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COST REDUCTION CONSIDERATIONS IN SMALL HYDROPOWER DEVELOPMENT*

by

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I. GENERAL CONCEPTS

1. Physical Components of Mini-Hydroelectric Generating Facilities (MHG)

The main man-made physical components of an MHG facility are:

a. Dams and/or other types of intake works;

b. Penstocks;

c. Safety devices against surges and water-hammers;

d. Anchor blocks and other penstock supports;

e. Turbines or reverse pumps with their runners, guidevanes, nozzles, and castings, as the case may be;

f. Control equipment for regulating turbine/generator speeds;

g. Voltage control devices;

h. Generating equipment;

i. Switchgear;

j. Power transformers, transmission lines and lightening protection.

2. The Main Tasks in MHG Plant Development

The principal technological tasks to be performed in the development of MHG plants are:

a. Site Surveys and Evaluation

The first step usually involves a desk study of maps (1:25,000 scale) followed by visits to the areas under consideration or by visual surveys of the areas from aircraft accompanied by interviews with people familiar with the locality and the streams under consideration.

b. Hydrology

Generally, hydrological work is carried out by on-site investigation as well as by computations from fresh data or from hydrological data already recorded and available for the area.

c. Geological Survey-Engineering Geology

Field investigations by borehole and other rock sampling, exploration pits, trenches or adits are often required in order to facilitate the design of civil works.

d. Mapping

It is then necessary to prepare detailed maps (1:2,000) if further work is warranted. This usually necessitates land surveying.

Consequent on these activities, if the site is selected and the prefeasibility study indicates the site as favourable, the decision may then be taken to proceed to a full-scale feasibility cum engineering design.

e. Feasibility, Engineering Design and Social-Economic Considerations

Because of the scale of MHG it is modern practice to combine the feasibility study with engineering design activities in order to reduce costs and increase the likelihood that the feasibility study will be realistic. It is important that this stage also involves an appropriate evaluation of the social benefits of the MHG project. The conceptual design of the power plant, the routing of transmission lines, access roads and the design criteria for the plant and the penstock should be clearly accomplished at this stage.

f. Detailed Civil Engineering

This task is performed in close collaboration with the professionals performing the electro-mechanical design. The civil works design must involve a proper hydraulic analysis which should take into consideration domestic supply, irrigation requirements and the power generation requirements.

This design must also include the weir, dam (if necessary), setting basin (if necessary), head race, forebay, penstock and the power station building.

g. Tendering and Construction

Tender documents are next prepared. After selection of the civil works contractor, civil works construction is commenced. It is good practice for the group involved in the civil works design to keep close touch with the progress of the works so that the expected quality of the work is maintained and required design modifications may be made on a professional basis.

h. Electro-Mechanical-Detailed Engineering, Tendering

In conjunction with the activities in civil works design, the electro-mechanical engineering design is undertaken bearing in mind the special requirements placed on rotating equipment and control equipment for MHG application discussed elsewhere in this paper. Tendering out next takes place followed by plant selection, assessment, negotiation and award of contract. The equipment should be inspected and tested before installation as subsequent corrective measures can be costly.

i. Installation and Commissioning

Within the first year of an MHG plant it is vital that its performance be closely monitored so that future designs may be informed by the insights gained thus. Furthermore in the Caribbean region, MHG plants are not yet well known so it is necessary to work out detailed maintenance schedules before start-up which may be improved subsequently as a result of monitoring and evaluation.

II. SOME WAYS OF REDUCING CAPITAL COSTS IN DEVELOPING COUNTRIES: Target areas for cost reduction

1. Penstocks

Conventional penstocks for small hydro and larger installations have usually been made of prestressed concrete or high pressure steel, but steel is expensive and it can be demonstrated that in most cases of prestressing for small hydro units this needs not to be so. The techniques of prestressing concrete are suitable when adequate facilities exist nearby but in the hinterlands of many developing countries such facilities do not exist and in any event the scarcity of cement and the expense of its transportation may well increase the capital cost of civil works.
Some of the materials that are currently being used with great cost reductions in penstocks are PVC, wood, fibre glass reinforced polyester, polyethlene and asbestos cement.

a. PVC

PVC pipes can be supplied to withstand heads of over 150 meters so long as an appropriate method of making joints is utilized to guarantee proper sealing. Although in many developing countries it is not possible to obtain PVC pipes in excess of 5 meters long with more than a 12 inch internal diameter, it is possible and even desirable where required to run two pipes in parallel in order to approximate a larger diameter penstock. But PVC has a low impact resistance and becomes fragile from prolonged exposure to sunlight ultraviolet radiation, so it is recommended that such penstocks be installed underground to increase the life of the installation.

