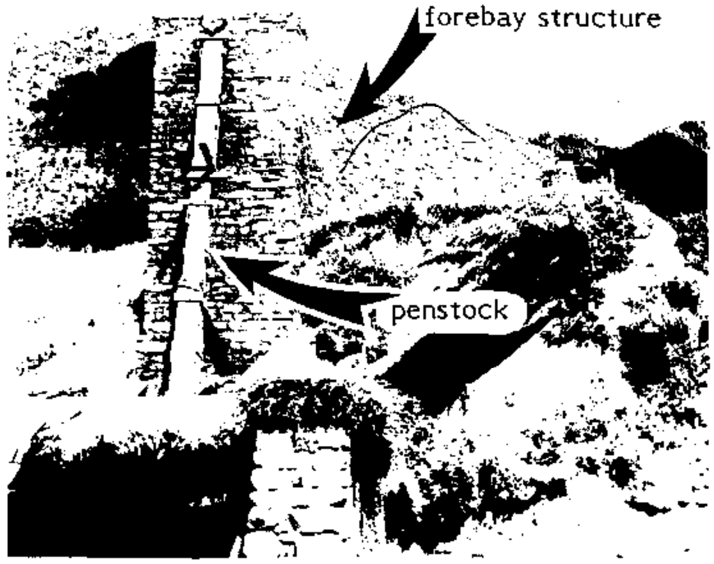

Fig. 13. A close-up view of the dry-rubble masonry forebay structure and wooden penstock at Bishband.

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are then transported to the site where they are bolted together. A gate valve is included just before the nozzle, eliminating the need to run up to the intake of the penstock each time the flow has to be changed to match the load. At lower head sites, 200 litre oil drums are sometimes used (Fig. 14). These are generally welded in pairs, bottom to bottom, and then transported to the site where they are secured together with clamps. Or, at the lower end of the cost spectrum, wood which is sometimes locally available in fair abundance is also used (Fig. 15). These penstocks of rectangular cross-section are fabricated of heavy, longitudinal planks, secured by large nails where appro-

Fig. 14. Oil-drum penstock leading to the turbine which is placed below floor level at the Lillonai (1) powerhouse.

Fig. 15. Wooden penstock for use at the micro-hydro scheme at Mandal.

priate and reinforced by occasional wood and steel clamps. The inner surface and joints are painted over with coal tar to seal any small openings. If the penstock is constructed of either oil drums or wood, no gate valve is used. Instead, the flow is controlled by placing a board across the intake to the penstock.

The respective positions of the forebay and powerhouse are usually selected to minimize penstock length for the available head, that is to maximize slope, and to avoid the need for any bends along the penstock. The penstock is consequently fairly steep

Fig. 16. A view of the turbo-generating area below floor level at the Lillonai (1) powerhouse. The last oil drum used in the penstock is tapered to form a rectangular nozzle leading to the turbine (under wooden cover). Also visible is the generator and separate exciter.

and usually about 5 - 15 meters long. The upper end of the straight penstock is incorporated within the wall of the forebay. The lower portion ends with a rectangular nozzle fabricated of sheet steel (Fig. 2 and 16). At some sites, the longitudinal thrust of the penstock due to its weight is virtually completely supported by the mass of the forebay. At others, it is supported by a mass of concrete or stone in the power-house (Fig. 14 and 17). In both cases, lateral thrust is supported by the forebay and the stone wall of the powerhouse. Because of the short length of the penstock and its steep slope, anchors along its length are not frequently used.

Fig. 17. Oil drum penstock at the Alpuri powerhouse. Operator's bed is in foreground.

Fig. 18. The Bishband powerhouse.

5. Powerhouse

The powerhouse is generally constructed of dry-rubble masonry with a timber roof and open on the downhill side (Fig. 18). To maximize the available head without having to expend a lot of effort excavating for the entire powerhouse, the turbine is often set one to two meters below the level of the powerhouse floor. The two bearings supporting the turbine runner shaft are secured to a concrete foundation. The nozzle is fixed independently of the runner, with a clearance of up to a couple centimeters between the two. A simple galvanized iron sheet or wooden cover is used over the runner to shield the bearings, pulleys, belts, and generator from the spray of water emerging from the turbine. A single stage of several v-belts couple the runner with the generator, which in turn is usually located somewhat above the turbine, closer to floor level (Fig. 19). In addition to including the electrical equipment required for the generation of electricity, the powerhouse may also serve as a workshop containing a variety of tools. These are driven by flat belts off a long intermediate drive shaft which itself is directly belt-driven by the turbine. Belts are simply thrown over appropriate pulleys as the various tools are needed.

