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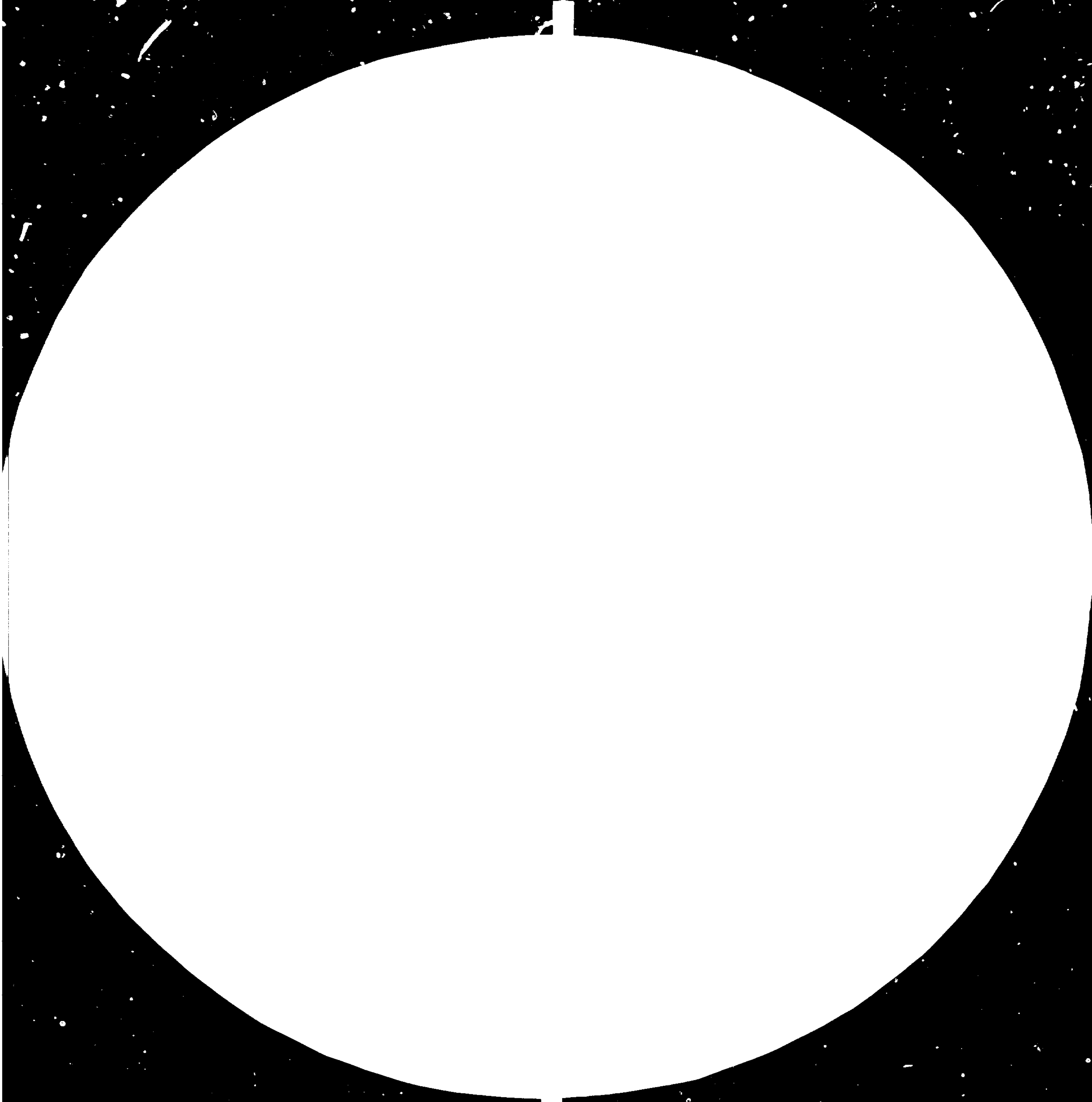

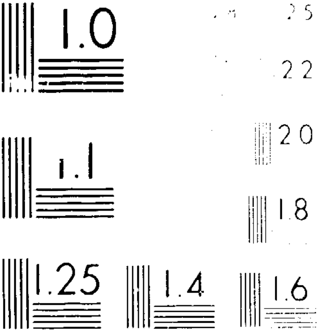
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THE PLANNING AND DEVELOPMENT OF MINOR-SIZED HYDROELECTRIC PROJECTS*

by

ESCAP**

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A. INTRODUCTION

1. Early history

1. The use of the potential of flowing water, or water falling, to provide motive power, is very old. More than one hundred years ago, in both Europe and Asia, wooden waterwheels were in use, in many cases with a direct drive to a grinding mill to crush grain.

2. Figure I shows a wheel with flat wooden paddles, partly immersed in a flowing stream, the banks and bed of which having been crudely shaped with logs and rocks.

3. Figure II shows a situation where there was a contrived waterfall of a metre or two in a navigation canal (usually combined with a lock) or at a check point in an irrigation canal. The water overshot the wheel, and instead of paddles rough wooden buckets were used.

4. Figure III depicts a variant in which the water fell on the near side of a wheel of the same construction.

5. In each case, the width of the wheel was approximately equal to the available width of the water passage. The flow of water varied with the season, and occasionally was insufficient to drive the wheel. The motive power obtained also varied, and moreover the efficiency was quite low, owing to residual friction and escaping water. However, intermittent operation was quite satisfactory for grinding grain, and the load could be varied to suit the water flow by controlling the infeed of grain.

6. With the advent of electrical generation, in some cases a large pulley was installed on the shaft, with a belt drive to a small pulley on a generator, and the fundamental problem was revealed that the times and amounts of electric power were fixed by the requirements of the electrical loads, and not by the availability of the water.

9. Considering the small amounts of power being produced, of the order of one or two horsepower, intermittent direct current generation with the energy stored in batteries was quite feasible. The efficiency of a small generator with controlled voltage output at variable speed (as for a motor vehicle) was only of the order of 50 per cent, and coupled with the residual friction and the escape of water, the over-all efficiency of the system might only be of the order of 20 per cent.