Among the many advantages of using PVC in small hydro installations are the ease of adaptation to the desired penstock profile because each pipe length can readily accommodate up to five degree flexture and joints need no welding so that by comparison with metal penstocks, the cost of welding is virtually obviated.

Another advantage which leads to a lowering of cost results from the low weight of PVC piping compared to steel. This has implications for transportation costs and, of course, facilitates installation. Another advantage of the lower weight of PVC and by extension other plastic is the reduction in the need for supports and anchoring. Of course, installation time may be reduced by as much as a factor of 5 which may be very critical as far as controlling costs especially since it can be demonstrated that the installation costs for a PVC penstock are in most instances as much as half of those for a steel penstock for comparable purposes.

b. Wood Stave Penstocks

The wood penstock is an old and well tried type of conduit with numerous good points. It requires a minimum of levelling and foundation work and may undulate through rugged terrain with a curve radius as little as 60 times the pipe diameter. The smoothness of the pipe interior which often increases with time, unlike steel, ensures very low friction losses. If manufactured from quality materials and professionally assembled such penstocks will normally have a long life. It is to be noted that the steel hoops are the carriers of the water pressure. In many developing countries wood for penstocks is still in relatively great abundance so that at $2 or even $1.50 per lb. for steel the need to critically examine possibilities for using wood penstocks in a given application is clear and should not be neglected.

c. Polyethelene Penstocks

Polyethelene pipe is sold in lengths requested by the customer at diameters up to 12 inches and can withstand heads up to 150 meters. Joints are made with special steel accessories. When this material is used in small hydro plants it is recommended that the longest possible individual pipe lengths be used in order to reduce the number of joints because such joints may result in unacceptably high levels of pressure drop. The high flexibility of polyethelene penstocks results in reduced need for excavations and fills to smooth out undulations in the terrain and in most cases surface modifications may be generally kept to a minimum or avoided.

Very little anchoring is necessary for polyethelene penstocks, and because pipe lengths may be selected to faciliate ease of transportation, and because relatively large diameters of pipes can be supplied at lengths up to 50 meters, there is really little or no justification for using metal penstocks.

d. Fibreglass Reinforced Polyester

Penstocks for heads up to 150 meters and an internal diameter of 80 inches can also be made from fibre glass polyester pipe. It is recommended that for low head applications where the total length of the penstock is not great, the use of fibreglass polyester should be considered because capacity for capacity the cost of steel and steel fabrication for these low pressures far exceeds the cost of the equivalent fibreglass penstock.

e. Asbestos Cement Penstocks

Asbestos cement penstocks need to be considered again in low head applications. The main advantages of using asbestos cement piping are due to the following:

i. Ready adaptation to overland profile because deviations of up to 5 degrees can be easily accommodated at joints without causing leaks.

ii. There is no need for expansion joints since the unions can be designed to obviate most expansion effects.

Of special advantage is the relatively low headloss from friction because of the smoothing and general smoothness of the piping and because scaling is not a problem in asbestos cement penstocks.

2. Speed Control

a. In the traditional method of control, the speed regulation system is designed to sense positive or negative deviations of turbine shaft speed from a predetermined rate of rotation. This error signal is fed to an actuator which adjusts the flow of water through the turbine until the error signal is reduced to an allowable level. To accomplish this flow regulation, significant force must be exerted to adjust the vanes. The rapid change in water flow rates sometimes required can set up dangerous surges and water-hammers within the penstock which are costly to obviate or protect against. Furthermore, the time difference between the occurence of a speed change on the rotating shaft and the effective reaction of the controller can be sufficiently long to cause overspeeding of the turbine and alternators. Consequently, these machines may be damaged unless they are specially designed to withstand the often catastrophic centrifugal forces that do develop. Machinery designed to withstand overspeeding is, of course, more expensive.

b. There is a radically different speed control philosophy that uses an electronic sensor (there are several basic types) to read the rate of rotation either as a function of generated frequency (for synchronous generators) or as shaft speed. This digital signal is converted to an analogue output which applies a voltage to a load current control device such as a bank of thyristors.

The bank of thyristors control the load current which flows through a bank of resistive loads which are part of the MHG plant hardware. This in-house load is electrically in parallel to the external load. When the external load is reduced the prime-mover will tend to speed up but this generates an error voltage which increases the current through the in-house "dummy" load. In this way the turbine-alternator system "sees" an invariant load. This design philosophy goes by the name of "load-dumping" because generating capacity in excess of consumer demand is dumped on the in-house bank of resistors.