Fig. 19. Generator and control panel at the Alpuri powerhouse. An old cross-flow turbine is visible in the background.

B. Turbogenerating Equipment

1. Turbine

The ATDO selected a cross-flow turbine as the most appropriate type because it is suited to the low heads found at most sites and is easy to fabricate, requiring no precision machining or close fits. The end plates of suitable diameter are cut from 6 mm mild steel plate and the blades of sufficient length are shaped by hammering strips of 3 mm mild steel sheet to the proper curvature. With some units, blades are cut from steel pipe of appropriate diameter. The end plates are marked to indicate the position of the blades. The components are arc-welded together and onto the steel shaft. No jigs have been used to date in the fabrication of the units and there has been no attempt at standardization. Both lab and field measurements indicate a turbine efficiency of 50% - 60%.

2. Generator

The generators used are made in the People's Republic of China and operate at 1500 rpm, usually generating three-phase power at 220/380 V. They have a static excitation system and a manually operated voltage regulator. No effort is made to ground the system. A panel board often carries an ammeter for each phase, one or more voltmeters, and possibly a frequency meter. A main thermal circuit breaker box and switch fuse units are also included (Fig. 20).

Having reduced the cost of many components of their micro-hydro schemes, the cost of the generator is now easily the largest component of the total cost (Table 1). To reduce these costs, work towards local fabrication of generators is being organized by the ATDO and undertaken at the University of

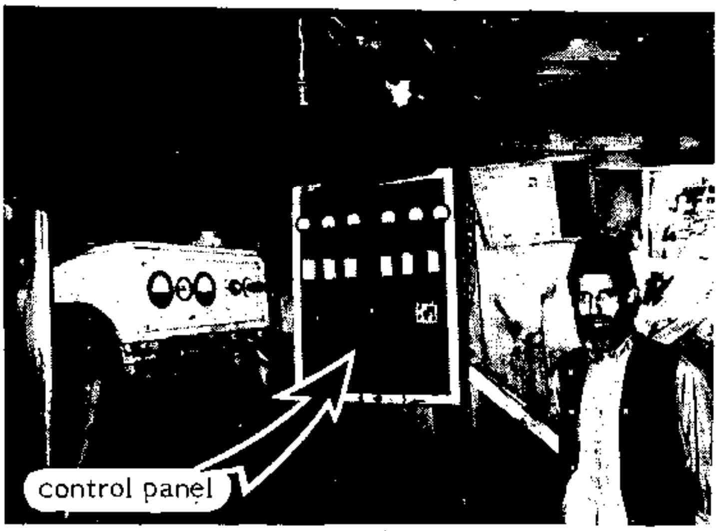

Fig. 20. Control panel at Lillonai (1), ATDO's first micro-hydro plant. Three other plants have since been installed in that village.

Engineering and Technology, Lahore, with a grant from the ATDO. They have built several 1000 rpm generators of locally available components and imported sheet steel laminations. Laboratory efficiencies of about 60% have been measured. Several units are about to be field tested. However, with a cost reduction of only 25% over the price for the imported Chinese generators, the ATDO is examining whether large-scale local fabrication would ultimately prove cost-advantageous.

3. Governor

No governor or load controller is used with the turbogenerating equipment to maintain a match between water power available and the imposed electrical or mechanical load. Equipment costs are, therefore, noticeably reduced. At lower head sites, where no valves are included along the penstock, the operator maintains the runner speed within acceptible limits by regulating the flow <u>into</u> the penstock with a wooden sluice gate included in the forebay. The penstock may then operate partially full, resulting in reduced head and jet velocity. When the turbine, which should continue to drive a generator at 1500 rpm, then operates at reduced head, it operates at reduced efficiency. But, given the adequate flows generally available in the headrace, this is of no concern. At higher head sites, a gate valve at the base of the penstock is used to control the flow to the turbine. At reduced load, use of the valve introduces disturbances in the jet causing reduced efficiency, but this again is generally of no concern.