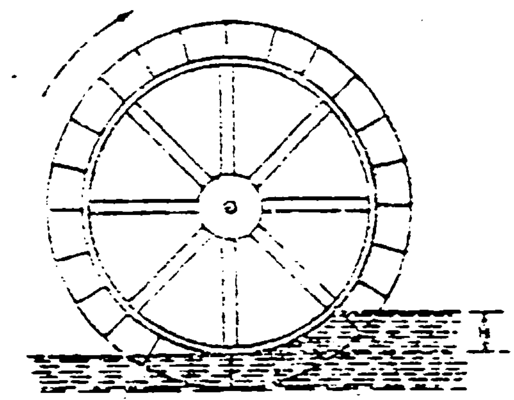


Figure I. Stream waterwheel

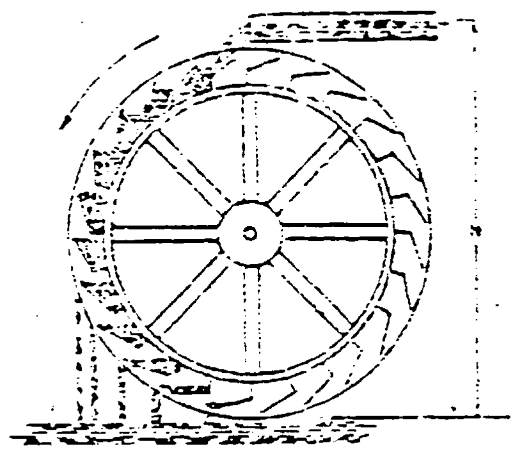


Figure II. Overshot waterwheel

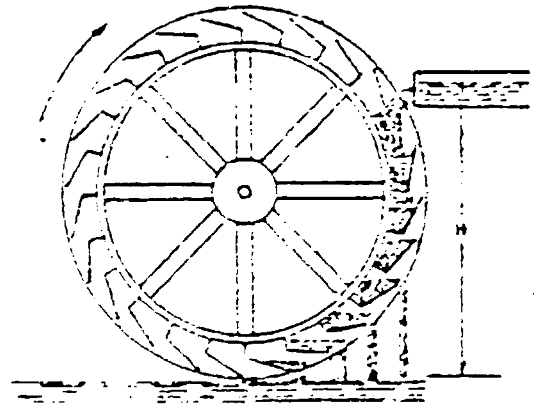


Figure III. Pitch-back waterwheel

2. Engineering approach

8. In the early 1900s, there already existed substantial technical knowledge in civil engineering and metal fabrication, and a growing body of knowledge of electrical engineering, and it was natural that the subject of generation of electricity from water potential should receive detailed attention.

9. Emphasis was placed on assessment of potential under uncontrolled stream flow conditions and under controlled conditions with upstream storage, the reliability of the water supply, the confinement of the water to prevent escape, the improvement of the efficiency of the waterwheel (turbine), the governing of water flow and machine speed, the improvement of the efficiency of the generator, the reliability of the electricity supply, and the transmission of the electrical energy to nearby potential loads.

10. An immediate result of the investigations was the realization that all the physical aspects, from the provision of upstream storage through to the transmission of the energy, required the expenditure of cash in addition to labour, and it would be necessary to recover the expenditure by selling the output. Moreover, the over-all efficiency and the unit cost of the electricity could be dramatically reduced by increasing the scale of the operation, and the chances of selling the output would be correspondingly increased.

11. Schemes of the order of tens of kW, then hundreds of kW were designed, constructed and operated, mostly in developed countries, and the state of the art had progressed in a few years from home-made devices to commercial enterprises, while the earlier installations were relegated to the field of antiquities.

12. As an example from the region, in Japan up to 1919, 155 minor-sized hydroelectric units were commissioned, with an average capacity of 750 kW, and from 1920 to 1929 a further 240 units were commissioned, with an average capacity of 880 kW. As in other countries, the developing availability of long-distance transmission reduced the need for local generation, and with emphasis on very large central power stations, including hydroelectric power stations with capacities of hundreds of MW, the construction of minor-sized hydroelectric units stagnated, and from 1930 to 1978 only 95 units were commissioned, with an average capacity of 1,000 kW. Of the total 490 minor-sized units commissioned in Japan, 175 were less than 500 kW, 129 between 500 and 1,000 kW, and 186 between 1,000 kW and 2,000 kW.

13. In the mean time, in countries in the region where industrial development was less advanced, and transmitted supply was not readily available in some areas, the power supply authorities, or local or commercial companies, constructed (and are constructing) a few small hydroelectric stations, ranging from 10 kW to about 300 kW. for local supply. Examples are available in Bhutan, India, Indonesia, Nepal, Papua New Guinea and Thailand.

3. Effect of energy crisis

14. Since the energy crisis of late 1973 there has been a resurgence of interest in renewable energy resources, and a considerable amount of (mostly uninformed) literature has been produced. In the field of minor-sized hydro-electric generation, emphasis has been placed on such aspects as the waste of potential in small streams and canals, the possibility of various home-made devices for single-user application, and the desirability of rural communities providing their own energy supplies by constructing small hydroelectric stations.

15. The units have been categorized, micro hydro usually referring to the range 0-20 kW, and mini hydro usually referring to the range 20-200 kW.

16. However, the essential engineering and economic facts have not been altered by the production of the literature, and the need still remains for an adequate investigation, design, construction and operation procedure for any small hydroelectric station.

17. Nevertheless, although the construction of small hydroelectric stations over recent years has been limited, those that have been built have had the benefit of advances made in hydroelectric engineering generally, with a cost-conscious approach, and relatively obscure companies have continued to develop and refine suitable power station components.

B. INVESTIGATION

1. General aspects

18. Development of small hydroelectric plants is always attractive in principle, wherever the basic potentials of head and flow exist. This is especially so in rural areas, but most rural population and development is typically concentrated in the flatter areas, and the required head available for an economic installation is frequently only available at a location some distance from the prospective consumers.