Thyristors are now relatively inexpensive and the components of the clocks, frequency comparators and multipliers, digital/analogue converters (and optional microprocessor master controller and peripherals) are obtainable at very low cost or can be pirated and reconfigured from a variety of increasingly commonplace electronic equipment. The in-house resistive load dump can be locally manufactured.

For practical purposes this type of control is not yet recommended for power generating units of above 500Kw capacity. The main advantages are:

- cost of manufacture and installation of this controller is at least ten times less than conventional governors, and these prices could fall with improvements in design and fabrication;
- there is far greater stability achievable with rotating equipment;
- because the risk of sudden load changes on the turbine is very, very small, penstocks may be designed with lower safety factors and some surge protection devices are not necessary. This leads to up to 40% reductions in penstock cost;
- frequency control is precise; and
- redundancy can be built into the controller at low cost and maintenance can be simplified by modular design.

This approach, which is the result of independent work in Korea, ATI (U.K.), Jamaica, Malaysia, Curacao, etc., by instrumentation/ electronics engineers working on MHG and wind generators leads to one of the most important differences in technology between MHG and larger hydro and between traditional and state-of-the-art MHG.

This type of controller can also be a voltage regulation device and can be used on isolated systems or in systems synchronized to a local grid supply (with some modifications in circuitry).

3. Turbines and Reverse Pumps

Despite the prevalence of the practice of using centrifugal pumps as turbines in some countries it is sometimes amazing to find that this option of using centrifugal pumps as a prime mover is not exercised and not even considered, primarily because the calculations involved in sizing and selecting an off-the-shelf centrifugal pump is sometimes daunting but the cost is for the time of the designer to make the necessary calculations but having completed these calculations correctly the reduction in capital expenditure for the prime mover can be quite considerable because centrifugal pumps are quite often obtainable off the shelf so-to-speak. (The suppliers of centrifugal pumps should be encouraged to develop and publish tables, graphs, etc., which simplify design and selection of reverse pump prime movers.)

In the preceeding section on speed control it was mentioned that, in effect, the load dumping technique results in an invariant load on the prime mover. This has many implications for turbine manufacture. For one, if the load seen by the prime mover, in this case the turbine, is invariant, then there is basically no need for guidevanes to be adjusted, hence fixed vane turbines can be used and ought to be used in such applications with clear cost reductions resulting. Furthermore, because the load seen by the turbine does not change except under highly unusual circumstances of failure, the expected risks from water-hammers and other surge-type conditions to penstock installations must be reduced. Consequently design can focus less on surge conditions and water-hammers and more on reducing the cost of penstocks associated with turbines which are governed by electronic load dumping techniques.

In short, what is being recommended is that for all run-of-the-river schemes, Workshop should seriously consider making general recommendations that load dumping techniques with the direct savings resulting from cheaper governors, and the less direct but even more meaningful savings resulting in such construction and component modifications as fixed vane turbines, less expensive penstocks and simplified switchgear be widely applied in order to slash initial costs and simplify operation and maintenance costs.

4. Voltage Control Devices

When one examines small hydro installations in various countries, there still seems to be a preponderance of analogue devices being used in the sensing and control of voltage. Voltage regulation need not be performed by analogue devices and indeed reliance on such methods even without consideration of the loss in precision, is unjustified given the low cost of digital devices. Digital devices are essentially worry free when used in such applications as voltage regulations; and furthermore, micro processors and the software necessary for them have become so inexpensive that it is difficult to understand why this type of technology has not proliferated greatly in some of the more modern micro, mini and small hydro projects being implemented.

5. Standardization of Parts and Reduction of Equipment Variety Being Used in Developing Countries

In a more universal treatment of the problems of cost reduction in plant and equipment expenditure, it seems that UNIDO or regional groupings such as this Meeting may well find it useful to recommend that institutions such as the World Bank, various regional financing institutions and various standards bureaus throughout the developing and developed world should seek to establish standards for small hydro units and also a unified system of nomenclature along with a high degree of interchangeability of parts. This would considerably reduce the problems of design and would indeed hasten the spread of this very necessary technology.

Perhaps a theme of the next study tour/workshop may well be on standardization of small hydro equipment.

III. OTHER COST REDUCTION CONSIDERATIONS

1. Feasibility Studies/Design Engineering

The very far reaching and extremely commendable efforts of UNIDO, the Norwegian Government, the Austrian Government, and other collaborating agencies both within and without the developing world will not be able to bear as much fruit as has been intended unless the non-capital costs associated with small hydro development are significantly reduced. And although this paper is not concerned primarily with non-capital costs, it does seem appropriate that a word be spoken about feasibility studies.