In actual operation, there is little need for the operator to continually monitor the net load or, more precisely, the frequency or voltage. The risk is actually greater that the operator will fall off to sleep because of the infrequency with which adjustments to the flow are required during the night. The operator remains near the unit all night. At one site, an alarm to alert the operator of over-voltage conditions has been installed. Also included is an over-voltage trip which then removes the excitation from the generator if the operator has not taken the necessary corrective measures. For short durations, the generators can accomodate the turbine runaway speed encountered when the excitation is removed.

C. Distribution

The powerhouse is generally located close to the village and no transmission system is necessary. A simple distribution line of suitably sized, bare copper wire serves to carry the power to the consumers. A maximum voltage drop is set at about 10%. Wooden poles support the lines. The section of these poles under ground level are painted with coal tar. No lightning arrestors are included since lightning storms apparently pose little threat in the area. Often each phase is distributed to a different part of the village and occasionally, one phase is kept at the powerhouse/workshop. Although, in the design of the scheme, an attempt is made to balance the average expected load on each phase, no attempt is made to continually balance loads during operation of the system.

The wiring standard used varies from nationally recognized standards in the well-finished homes to rudimentary wiring in most of the stone, brick, and/or mud-wall homes. In spite of this, no accidents have occurred to date. With some schemes, fuses are mounted on the power poles in addition to installing them in each home (Fig. 21). For lighting, incandescent lamps are used though the use of fluorescent lamps is encouraged in cases where the consumer can afford the initial cost.

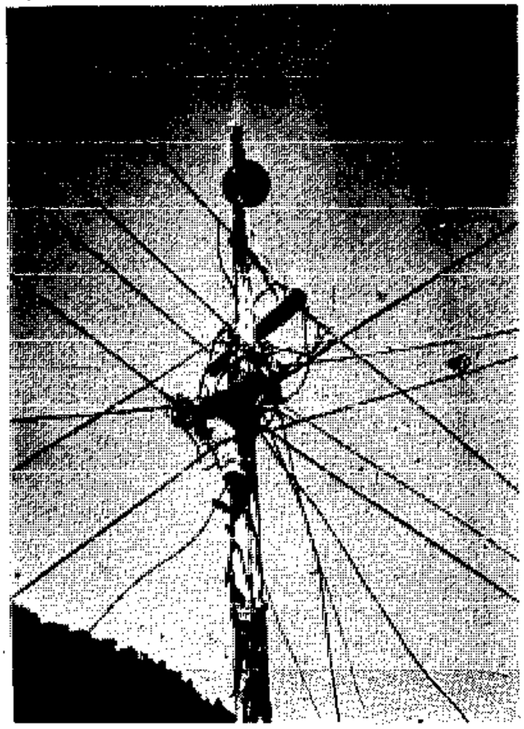

Fig. 21. A power pole, with street light and fuses, at Alpuri.

V. Costs

Around 1978, the ATDO prepared tables of both the capital costs (Table 1) and recurring costs (Table 2) for the range of their micro-hydro schemes installed to date. This costing information is presented in Rupees (Rs. 1 = US $0.10). The unusually low cost per kilowatt for the ATDO's micro-hydro schemes, ranging from US $250 - $400 / kW (in 1978 dollars), is due to several factors:

(1) low administrative costs;

(2) contribution by the villagers of all the labor;

(3) maximum use of local materials;

(4) local fabrication of some of the equipment;

From: Mini & Micro Hydel Plants, ATDO

Plant Capacity (kW)	Generator	Turbine and Accessories	Civil Works	Technical Assistance	Total Installed Cost	Distribution Cost	Total Cost Delivered	Total Installed Cost/kW	Total Cost Delivered/kW
5.	9,350	1,500	5,000	3,520	19,370	4,000	23,370	3,874	4,674
7.5	12,950	1,500	6,000	3,520	23,970	6,000	29,970	3,196	3,996
10.	14,250	2,000	7,000	3,520	26,770	8,000	34,770	2,677	3,477
12.	16,780	2,000	8,500	3,520	30,300	9,600	39,900	2,525	3,325
15.	20,800	2,500	10,000	3,520	36,820	12,000	48,820	2,455	3,255

Table 1. Breakdown of fixed costs for ATDO micro-hydel plants.

(5) appropriate system design (e.g. no attempt to maximize system efficiency, no governor, no full-time staff);

(6) no provision for a profit margin included in most costings for micro-hydro installations; and,

(7) minimal use of costly technical expertise and supervision.