19. Another factor adverse to a hydro installation is that the cost of engineering, including investigation, per kW is likely to be high. It is essential that engineering costs be held to an absolute minimum. Whereas a large team of experts in many different fields might be employed on the investigation and design of a large hydroelectric project, this would not be possible for a small project. The employment of, say, four persons with long and broad backgrounds of experience in hydroelectric engineering, not only with knowledge of investigation and design procedures, but also capable of devising short-cut methods and understanding the realistic consequences of reduction of margins, might be a more acceptable approach than hiring specialist consultants, using enthusiastic but relatively untrained local officers, or leaving major decisions to an equipment manufacturing company. A typical group, who would operate in sequence, would be an investigator, two detail designers and one construction engineer.

2. Market survey

20. A highly rational approach must be adopted by the investigator in assessing prospective consumers. The most important point is the ability of each consumer to pay, not only for the electrical energy which he states he would need, often a progressive amount, but also for the equipment which would consume the electricity, and wiring and switchgear within his premises. In many rural areas, discussion of this aspect might result in scaling down requirements to modest lighting only. It would then be important to establish the geographical location of such consumers, to fix the location of transformers and the extent of low voltage transmission, the cost of which might be relatively high.

21. In the case of a workshop or commercial building, it would be necessary also to examine the existing source of energy, as if the cost of transmitted electricity were high the owner might not change over, whereas if there were an economic advantage to change over, the owner might expect to be compensated for his existing equipment. It must also be established whether such a consumer would be prepared to make an advance payment to cover the cost of an individual transformer or the extension of the transmission line to his premises.

22. Adding the individual demands obtained from a sampling procedure, rationalizing, and allowing for diversity of demand in time, figures would be obtained for the total demand (kW and energy) on initial availability,

5 years later and 10 years later. These figures would be used as the basis for searching for a suitable site for the project. It would also be highly desirable that the sources of funds be established in principle at this stage.

3. Field investigations

(a) Project size

23. The potential gross power (P in kW) of a project is obtained from the quantity of water (Q in m^3/sec) and the gross head (H in m) by the relation

$$P = 9.81\ QH$$

Thus a stream or canal of cross-section 1 m^3 and flowing at a rate of 1 m/sec, over a fall (head) of 1 m, would have a potential of about 10 kW, but after allowing for efficiency and average effective head the net output might be about 5 kW or less.

24. Normally the equivalent additional head given by the velocity of the water would be neglected, but in the case of a very low head project it could be calculated from

$$H = \frac{v^2}{g^2}$$

where v is the velocity in m/sec
g is the gravitational acceleration (9.81 m/sec/sec)

For the above case, the gross additional head would be 0.05 m increasing the gross potential power by 5 per cent. If the velocity had been 2 m/sec the gross additional head would have been about 0.2 m, but such a velocity would be quite unusual. It may be noted that such a calculation disposes of the argument put forward by some writers in the popular literature that the velocity alone could be a large source of electrical power. Figure I shows how the velocity may become effective head for such a simple case.

25. For the case outlined above, with typical ratios of width to depth, in order to get 5 kW. the investigator would be looking for a stream or canal with minimum flow about 3 m wide, which is quite a significant size, and the civil costs could be high, considering the likely maximum flow. Nevertheless, such projects, and even smaller ones, have been constructed, using modified bulk-type turbine-generator sets, or vertical or horizontal propellers connected by shaft or belt to a small generator.

26. Usually the need is for greater power output, and the investigator would concentrate on looking for higher head, with the possibility of upstream storage to regulate the flow to a value above the normal minimum. For instance, 1 m^3/sec with a head of 20 m would have a gross potential of 200 kW. In looking for such a head, attention would be paid, not only to the possibility of bypassing waterfalls or rapids, which are obvious cases, but also to the possibility of running a canal or raceline around a spur so that the water could be dropped into another valley with a lower floor level.

(b) Topographic surveys

27. Survey maps of the area of interest might not exist. At best, there might be small-scale maps which were originally prepared for military purposes. If a map were available, it could be used for preliminary selection of possible sites. If not, the investigator might have to rely on his impressions from a reconnaissance by air or on foot.

28. Detailed mapping is unlikely to be justifiable, and the usual solution would be for the investigator to mark out the scheme on the ground, using an Abney clinometer and tape, and then, if the scheme seemed promising, to call up a survey party to run a theodolite survey with a few cross-sections at key points to give a basis for design.

29. The investigator should also check ownership of land involved, and any laws relating to the rights to divert water from a stream.

(c) Geology

30. For economic reasons, geological investigations could involve little more than the close observation of the type of rock and frequency of rock outcrops. This might involve the clearing of undergrowth and the digging of a few exploratory pits.

(d) Materials

31. Local materials must be used to the greatest extent possible. Inspection of local houses would usually indicate whether timber, sand, gravel and stone would be locally available, and whether cement, wire and light reinforcing bars could be readily obtained.

(e) Hydrology

32. The stream flow characteristics are probably the most difficult item to assess. If time permitted, it would be prudent to install a stream gauging station and take readings for as long as possible before a decision was made to construct the scheme. It would be more important to measure low flows than high flows, and a V-notch weir could be satisfactory, with daily readings.

33. The area of interest might be part of a larger catchment, and rainfall data and local knowledge would be consulted to establish possible flood flows, and possible low flow periods.

4. Preliminary report

34. The investigator would report his findings to the party concerned, which might be a semi-political body such as a local council. If it appeared that a project of appropriate size was feasible, the semi-political body might then instruct the investigator to proceed with a layout of the project.

C. PROJECT LAYOUT

1. General approach

35. In a typical case, the over-all design basis might be to provide waterways and equipment for an output equal to the projected demand 10 years after initial operation, or twice the expected demand on initial operation, whichever were the lower.

36. Maximum use must be made of standardized designs because the cost of providing unique designs for each of the structures involved, and the various items of equipment, would be prohibitive. Standardized simple designs of water control structures, amenable to adaptation to site conditions during construction, have been used for many years by irrigation authorities. Standardized designs for valves, turbines and generators are available from some manufacturers, and it would be appropriate to vary the project layout to give the required water flow and head to suit a standard design. Electrical equipment is generally independent of site conditions, and a range of suitable equipment is readily available.