Too many of the feasibility studies cum design engineering now taking place in the developing world by consultants from the developed world, and even consultants in the developing world, are so costly that the costs of the studies per project are a significant percentage sometimes as much as 40 - 50% of the total capital expenditure on the project. This is clearly unacceptable. One way out of this problem has been pioneered by the National Electricity Authority of the Philippines; and, no doubt, Mr. Hoesni's group here in Malaysia is having some success in this direction. The way has to do with the standardization of methodology for MHG feasibility studies. Technical, economic and fiscal decisions on project viability and feasibility are essentially logical ones; so that if a framework and forms and formulas are carefully worked out and fitted together in such a way that relatively unsophisticated but thorough individuals assisted by computing machines work from basic physical measurements and economic data concerning projected plant, it should not be too difficult a task to develop computer software or clerical routines within SHG departments to simply go through and make computations based on the data to determine viability and feasibility conditions. These are purely logical decisions which, of course, will have to be considered against social and political realities. But the point that is being made is that there does not seem to be justification for so many customized feasibility/design studies at this time, given the relatively wide body of experience in existence for small hydro under various conditions of terrain, weather expectable, and of end uses.

2. Potentials for Further Cost Effectiveness Through "Load Dumping"

This paper devoted much space and laid great emphasis on "load dumping techniques". But, again, a load dumping technique need not represent an energy wasting situation if applications for the energy diverted away from the demand can be found. For example, power which would normally be placed on dummy resistive elements, could well be used in the production of fertilizers, pharmaceuticals, etc. The idea is not really new, as the work of Wang (1980) and others in China has amply demonstrated. What is new is that the load dumping technique which so many misinformed workers have decried as representing a waste of electrical energy, could, in fact, become even a greater boon than it already promises, if the so-called wasted energy could be harnessed for the production of useful commodities inexpensively.

3. Hydrological Studies for Small Hydro Projects

The tendency to use the very same major hydro methodology of data collection and analysis, prior to deciding on whether or not a small hydro project may be implemented, especially in rural areas is again a sore point. One approach that has been pioneered in a number of other countries is the interviewing of local inhabitants in a community to determine capacity and dependability of flow in rivers. This has its pitfalls; so the method of obtaining such data from the recent oral history of a community needs to be carried out by trained interviewers with a significant degree of sophistication.

4. Formal Professional Training in Small Hydro Power Development

Finally, we would like to make a specific recommendation concerning training re hydro-energy. It is recommended that the significant body of expertise in small hydro that exists in the ESCAP Region, particularly in China, the Philippines and Malaysia be made available, through some programme of assistance to civil engineering and hydrology engineering faculties of universities in other developing countries through the mechanism of specialized course assistance for final year under-graduate students. The significance of hydro-energy to developing countries is so great and the potential impact on the rural areas so clearly demonstrable that it would seem only right that universities should offer courses in this science as part of their regular curricula. This move will aid the establishment of specialized small hydro teams in various countries.

The present informal approach to small hydro-energy development work and studies was a necessary first stage; but it is a stage that cannot continue given the urgency of the energy problem and the potential of small hydro for making a significant contribution to abating this problem.

5. A Final Recommendation

There is need to focus less on surge conditions and water-hammers (since inexpensive pressure release valves are available to replace surge tanks, etc.) and more on reducing the cost of penstocks working with turbines which are governed by electronic load dumping techniques. In short, what is being recommended is that for most run-of-the-river schemes, this Workshop should seriously consider making general recommendations that load dumping techniques with direct savings resulting from cheaper governors and the less obvious but even more meaningful savings in construction and equipment modifications such as fixed vane turbines and less expensive penstocks, etc., be widely applied throughout the small hydro industry.

IV. CONCLUSION

There is a great scope for reducing the development and capital costs of small hydro projects. "LOAD DUMPING TECHNIQUES" result in several related cost reducing modifications in machinery and civil works.

V. REFERENCES

HAUNG BINGNAN and CAL XUXIAN, (1980) "The Application of Prestressed Concrete Pipes in Small Hydro-Electric Stations", Ministry of Water Conservancy, People's Republic of China.

ITINTEC, (1980) "Desarrolla" Technologico Para el Equipamiento de Pequenas Centrale Hidroelectricas, Itentec, Lima, Peru.

NATIONAL ELECTRICITY AUTHORITY of the Philippines (1980), "Feasibility Studies Manual", NEA, Manila.

MINOTT, DENNIS A. (1981) "Mini-Hydroelectric Generation - Local (Caribbean) Manufacture", Caribbean Development Bank, Barbados.