The ATDO initially financed most of the machinery and materials required in the installation of the micro-hydro schemes. This was was partly for promotional reasons -- people needed to be aware of what the "product" was as well as its usefulness before they would consider buying it. In addition, capital is generally in short supply in rural villages. Now, as the technology is establishing itself fairly widely and its potential use is becoming visible, the ATDO contribution is being phased out. Its role of designing and disseminating this technology has largely been completed. The local population and provincial authorities are carrying an increasing

From: Mini & Micro Hydel Plants, ATDO

Plant Capacity (kW)	Labor	Belt	Miscellaneous Repairs	Total Operation and Maintenance Costs
5.	1,800	200	150	2,150
7.5	1,800	250	200	2,250
10.	1,800	300	250	2,350
12.	1,800	375	350	2,525
15.	1,800	450	450	2,700

Table 2. Breakdown of operation and maintenance costs for ATDO micro-hydel plants.

portion of the capital costs. At present, the cost of ATDO's technical services and half of the generator cost are covered by the ATDO, the other half of the generator cost is borne by the NWFP provincial government, and the civil costs are covered by the villagers. The cost of the turbine and materials necessary for the distribution and house wiring is split up among the three parties depending upon the situation.

The ATDO has also performed a cost analysis for the same size plants as those noted previously. For this analysis, the ATDO assumed a plant life of 25 years, a 13% interest

From: Mini & Micro Hydel Plants, ATDO

Plant Capacity (kW)	Annual Energy Generated (@ 30% plant factor (kWh)	Annual Energy Delivered (@ 5% distribution losses (kWh)	Total Installed Cost (Table 1)	Annual Equivalent Installed Cost, (@ i = 13%, n = 25 yrs	Annual Operation and Maintenance Costs (Table 2)	Total Annual Cost, without distribution	Total Annual Cost/kWh, without distribution	Total Cost Delivered, i.e., including distribution (Table 1)	Annual Equivalent Cost Delivered, (@ i = 13%, n = 25 yrs	Total Annual Cost, with distribution	Total Annual Cost Delivered/kWh
5.	13,140	12,483	19,370	2,643	2,150	4,793	0.36	23,370	3,188	5,338	0.44
7.5	19,710	18,725	23,970	3,270	2,250	5,520	0.28	29,970	4,089	6,339	0.34
10.	26,280	24,966	26,770	3,652	2,350	6,002	0.23	34,770	4,744	7,094	0.28
12.	31,536	29,959	30,300	4,134	2,525	6,659	0.21	39,900	5,443	7,968	0.27
15.	39,420	37,449	36,820	5,023	2,700	7,723	0.20	48,820	6,660	9,360	0.25

Table 3. Cost analysis for ATDO micro-hydel plants.

rate, a 30% plant factor, and distribution losses of 5%. Their findings are noted in Table 3. For the range of power outputs covered by the ATDO micro-hydro schemes, costs/kWh generated range from US $0.02 - $0.04 / kWh (in 1978 dollars).

VI. Issues and Problems

Continuing progress in implementing micro-hydro schemes in the rural areas of Pakistan and growing awareness of their potential is leading to an increased demand for assistance. Several questions come to mind:

A. Expanding the Scale of the Program

Is it possible to maintain the effectiveness of the present program and yet to continue to implement projects to keep pace with increasing demand for assistance? What constraints lie in the way of achieving this goal?

At present, responsibility for all design work and other technical assistance, arrangements for financial support, administration, and coordinating activities with interested villagers falls upon the very limited staff of three supported by the ATDO. Not only is much time and effort taken up in addressing these functions per se but equally as demanding is the time and effort required in covering ground, in visiting the widely separated villages in remote areas of the country.

One approach might be to increase staffing of this implementing organization and possibly to open an "office" in each district where substantial work has been or is being undertaken. But this prompts two further questions:

(1) What would be the source of financial support for this enlarged staff? Could the provincial government provide such support? And if so, would the program's present effectiveness be impaired by accompanying political contraints, bureaucratic inefficiencies and delays, and lack of staff

motivation? On the other hand, by possibly redesigning its implementation strategy and passing on its costs to its customers, could such an organization be virtually self-supporting ? Could the ensuing financial burden be minimized by making loans available to those villages undertaking micro-hydro schemes, loans which could then be repaid by collecting monthly fees without increasing those fees from those presently charged? Or would this place an unacceptable burden on those in the rural areas?