2. Civil engineering works

37. A typical project would have, as civil engineering works, a diversion structure, a desilting basin, a raceline, a head pond, intake structure, a pressure pipeline, a power station structure, and a tail race (see figure IV). Of these, a low-head canal scheme would use only the intake structure and screens, the power station structure and the tail race (see figure V).

(a) Diversion structure

38. Generally, a small dam would be required to divert the water, but might be made somewhat larger to store some water if there were a pronounced dry season. The cost of a permanent structure often could not be justified, and a gabion-type structure with an impervious upstream face might be satisfactory, particularly where there were good sized boulders of sound rock available. The dam should be located on a non-erodible foundation, with sound abutments, and with a sufficient crest length to be able to pass floods over the top without too great a build-up in water level upstream.

39. The offtake should be a short closed conduit, fitted with an intake screen. It would be desirable to have a by-pass sluice adjacent to the offtake to clear gravel and sand, closed by stop logs.

(b) Desilting basin

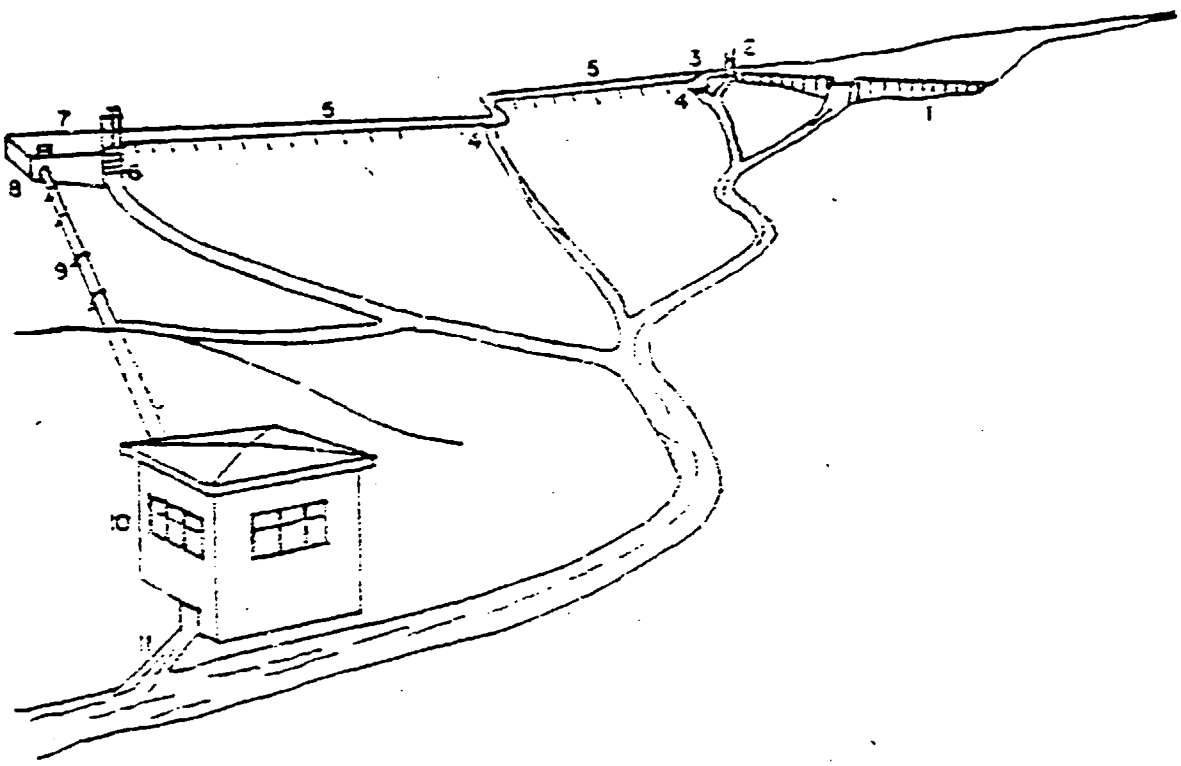
40. It would be desirable to have a desilting basin at the end of the offtake conduit, to reduce the water velocity and deposit sand before the water entered the raceline. A long-crested weir would limit flow into the raceline.

(c) Raceline

41. Cost would generally rule out a closed conduit to carry the water to the head pond, and an open raceline or channel with a gradient of 0.1 per cent or less is commonly used. This could be unlined if the earth were relatively impervious, or a concrete lining or box flume might be used. Because of the possibility of blockage through batter slip or debris, spill points should be included, so that the water could be directed down defined paths. Also, if convenient, a further desilting basin might be an advantage. Normal construction practices for channels in sidehill country would apply, with elevated flumes or inverted siphons used for crossing intermediate valleys.

