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RCII/UNIDO/RED/Covernment of Malaysia
7 - 15 March 1983, Kuala Lumpur, Malaysia

[SMALL HYDRO POWER DEVELOPMENT -]

I. Methodology for Feasibility and other Studies Appropriate for Small Hydro Power Development.

II. Local Manufacture of Small Hydro Power Equipment (Turbine).

III. Ways and Means of Cost Reduction Compatible with Viability and Utility Requirements. *

by

ESCAP Secretariat **

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** United Nations Economic and Social Commission for Asia and the Pacific (ESCAP), Bangkok, Thailand.
1. METHODOLOGY FOR FEASIBILITY AND OTHER STUDIES
APPROPRIATE FOR SMALL HYDROPOWER (SHP) DEVELOPMENT

Hydroelectric projects are by nature site specific. Each site presents different hydrological parameters and many physical alternatives, such as layout. Therefore it is difficult to find out a common methodology for various studies applicable to all sites. However, a general approach could be drawn, adaptation of which to specific sites will require the services of experienced personnel. Before going into further detail, the fundamental question of the concept of small hydropower is reviewed. Is SHP a scaled-down version of macro-hydro? If not, should one follow the methodology for various studies adopted for macro-hydro? The answer is not a simple "no". The small hydropower technology is not as widely known as macro-hydro technology. People in many cases are experimenting through adoption of methodologies used in macro-hydro. The search of methodologies for feasibility and other studies appropriate for SHP today is nothing but trying to simplify or to screen out some steps that are not required or that can be merged with others.

Along the above line, the Electric Power Research Institute, California, recently published a study report¹ which analysed the step by step approaches that could be followed in the preliminary appraisal of the power potential rapidly and at little expense. The steps which are followed in developing a project to its ultimate completion are outlined in Figure 1. A reconnaissance study is a first level investigation of a potential site. A pre-feasibility or appraisal study determines the cost of a project, evaluates its potential and outlines the scope of possible further studies. A feasibility study is a rather detailed study which is normally made at a level appropriate for committing funds. For small hydro projects reconnaissance and pre-feasibility studies are frequently merged and called preliminary analysis. Sometimes pre-feasibility and feasibility steps are also merged for further simplifying the steps.

No matter what terminology is used, investigation procedures involve making inventory of the possible sites followed by techno-economic evaluation of suitable sites. Two analytical procedures

may be adopted, depending on the preliminary investigation; "Simplified analysis" which is rapid and more approximate and "detailed analysis" which would require a greater effort and higher level of technical input. Figures 2 and 3 are the study flow charts of the simplified and detailed procedures respectively. These steps have been drawn for stations of capacities 200 - 15000 KW. For plants below 200 KW still greater simplification and specialized approach has to be found. This special approach will be site specific and country specific.

From figure 2 it may be seen that for simplified procedure, benefit-cost ratio is the determining factor of a potential project. If the ratio is greater than one, the project is turned feasible, if it is between 0.8 and one, the project may yet be feasible subject to further study. Now the question is should this be the only criterion to determine the fate of a project? The answer could possibly be found in another question - is rural electrification in all cases benefit-cost effective? Social benefits which are difficult to be accounted for should also be considered in the assessment of cost and benefits. One way of determining monetary values to the expected energy generation could be obtained from the costs of generation by alternative sources, for example, from diesel generation if it is an isolated area or from the load (associated with extension costs) drawn from the system. For determining annual cost, table 1 could be followed. It may be observed from the table that recurring annual cost has been estimated as 1.2 percent of the capital cost.

Coming back to the procedures followed in the simplified analysis the main step is the estimation of the physical characteristics of the potential power plant. These characteristics include power plant flows, available head based on which power plant generating capacity and energy generation can be calculated. Details and accuracy of these characteristics are the key factors for all sorts of analysis.

**POWER PLANT FLOW**

In a reconnaissance study, the maximum flow to be passed through the power plant should be calculated. This flow is a function of the pattern of available flow and the economics of site development. Two alternate techniques available for simplified estimate of the maximum power plant flow are 3/:

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1) Utilization of a flow-duration curve. A flow-duration curve is a curve plotted using the data available for the entire period of record, or a selected period if this can be considered as representative. Figure 4 is an example of such a curve. To estimate the power plant installed capacity a maximum flow corresponding to a 20 percent exceedance interval may be chosen as a first estimate.