(2) And, assuming that the financial problems can be resolved, can individuals with the same dedication to the job that is apparent among the present staff be recruited? This can well prove to be a more difficult point to resolve. Though work in rural areas is often personally rewarding, it is very demanding. That may well be one reason why, while resources continue to pour into the urban areas, the rural sector is generally largely neglected. Dr. Abdullah has already attempted recruiting but his experience to date confirms the difficulty that will be encountered. Not only must the potential candidates be willing to undertake the work but other factors such as their age, motivation, and sensitivity must also, of course, be considered.

B. Increasing the Capacity of the Plants

The hydropower plants implemented to date by the ATDO have had capacities ranging up to approximately 15 kW. Economically, its approach appears very attractive, especially in view of general experience with small hydropower projects undertaken by the public and private sectors around the world (Fig. 22). Can the ATDO approach be applied to the implementation of larger schemes? How does increasing size change the overall design? What new problems might be encountered?

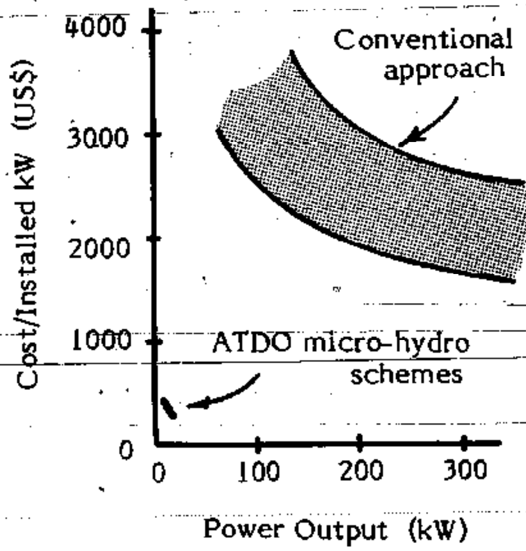

Fig. 22. Comparison between the costs of ATDO-sponsored schemes and conventionally implemented small hydro projects.

One factor which cannot be avoided when generating increased power is the requirement for an increased flow of water and/or an increased head. This introduces several possible problems in the implementation of larger projects. In the first place, sites near adequate load centers where these conditions are met must first be found. Secondly, where sufficient water is found but is limited at times because of other end-uses for that water, especially for irrigation, conflicts might arise. Any water used by a hydropower plant is lost to productive land between the elevations of the intake and the tailrace, though it is, of course, again available at or below the elevation of the tailrace. And finally, a larger scheme might well involve more extensive civil works which could occupy or interfere with presently productive lands, causing further conflicts. The small ATDO schemes already implemented are either well integrated within the existing system of irrigation or else occupy short strips of land which are situated along the river, land which is unsuited for agriculture.

The low capital outlay required to implement micro-hydro schemes such as those installed by the ATDO is a direct consequence of their approach to implementation (see pp. 25-26). The technical aspects of this approach are in part applicable to larger schemes. Appropriate designs of the individuals components as well as of the overall system can continue to reflect the realities encountered in the context of small decentralized hydropower. However, the use of increased flow and head with larger projects will affect their design. Increased flow will tend to imply civil works and turbines of larger cross-sectional dimensions. Increased head will imply a greater working pressure imposed on the turbine and penstock. Materials used in the construction as well as designs adopted must reflect these changes. Though the approach of simply reducing the dimensions of designs used for larger hydroelectric projects should continue to be guarded against when dealing with small decentralized hydropower, the designs and materials used with small projects will tend towards those used by these larger projects as plant capacity increases. This may well imply higher cost materials. It might also put locally fabricated turbines to the test.

Fig. 23. The ATDO approach encourages self-reliance. Rather than relying uniquely on store-bought steel pulleys, villagers sometimes construct their own pulleys of wooden half-sections bolted together around the shaft and wrapped with a strip of canvas belting.

As a plant's capacity increases, the accompanying larger and more varied electrical end-uses may well require more sophisticated and costly governing and protective devices. Depending on the size and the layout of the villages which are to be tied to these plants, transmission might have to be considered. To date, costs have been maintained low because only rudimentary protective devices are being used and no governing devices and no transmission are necessary.