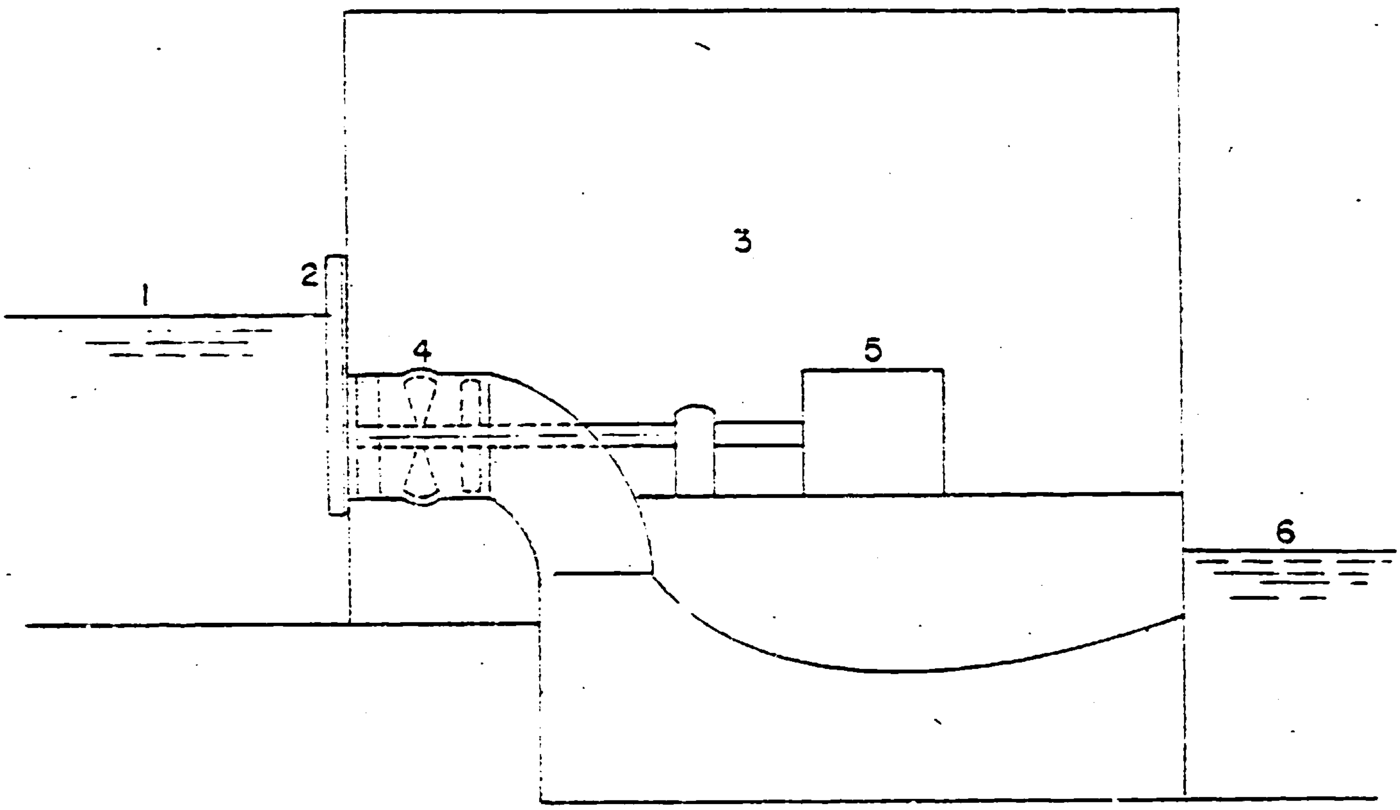
(d) Head pond and intake structure

42. A head pond would usually be constructed immediately before the intake to the pressure pipeline. This should be large enough to act as a



1. Diversion structure
2. Intake with screen and bypass sluice, and conduit offtake
3. Desilting basin
4. Spill points
5. Raceline
6. Spill point and sluice
7. Head pond
8. Intake structure with screen and stoplogs
9. Pressure pipeline
10. Power station
11. Tail race

Figure 14. Typical layout for medium head



1. Intake structure
2. Screen
3. Power station
4. Turbine
5. Generator
6. Tail race

Figure V. Typical layout for low head

final settling pond to remove any silt or sand and to cope with any water demands created by sudden increase in loading on the turbine. It might also act as supplementary storage to reduce the size of the diversion structure if the latter has poor access for construction. A final spill point should be arranged from the head pond, preferably including sluicing, and with the water conveyed a short distance in a chute.

43. The intake structure would include the final (removable) screens, protected by vertical bars. The screen box should be totally enclosed, with the sill level set as high as possible above the floor level of the pond. Entry to the pressure pipeline from the screen box should be through a tapered piece to keep entry velocity down to say 0.5 m/sec to minimize the risk of air entry by vortex formation, and should be well below the water level in the screen box. If there were a sudden downward change of angle in the pressure pipeline a short distance downstream of the entry, an air bleed pipe should be introduced. For a low head canal scheme the physical size and cost of the intake structure would be significant.

(e) Pressure pipeline

44. Generally, the pressure pipeline would be a relatively thin-walled steel pipe, which would be supplied from an external source. The pipe could be galvanized or of black steel if water quality permitted. The pipes could be flanged, with rubber ring joints, or prepared for welding in the field. Other materials, such as asbestos cement or fibre-reinforced plastic, could be used, the choice being one of maximum economy, taking into account maintenance or possible future replacement. Pipe diameter would generally be kept as small as possible, with a preference for pipe sizes readily available.

45. The pressure pipeline would normally be buried to minimize expansion and contraction problems and simplify anchorage. Usual design practices would be followed, possibly with some reduction in factors of safety where damage from failure would be minimal. A valve would normally be provided outdoors, at the bottom of the pipeline.

(f) Power station structure

46. The station building should use local materials and building methods to the maximum extent possible. The main floor should be of reinforced concrete and in general should be above maximum tailwater flood level so as to diminish drainage and water-tightness problems and to minimize excavation.

This would normally present no difficulties with impulse turbines, other than some loss of head. Some problems might arise with reaction turbines, which must be set relative to minimum tailwater level on cavitation considerations, but it might be most economic to sacrifice a little head and install a control weir to provide the necessary back pressure. For low head canal schemes the latter possibility would not apply and substantial excavation and concreting would be necessary.

47. The size of the main structure should be minimal, conditioned by the floor space required for the machines and a spare bay, and the height necessary to move major parts with a wall-mounted or free-standing travelling hoist. The control room, switchgear room, store room and battery room should be in annexes of normal height. Living quarters, if necessary, should be separate and of typical construction for the area. Although some attempt may be made to blend the structure in with the surroundings, any impulse to make the station a show place should be rigorously subjugated, as the cost increase could be significant.

(g) Tail race

48. A formed tail race could be provided for a short distance from the power station, and a control weir might be needed as noted above, but since the flow of water would be comparatively small the only real need would be to enable the water to flow away without obstruction.

3. Mechanical and electrical equipment

49. Desirable features for all equipment would be low first cost, standardization, simplicity of operation and maintenance and suitability for relatively unskilled personnel, durability, reasonable protection against malfunction without exotic protection equipment, and ready availability of spare parts.

50. It could be argued that, in an area where there was formerly no electric power, one generating unit could be satisfactory, since there would be only one raceline to the station, and daytime outages for maintenance on Sundays would not cause serious inconvenience to consumers, and this would mean minimum cost for equipment and station structure. However, since the suggested basis for over-all design of the scheme was to provide for about twice the output requried at initial operation, it would be reasonable to consider installing two units, each rated at 120 per cent of the initial output required. This would allow for any initial difficulties with the equipment, and the restriction of load on loss of one machine would not be serious for some years, by which time other developments might have occurred.