2) Utilization of the average annual flow. In this method, the maximum power plant flow is estimated as a factor times the average annual flow. This factor will vary according to the flow-duration curve and has to be derived empirically from consideration of several flow-duration curves typical of the area. If the maximum flow and the corresponding minimum turbine flows are applied to the standardized flow duration curve, an average annual energy can be obtained and converted to a plant factor. This empirical plant factor can be used for sites being studied. This method is therefore used when many sites are involved.

POWER PLANT HEAD

The head as known to all, is static head (that is the difference of upstream and downstream elevations) less friction and other losses in the conduit. For approximation these losses are estimated as five percent. If the upstream water surface elevation is virtually constant the above is the power plant head but if upstream elevation varies static head is approximated to 80 percent (varies with sites) of the maximum static head.

POWER PLANT GENERATION CAPACITY

Based on the above basic data power plant capacity can be calculated by using the equation

\[ P_C = \frac{Qh}{14} \]  
(assuming plant efficiency of 85 percent)

where \( P_C \) = power plant capacity (kW) 

\( Q \) = maximum power plant flow (cfs) 

\( h \) = power plant head (ft)
AVERAGE ANNUAL GENERATION

If the maximum power plant flow was calculated using flow duration curve, project energy can be calculated from the same curve. The area bounded by the line AB (fig 4) drawn horizontally across the curve at a flow equal to the maximum power plant flow and the line CD drawn vertically to the point corresponding to 30 percent of the maximum power plant flow, the curve axes and the curve will be equal to the average annual flow (Q') available to generate energy through the power plant. The average annual energy (E) is therefore calculated as follows.

\[
E = (\text{kWh}) = \frac{(Q' h') \times 8760 \times 0.95}{44}
\]

(Allowing unavoidable water loss factor of 0.95)

where \(Q'\) = Average annual power plant flow (cfs)
\(h'\) = power plant head (ft)

DEPENDABLE CAPACITY

The dependable capacity can be approximated using the flow which occurs 90 percent of the time on the flow duration curve as the minimum dependable discharge. This flow would then be used in the power equation to obtain dependable capacity. However if the head is not constant and no minimum operating head data is available it can be assumed to be 60 percent of the maximum head.

This completes the analysis of power estimation. It must be pointed out that many approximations are involved, but that the estimates are conservative.
FIGURE 1
STAGES OF PROJECT DEVELOPMENT

START

RECONNAISSANCE STUDY

PRE-FEASIBILITY STUDY

POWER MARKETING (IF ANY)
FINANCIAL / ADMINISTRATIVE
APPROVAL OF STUDY FUNDS

FEASIBILITY STUDY
FIELD INVESTIGATION
FERC LICENSE

PROJECT APPROVAL
PROJECT PLANNING

DEFINITE PLAN
BID DOCUMENTS
DETAIL DESIGN

PROJECT CONSTRUCTION
AND ACCEPTANCE

PROJECT OPERATION
POWER PRODUCTION AND
FINANCIAL CONTROL

PRELIMINARY ANALYSIS

Source: 1/ ibid
DETERMINE
CAPITAL
COST

IDENTIFY
PROJECT

DETERMINE
PHYSICAL CHARACTERISTICS;
FLOW, HEAD AND CAPACITY

DETERMINE
POWER
OUTPUT

CALCULATE
ANNUAL
BENEFITS

CALCULATE
ANNUAL
COST

CALCULATE
BENEFIT-COST
RATIO

PROCEED/DO NOT PROCEED WITH FURTHER STUDY

Source: 1/ ibid
Figure 3  STUDY FLOW CHART - DETAILED ANALYSIS

Source: 1/ ibid
Figure 4  PROCEDURE FOR USE OF FLOW-DURATION CURVE

Source: 1/ ibid
TABLE 1

ECONOMIC ANALYSIS

<table>
<thead>
<tr>
<th>Project Data</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power Plant Capacity kW</td>
</tr>
<tr>
<td>Power Plant Head ft.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Costs</th>
</tr>
</thead>
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<tr>
<td>Capital Cost $</td>
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<tr>
<td>Annual Cost Factors -</td>
</tr>
<tr>
<td>Interest</td>
</tr>
<tr>
<td>Sinking Fund</td>
</tr>
<tr>
<td>Recurring Annual Cost $0.0120</td>
</tr>
<tr>
<td>Taxes</td>
</tr>
<tr>
<td>Rate of Return if Applicable</td>
</tr>
<tr>
<td>TOTAL</td>
</tr>
<tr>
<td>Annual Cost = (1) x (2) $</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Benefits</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average Annual Energy kWh</td>
</tr>
<tr>
<td>Value of Energy Mills/kWh</td>
</tr>
<tr>
<td>Annual Benefit = (4) x (5) $/1000</td>
</tr>
<tr>
<td>Dependable Capacity kW</td>
</tr>
<tr>
<td>Capacity Value $/kW</td>
</tr>
<tr>
<td>Annual Benefit (7) x (8) $</td>
</tr>
<tr>
<td>Total Annual Benefit (6) x (9) $</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Benefit-Cost Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>B/C = (10)/(3) =</td>
</tr>
</tbody>
</table>