Whether the other, non-technical, aspects can be incorporated in the implementation of larger schemes is uncertain. Village leaders established in the community were, for any one of a variety of reasons, instrumental in the initiation and management of the small ATDO schemes to date. And these schemes were implemented with substantial inputs and commitments from the local community whose bond to these leaders was often based on a trust which had evolved over time. These factors reduced cost markedly and increased the viability of the projects. Is this possible for larger schemes? Schemes with a greater capacity would often cover a wider geographical area. Several villages might be involved. Is it still possible to find a homogeneity of interest and willingness to work together as a larger group. How large, and increasingly complex, a system can a virtually untrained individual manage and operate effectively? Would this require additional financial, managerial, and technical inputs which would no longer be as readily available at the village level?

Near Gilgit in the Northern Areas, the ATDO is presently implementing a 50 kW hydropower scheme, a size significantly larger than those presently installed. Their experiences with this scheme should provide further insights into both the


ATDO

Fig. 24. Direct belt-drive powers grinding wheel (being used to sharpen a band-saw blade), wood lathe (turning a leg for a bed), and grain milling machine in background.

problems that might be generally encountered in implementing and managing larger schemes and the costs that will be incurred.

C. Benefit to the Rural Sector

When all is said and done, do small decentralized micro-hydropower plants really contribute to an improvement in the lot of the rural poor? Or are the "rich" the real beneficiaries? Is electricity a luxury, a projection of the felt needs of urban-based planners on the rural population? Does it not make the poor more dependent on forces largely outside their control for access to the necessary end-use appliances and expertise to maintain both the system and the appliances?

The method of implementation of ATDO schemes relies on a few individuals to initiate, coordinate, and manage the entire undertaking. But they, by virtue of their standing, economic or otherwise, are apt to benefit more directly from the villager inputs, both financial and labor, towards the scheme. Are the villagers assisting the "rich in getting richer" at their expense or are they reaping actual benefits in proportion to their inputs? Can a villager withdraw from the system, should he so decide, without any net loss to himself? Over time, might the

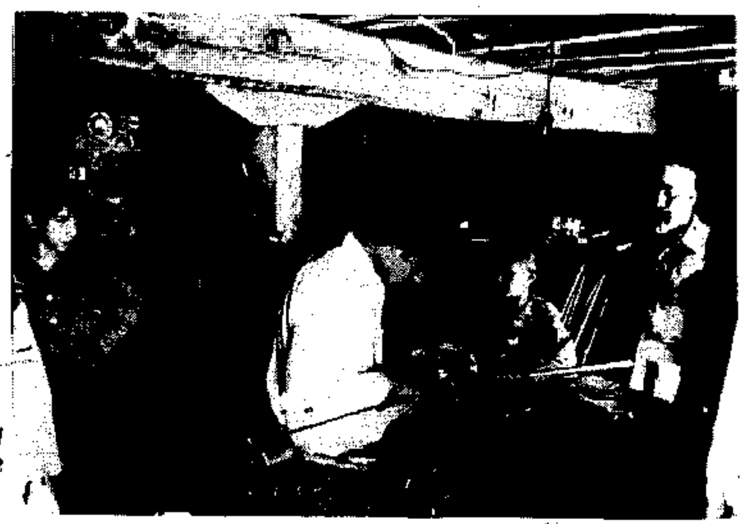

Fig. 25. Workshop utilizing power generated at the Barkalay powerhouse.

manager of a scheme gradually manage the scheme to his own end on the pretext that the villagers have already reaped benefits commensurate with their original contributions, both physical and monetary. Though these would appear to be possibilities, there seems to be no indication at present that these concerns are warranted in the case of the ATDO-implemented micro-hydro schemes.

Because the poor are often living not far beyond a subsistence level, they are often conservative, hesitant to accept new ideas which might compromise their already precarious economic position. But the fact that the villagers do tap onto the electricity system at the ATDO sites and seem willing to continue paying the monthly tariff seems to indicate that they must feel it to their advantage, that it does improve their lot. The ATDO has recently completed a survey of the impact of their work and their findings are expected to be available shortly. This might answer some of these questions.

Assuming the schemes continue to be managed equitably, are the stated villager benef ts, primarily electricity for lighting, actually net benefits? If electricity replaces kerosene or wood which was previously used for the same purpose, any net benefit can be fairly easily determined. A cash value can be assigned to it. If, however, electricity is used because it is now available whereas nothing was used previously, the conclusion is not clear-cut. A new expense will definitely be incurred on the part of the villager and additional income will be required to cover it. In cases where newly introduced lighting contributes to increased income-generating productivity, then net benefits can again be more easily determined.