(a) Turbines

51. Turbine manufacturers have developed a range of standard designs in which one design can be used over a range of heads with appropriate variation in speed, output and discharge. There is a strong tendency for plant costs to diminish with increasing head. Impulse turbines would be likely to be cheaper than reaction turbines because of the simpler construction and governing gear. Manufacturers of small turbines have recognized this by adopting special designs of impulse turbines suitable for lower heads than the traditional Pelton type. Two such designs are the Turgo (proprietary name), which is suitable for heads down to 30 m or less in very small units, and Banki, suitable for even lower heads. Both types offer quite high efficiencies over a wide range of output.

52. Governor costs follow the trend of reduced cost with increased head, because the regulating mechanism, like the turbine, would be required to handle a smaller quantity of fluid. In applications where there would always be some surplus of water available, a particularly economic form of "water wasting" governor may be used for Pelton or Turgo turbines, in which the flow into the turbine would remain constant and a purely centrifugal governor (that is, no oil pressure system) would deflect surplus water away from the runner. There would also be a small increase in output because no governor oil pump would be needed.

53. In addition to their plant cost penalty, medium to low head reaction turbines require a draft tube to convert the large percentage of velocity energy in the water leaving the runner to pressure energy.

54. One of the various forms of tubular turbines and generators might offer the best solution for heads of a few metres, but there are as yet no standardized designs for this type.

(b) Generators and associated equipment

55. Three-phase generators are generally preferred to single-phase generators because of their greater output-to-weight ratio. Standard salient pole AC synchronous generators could usually be used except that modifications to allow for high runaway speeds are usually necessary. Low head installations would generally require the speed to be stepped up, by means of a V-belt drive or gearbox to give a speed at which the generator would be less costly and lighter in weight.

56. The field circuit could be supplied by a conventional DC shaft excitation system, but "brushless" excitation would be preferred, thus eliminating the slip rings, the commutator and the shaft extension and space required for the exciter.

57. An automatic voltage regulator (AVR) in its simplest form could be with the older method of a carbon pile regulator in the field circuit, but would preferably be electronic, to give greater accuracy and speed of response. "Self-regulating" schemes have also been used which do not employ an AVR, separate compounding transformers being used to provide the necessary variations in excitation.

58. For parallel operation of generators in the same station, a signal proportional to output current from one generator must be conveyed to and incorporated in the voltage regulator of the other generator.

59. If the generator is intended as a supplement to other generation, then the simple design and robust construction of an induction generator could be attractive.

60. The minimum requirements for indication of the generator condition would be three ammeters, one for each phase, kW demand meter, power factor indicator, voltmeter and frequency meter.

(c) Switchgear

61. Each generator should be connected to its switchboard by cable, which might be laid in a trough in the main floor.

62. If the loads were all local, the generating voltage might be fixed at 415 volts, and the switchboard could consist of metal-enclosed, single bus 415-volt switchgear, with one circuit-breaker for each generator, one for each outgoing line, and one for station services. Such an arrangement would require very little maintenance, provided it was suitable for ambient conditions (tropic-proofed if necessary).

63. If a higher voltage were required for transmission, depending on the total load and the distance from the power station to the loads, a decision would be required between:

(i) Generation at 415 volts, with 415-volt switchgear on the generator circuits with offtakes for station supply, individual generator transformers to the higher voltage, say 11 kV, and a single-bus, 11-kV metal-enclosed switchboard, with one circuit-breaker for each line; and

(ii) Generation at the higher voltage, with a single-bus, 11-kV switchboard with one circuit-breaker for each generator and each line, and one for a step-down transformer for station supplies.

The choice would be made on the basis of cost, convenience of layout, and transport arrangements for transformers, which might be bulkier than the largest indivisible piece of other equipment.

64. With two (or more) generators, synchronizing facilities would be necessary. Normally, manual synchronizing using a wheeled synchronizing trolley would be satisfactory, provided the machines had reasonable inertia to minimize hunting, and the time delay in closing a generator circuit-breaker was reasonably constant in order that the synchronizing angle could be predicted to avoid system shock on closing.

65. Each circuit-breaker should be automatically responsible to signals of overload, short circuit, overvoltage and undervoltage.

66. It is inherent in the design of most hydroelectric machines that the auxiliaries would be self-contained, running up with the machine, so that a machine could be started, without external power supplies, by operating the valve to allow water to enter the turbine. However, with no machines in the station operating, lighting, communication and drainage pumps would have to be supplied from the station battery, and there might be a case for installing a small diesel standby generator, particularly if the station were to be operated intermittently. Alternatively, there might be a standby set at a major load point, which could feed a small amount of power back to the power station if required.

(d) Transmission

67. If generation were at 415 volts, with no step-up transformers, three-phase, 4-wire 415/220-volt transmission might be used. The number of circuits would depend on the number and dispersion of the load centres and the supply reliability required. The consumers could be protected by an earthing system earthed directly, via a continuous earthwire, or by a multiple earthed neutral system, the choice being made on the basis of earth resistivity and/or economics. On the premise that many of the consumers would not be accustomed to the dangers

of electricity, an earth leakage circuit-breaker scheme could be considered. Standard designs of transmission and distribution equipment, including wooden, steel and concrete poles, insulators and conductor fittings, fuses and isolators, and house entry arrangements, are readily available.

68. If step-up transformers were employed at the power station, they might be star-connexion on the low voltage side and delta-connexion on the high voltage side, and the transmission would be three-phase 3-wire, with or without an earth wire. The number of circuits would again depend on the number and dispersion of the load centres and the supply reliability required. Standard designs of poles etc. are readily available. At the load areas, care would be needed in selecting the optimum points for location of step-down transformers, which might be three-phase or single-phase, delta/star connected, preferably pole-mounted with fuses and possibly surge-diverters. Distribution at 415/240 volts would then follow the arrangements outlined above, with the addition that it would be quite normal to run the low voltage circuits on the same poles as the higher voltage where practicable.