Source: 1/ ibid
II. LOCAL MANUFACTURE OF SHP EQUIPMENT (TURBINE)

Indigenous fabrication of small hydropower (SHP) equipment has taken a variety of forms and degrees of development in the countries that have implemented it. At one end of the scale is China where over 88,000 units have been built entirely within the country. In India also there are indigenous firms who have been in production for quite sometime and their manufactured equipment is reported to be in satisfactory operation. In addition to meeting their own country requirements these two countries of the ESCAP region are also exporting their SHP equipment. Other countries, relatively new in the manufacturing field are trying to promote local manufacture of SHP equipment at least in part to bring down the costs of SHP development.

One of the main constraints in the SHP development is the high per unit power investment cost. Therefore the challenge of to-day to the SHP engineers is to reduce the cost of the projects. Although there are limitations, one way of reducing this cost is to use local manpower and materials as much as practicable and fabricate equipment locally. While subject to availability and suitability, use of local materials will definitely be effective, the manufacturing of equipment will be country or area specific and even site specific.

One way of looking at manufacturing is to improve the traditional turbines used in some countries from time immemorial. For example, in Nepal an estimate indicates that the number of water mills that exist may be between 25,000 to 50,000 or even more scattered all over the hills and valleys of Nepal. Most of these mills use wood alone. There is a scope of tremendous improvement in this traditional technology. The mills can be improved using wood alone, wood and metal or mainly metal. In Nepal a concept has been developed called the multi-purpose power unit (MPPU) which is being manufactured entirely in Nepal. The unit is made in three detachable sections, easy to transport in the remote areas. It has a penstock (instead of an open water channel), spoon-shaped blades (instead of flat paddles), bearings (instead of bushes); and the improved grinding stones enclosed under a dust cover. A very important addition to the mill is a pulley on the main axle which permits a power take-off for other machinery as well. The advantages of the MPPU include: it can be carried anywhere and installed within a few days (if replacing a traditional water mill), the investment is reasonable, and the technology can be understood quite easily by villagers. Presently such units are being used for the processing of agricultural products (grinding, hulling, threshing, oil expelling) and for mini electricity production, either 12V DC with a car generator or 220V AC with a 1.5 KW generator. Such an installation costs approximately US $2000.00 only and is reported to be found most attractive.

Another way of organizing local manufacture is the indigenous fabrication of turbines and accessories based on a standard design through utilization of simple facilities like small machine shops, metal casting shops moderately equipped. It might not be necessary to strictly follow the standard design in some cases. Someone may just reproduce some prototype types in use, or built elsewhere. In this locally made equipment, important issue is the availability of local skills and materials. Cross-flow turbines are now being manufactured locally in a number of countries.

The third category is the commercial manufacture of standard equipment. Where good market potential exists, there is no doubt that commercial manufacturing plants should be built (in fact in a few countries of the region, such plants are already in existence). If there is no adequate and sustained market local manufacture should be kept limited to adoption along with partial fabrication of certain components, particularly spare parts. Under "Technical Cooperation among Developing Countries", experiences already gained by some countries in the manufacture could be shared by others through technology transfer/adoption. In this respect the proposed Regional Network on SHP could play an important role. Countries where certain infrastructure exists such as macro-turbine manufacturing plants, pump manufacturing facilities it might be easy for them to extend their manufacturing line to SHP equipment with relatively low additional investment. It has been observed that recent trends in SHP turbine design are towards using pumps as turbines. Several studies have been carried out in the world to identify which pumps could be converted and what modifications be made to increase the efficiency. There are some manufacturers who are now offering standardized turbine-generator packages using their pumps in reverse. Therefore this is an area which countries having pump manufacturing facilities may like to look into.
III. WAYS AND MEANS OF COST REDUCTION COMPATIBLE WITH VIABILITY AND UTILITY REQUIREMENTS.

Before going for finding out ways and means for cost reduction one should know what are the factors and components of cost involved in a development project in general and a SHP project in particular. The cost of power generation by small-scale hydropower station depends on a number of factors, such as the nature of the site, type of installation, sources of equipment and material supply, availability of manpower for construction as well as operation and maintenance, utilization of plant, sources and terms of finance etc. Each of these factors can make or break a project. Each factor therefore needs careful consideration in determining the cost of a project and thus each of these is essentially a potential area for cost reduction study. Sometimes while talking about cost reduction, people talk about turbine-generator costs only. In fact turbine-generators cost only 20 to 40 percent of total project costs.