Social and other benefits, derived from electrification, which have no direct cash value may be sufficient rationale for implementing a subsidized scheme. However this is a luxury not afforded self-supporting schemes which have no alternative but to cover the costs they incur.

D. Replication in Other Countries

Given the prevailing trend of high cost per installed kilowatt for small decentralized hydropower installations around the world, the approach undertaken by the ATDO in Pakistan provides an attractive alternative. But two points must be stressed.

Firstly, the low costs of the small decentralized hydropower installations described in this case study are for plants with an output of 5 - 15 kW. Until plants with higher capacities are operational and experience has been gained, it would be erroneous to extrapolate from the experiences gained to date and to assume that the costs of hydropower installations would remain low for plants of greater capacity--that may or may not be the case. Further work in the field is necessary before the validity of this assumption can be substantiated.

Secondly, before it is assumed that such an approach and its associated low costs can be replicated elsewhere even for installations of only small capacity, those aspects which have been instrumental in reducing the costs of the schemes installed with the assistance of the ATDO should be considered. Some of these aspects (see pp. 25-26) are clearly more easily replicated outside Pakistan than others.

Local materials have already been used in hydropower installations of all sizes throughout the world, though there has often been a bias toward the extensive use of expensive, often imported, "better" materials. Though incorporating locally-available materials in the design of hydropower schemes can be maximized to reduce costs in other countries, care must be exercised. One obviously cannot assume, for example, that since low-cost earth headraces are used in Pakistan, such a headrace design is appropriate at other sites or in other regions. Though an attempt to maximize the use of local materials can always be made, the actual extent to which these are used is site-specific.

Not every developing nation may have the experience and capability of, for example, Indonesia in fabricating turbines for a wide range of operating characteristics as well as associated hardware. However, in the low power range being considered here, most countries have the skills necessary to undertake at least some local fabrication. Outside assistance might initially be necessary in designing appropriate equipment and in training the staffs of local workshops. On the other hand, the necessary expertise might well be found in the country, possibly in a university or a government ministry or department. Whether this expertise is available for this purpose is, of course, still open to question. Local fabrication of turbines could lead to cost reductions and any decrease in efficiency of the equipment could, in most cases, be easily offset by slightly increasing the capacity of the turbine. Local capacity for fabrication could also mean that turbines and related equipment could be repaired or replaced more easily when necessary.

Involvement of villagers in the implementation of the ATDO schemes substantially reduced the labor and administrative costs. Whether such an approach would be possible elsewhere would depend on villager motivation, and their resultant commitment to the project, as well as on possibly numerous social and cultural factors. Because of the varied forces at play in a traditional setting, active involvement of villagers in any rural development project rarely comes about on its own. In some cases, it may be difficult to initiate even with external inputs.

Approaches to appropriate system design which are similar to those used in Pakistan are clearly also possible, but individuals with knowledge of the needs of, and realities in, rural communities, as well as of engineering aspects and options, must be found. Devising appropriate designs within a new context requires creativity and flexibility and a need to often break away from conventional approaches. Finding appropriate individuals to address this task might be difficult.

Finally, one essential requirement for implementing small decentralized hydropower schemes on a regional basis is a real and long-term commitment on the part of the organizations and individuals concerned with following through with such a project. This requirement may well be the most difficult to fulfill. The approach taken by the ATDO is not the conventional approach and therein lies the major obstacle--it does not fit into the usual slot. It requires organizations and individuals who can address a wide range of new needs including:

* an integrated approach to implementation where technical aspects are only one small part of the overall work;
* new designs incorporating possibly non-conventional approaches and materials;
* new approaches to funding;
* possibly new organizations at the local level or at least a new scope of work for existing institutions;
* training of a new level of trainees; and,
* conscientious end-use planning and implementation.

It requires individuals who are willing to work for extended periods of time in, and are committed to, the more remote rural areas. It requires a change in the emphasis in the objectives of hydropower programs from imported fuel substitution to rural development.

Though not comprehensive, this illustrates the rather extensive scope of the effort that would be required. Unless a real and long-term commitment can be made toward such a project, the cost and viability of the resultant hydropower schemes may not attain those found in Pakistan. Careful planning for an effective project is essential; otherwise, any attempt may prove expensive and discouraging and may not achieve the project's anticipated objectives.

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