69. In general, apart from taking into account the expected increase in load over the 10 years or so after initial operation, it is desirable to overrate the conductors of the transmission lines by about 50 per cent, to keep voltage drops and line losses down during normal operation, and to have a margin during emergency operation. This approach is not usually necessary for transformers, which have low losses and an inherent cyclical overload capacity. In the distribution network, the same principle of overrating the conductors by about 50 per cent should be applied, as in many cases some individual loads may increase faster than others, causing temporary changes in the load diversity pattern. If in a particular area the load increase appeared to be permanent, it might only be necessary to change a step-down transformer, or add another at a new location, with minimum interruption to supplies.

4. Report

70. At the conclusion of his work, the investigator would submit his detailed layout report, with reasoning, including a cost estimate, and comments on any areas likely to be inundated, or effects of varying stream flow, including any other environmental considerations, to the semi-political body.

D. CONSTRUCTION

1. Economics

71. In considering the investigator's report, the semi-political body would pay particular attention to the cost estimate and the conclusions on probable load development over the first 10 years from initial operation, from which the necessary sale price per kWh of energy had been calculated.

72. The table below has been compiled to give an indication of the order of costs involved, and the corresponding sale price of energy. The basic figures for civil works and power station equipment were taken from information supplied by a manufacturer in the region, with some allowance for escalation, and the costs of transmission and distribution were taken as $400 per kW. Fixed charges were taken as 10 per cent of capital cost per annum, and operating charges were taken as 5 per cent of capital cost per annum. Two machine units were assumed in the power station. A profit margin of 10 per cent was allowed as a contingency.

73. Several conclusions could be drawn from the table:

(i) The very marked decrease in stream flow required to be investigated for the higher heads;

(ii) The high capital cost for which funds would be required;

(iii) The high annual charges;

(iv) The comparatively high sale price of energy.

74. The high fixed charges could be reduced if funds were available at low rates of interest, leading to some reduction in the sale price of energy, but this would not be *pro rata* as operating charges would still apply. The figures for energy produced are related to approximately full output, which would not apply for some years after initial operation. This implies that a grace period would be required in the loan repayment schedule in order to avoid applying a higher sale price in the early years of operation

2. Approval of project

75. If, after consideration, the semi-political body decided to proceed, it would normally have to submit the investigator's report, with its own recommendation, to the authority concerned, with a view to seeking funds.

CAPITAL COST AND SALE PRICE OF ENERGY

Station output (kW)	Head (m)	Flow (m^3/sec)	Type of turbine	Capital costs: Civil ($1,000)	Capital costs: Station ($1,000)	Capital costs: Transmission and distribution ($1,000)	Capital costs: Total capital cost ($1,000)	Annual charges ($1,000)	Energy at 60 per cent load factor (1,000 kWh)	Sale price (c/kWh)
100	3	4.7	Propeller	100	197	40	337	50.6	525	10.6
200	3	9.4	Propeller	166	263	80	509	76.4	1,050	8.0
100	20	0.71	Francis	51	80	40	171	25.7	525	5.4
200	20	1.42	Francis	62	107	80	249	37.4	1,050	3.9
100	40	0.35	Francis	83	80	40	203	30.5	525	6.4
200	40	0.70	Francis	161	107	80	348	52.2	1,050	5.5
100	200	0.07	Pelton	117	73	40	230	34.5	525	7.2
200	200	0.14	Pelton	239	97	80	416	62.4	1,050	6.5

It should be emphasized that this procedure would not necessarily be straightforward, as the authority concerned might conduct a detailed review, seek more information, propose modifications, conduct its own investigation of alternative supplies, delay consideration because of shortage of funds or delay approval because of the needs of unrelated projects of equal or higher priority. In the mean time, the investigator would have departed.

76. Assuming that in due course approval in principle were given, and funds promised, it would normally be a condition that a committee should be set up to further the project. It does not follow that the semi-political body which submitted the project should continue as the committee, as the requirements would be quite different. Although the committee should report to the semi-political body, and probably have a member of the semi-political body as chairman, it would logically consist of a small number of selected local people acting in a part-time and voluntary capacity, preferably including an engineer, a banker, a lawyer, a businessman involved in materials supply, a representative of local small workshops and a representative who could advise on labour availability.

3. Detailed design

77. A further two of the four experienced personnel referred to earlier, one civil engineer and one electrical and mechanical engineer, could then be instructed to proceed with the detailed design, specification and drawings of the various parts of the project.

78. In their work, the engineers would pay particular attention to the detailed comments made above on the various components, which would have been used as a guide by the investigator, but would now have to be translated into drawings and specifications. It would be inherent in the approach that existing designs and specifications for civil works should be used as far as possible, with adjustments made in details to suit the specific site conditions and materials and labour available locally.

79. In regard to the station equipment, it would be comparatively easy to arrive at a general plant specification in terms of power output, head, flow, operating speed etc., but a great deal of work would be required to define clearly the function and detailed characteristics of each item of equipment, including all auxiliaries. Specifications for equipment in similar stations are available, and modifications could readily be made to allow for any special needs of the project.

80. Similarly for the transmission and distribution components, standard designs and equipment specifications are available, and could be modified to

81. In order to be able to select the most suitable designs and specifications from those available, and to consider the modifications to them needed, it would be necessary for the engineers to go over the whole project area in detail, and in doing so they might find it desirable to introduce some changes to the original proposal. They should keep the committee informed, and use the committee as a whole, and the individuals thereof, in overcoming any prospective difficulties. The committee, on its part, should respect the experience of the designers, and accept reasoning based on technical grounds.

82. Another necessary part of the work would be examination of the best methods of proceeding with the construction and/or installation of each component, in terms of materials, transport, labour and time. Putting these together as a limited critical path network would indicate clearly the required timing of ordering materials, arranging transport and employing labour for each component. By judicious adjustment, it would be possible to arrive at a smooth flow of work, with continuous employment of transport and labour, and reduced possibility of confusion and overlap.