EQUIPMENT COSTS

These costs are perhaps best examined by first taking as a base line, the cost of modern equipment installed in a country. The components of capital costs can then be modified to suit a local situation, taking into account possible cost reduction factors or additional cost burdens as they may arise. It is true that overall investment costs of SHP unit is very site-specific. There are however, two elements that can be used as a starting point; first, the cost of an efficient set of electro-mechanical equipment available in the international market is fairly uniform and depends mainly on the flow of water and available head. A rapid decrease in costs has been generally observed as one goes from the lower end to the upper end of the scale in SHPs; while the equipment for a 50 kW unit may be around SUS1000.00 per kW, this figure is nearly halved at the 200 kW level. This is only an indicative trend and may not apply to different designs and situations.

OPERATING COSTS

Operating costs of SHP, as a consequence, are essentially capital (financing) related costs. However, maintenance and repair costs can be low, both because of simpler design and because the required labour is usually less skilled. A SHP set can be expected to have a life period of about 30 years, on the average. The annual cost for repayment is obtained by multiplying construction cost with capital recovery factor (crf) which is given by the equation:

$$crf = 1 (1 + i)^n - 1$$

Where "i" is annual interest rate

"n" is payment life in years.
AUXILIARY AND CIVIL ENGINEERING COSTS

Price of other powerplant components, such as station electrical equipment, miscellaneous equipment, civil construction costs, excavation for the powerhouse, site protection costs, foundation costs, also represent a significant portion in a project cost.

WATERWAY ITEMS

In addition to powerplant equipment components, the outlet works of the dam are integral parts of the unit. Basic items include an entrance channel; an intake structure; a penstock; a water-control system; by-pass valves; and any required access shafts, bridges and tunnels.

SITE DEVELOPMENT COSTS

Major cost factors under this component are access roads, land rights, water rights, drainage and erosion controls.

INDIRECT COSTS

These cover contingencies, engineering, administration, and construction management. Also included under this component are expenditures for feasibility study, license and permit applications, preliminary and final designs. Interest during construction (IDC) is also included here.

FINANCING

Financial feasibility sometimes depend largely on anticipated borrowing cost. These costs are the sum of the real interest, purchasing power risk premium compensating expected inflation, the business and financial risk and the marketability risk associated with low-liquidity of long-term debt.
Cost reductions can be achieved in a number of ways:-

(a) One may make use of existing hydraulic structures such as dams, irrigation channels, old hydraulic sites etc. A recent study by MITRE Corporation stipulates that the cost of fitting such structures with SHP units may be 38 to 69 per cent of the cost of new installation of a 15 MW station.1/ It may not be unreasonable to think that similar savings can be realized in the case of micro and mini-hydro stations.

(b) One may want to simplify and design the engineering of the proposed schemes. With trading efficiency of conversion and sometimes of working life of the equipment it is possible to use simpler and cheaper types of water turbines and speed governors. A classical example is that of the Banki-Mitchell turbine which has an efficiency limited to about 75 to 80 percent but does not require any castings or forgings.

(c) Local manufacture is usually a way of saving both in terms of foreign exchange and local currency. This is due to the fact that most conventional small turbines are individually made and have a high labour content.

(d) Standardization of the design saves money not only at the initial stage by cutting down on research, development, deployment and tooling costs but also later on spare parts are cheaper and more readily available. It is even possible to design Banki-Mitchell turbines of different sizes that have identical components.

By making use of most of the above mentioned cost reducing opportunities, the cost of a 19.2 kW unit in Peru has reportedly been brought down from $US72,000 to $US19,000.1/ In particular, the use of existing structure, local materials and local fabrication facilities was adopted.

Equipment sizing is another important economic issue. Short and medium-term demand forecast should be made as accurately as possible. As an indication of the power requirements for some typical rural development schemes the following very approximate examples have been quoted2/:

i) 50 KW would power a small village and school;

ii) 100 KW would power a medium-size village, school and medical centre;
iii) 200 KW would power a medium-size factory (like cotton) by day and a village by night.

iv) 300 KW would power a large sawmill by day and a village by night.

Thus it can be concluded that finding ways and means of cost reduction lies entirely with the engineers and economists who are directly involved in various phases of project implementation. Careful thought, studies and actions can save a lot money and make many SHP projects economically feasible.

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