83. Further, the individual specifications could be grouped together to provide packages of work. For instance, it would be desirable that associated equipment, for instance, turbine, governor, generator and switchgear, should be in a single package, so that problems of site co-ordination during installation and commissioning would be minimized.

84. Towards the conclusion of this work, the committee would advise the semi-political body that the design was complete, and request specific moderate funds to issue the design details and specifications to organizations which could do the civil works, and manufacturers which could supply and install the equipment. Most of the organizations and manufacturers would already have been approached by the designers, and the purpose of this exercise would be to enable the committee to request those organizations and manufacturers to submit specific prices and programmes. The semi-political body would relay this request to the authority concerned, noting that up to this point no major funds would have been committed.

85. On receipt of the bids, preference would be given to an arrangement which would have the minimum number of principal parties, for example, one contractor for the civil works, using local labour and materials as far as possible, and with provision of gates, screens, and pipeline from a subsidiary,

one contractor for electrical and mechanical equipment in the power station, and one contractor for transmission and distribution, using local labour and materials as far as possible.

86. At this point, the committee would place its recommendations before the semi-political body, which in turn would have to request the authority concerned to allocate the necessary funds in accordance with the proposed schedule of payments. There could be further delays, and the engineers would have departed. One or two members of the committee would then have to keep track of the situation, maintaining the validity of the bids, until funds were allocated and the committee could issue orders to proceed.

4. Physical construction

87. The fourth of the experienced personnel would then be called in, and designated as construction manager. His role would essentially be that of co-ordinator of all aspects, with detailed attention to programming, materials used, inspection of completed sections and recommendations for payment. In view of the physical area involved, and the various types of work in progress, it might be reasonable to provide him with say three local people to be trained as inspectors, one on civil works, one on the power station equipment and one on the transmission and distribution system. These people might be employed on the project when completed, or in any case would be useful later on, when the construction manager had departed, as supervisors for special maintenance or repairs.

88. The committee would function in approving payments and arbitrating in disputes, and the individuals would be available to advise the construction manager on matters within their competence.

89. At the conclusion of construction and commissioning, the construction manager would be released and the committee would retire from active participation, but would continue to process payments until they had been cleared with all contractors, and the final capital cost determined.

90. In the mean time, a full-time chairman of the new electrical utility would be appointed, to be responsible to the semi-political body. He would be an ex officio member of the committee during the concluding stages of construction and commissioning, and would receive all details of contracts, specifications, drawings and payments. He would also select and appoint

operation and maintenance staff. If considered desirable, two members of the committee could be retained as honorary vice-chairmen to assist him.

E. OPERATION AND MAINTENANCE

1. Civil works

91. The main requirement would be to keep the system operating, and this would best be achieved by frequent inspection of the waterways, clearing debris, cleaning screens and trash racks, flushing silt, carrying out minor repairs to racelines and embankments, and checking the anchorage of the pressure pipeline. Usually this work could be performed by one man, carrying a shovel and bush knife, with a wheelbarrow left near the diversion structure. The screens and trash racks should be raked twice each day at regular times.

92. The water in the raceline would normally be flowing comparatively slowly, so that small slips of earth into the raceline could be cleared without interfering with operation. If the downhill embankment were endangered, temporary repairs might be made with wooden planks, or heavy plastic sheeting, which might be stored in the power station. In the case of a bad slip which carried away the downhill embankment, it would be necessary, after shutting off the water flow, to rapidly gather sufficient men to dig the raceline route further into the hillside, or construct a wooden flume section. Speed of reparation would be the prime requirement.

93. From time to time it might be necessary to grease the screen guides and the mechanism of any gates, and repair paintwork on the metal portions of the structures and pressure pipeline. Particular note should be taken of any corrosion of metal parts, including buried sections of steel, as it might become desirable to install some minor cathodic protection.

2. Power station

94. With a normal operating régime, one machine and associated equipment could be taken out of service for a few hours each day during the off-peak period, and this would provide plenty of time for minor maintenance with a 10-minute restoration time. It would be essential that a prescribed list of routine maintenance tasks be established and followed rigorously, to minimize the possibility of forced outage. A special list would be kept of all items noted during daily inspection, to be taken care of when opportunity permitted.

It might be borne in mind that for such small sets dismantling and reassembly could probably be carried out over the off-peak period afforded by a Sunday or holiday, the period stretching from the decline of the evening peak on the day before the holiday to the increase of load on the day after the holiday.

95. From time to time, the operation of all devices, whether they were required to operate frequently or infrequently, should be checked and timed, and the calibration of instruments and indicating devices checked.

96. The station log sheet should include columns for half-hourly readings of current, voltage, kW output and power factor for each machine, current and voltage on each transmission line, and a remarks section showing times of start-up and shut-down of each machine, any protection operations and circuit-breaker openings and closings. Any alarms or irregularities of operation should be noted for attention. A secondary sheet could cover hourly or two-hourly readings of generator, bearing and transformer temperatures.

97. The minimum number of permanent personnel required for the power station could be quite small, consisting of a skilled electrical and mechanical fitter who would act as station manager, senior operator and director of maintenance, three shift operators who could also carry out routine maintenance, a trainee operator who could take readings in the day-time during the periods when the shift operator was otherwise engaged, and assist the manager, and a cleaner/handyman responsible for general housekeeping in the station and grounds. This minimum number presupposes that two or three electrical or mechanical fitters would be available in the village to assist with major maintenance. (In the case of a very small station, the permanent personnel might consist of only one man, with the provision that if a fault occurred the station would automatically shut down and alarm bells would ring in the station and in his living quarters. Reliability and records would, of course, be of a much lower order.)

98. It would probably be necessary to have two electrical linesmen to look after the transmission and distribution system, working during the day and on call durig non-working periods. Trimming of brush and weed growth under the transmission lines, and minor earthworks on the line routes, could be covered by minor contracts.

3. Financial control

99. One of several methods could be adopted for ordering equipment and stores, keeping track of all salaries and expenditure, arranging for new connexions, reading of meters, collecting from consumers, and making loan repayments. A small office could be established in the township, with a direct telephone connexion to the power station. It is strongly suggested that all approaches by the consumers and public should be directed to the Chairman, at the office, and that the Chairman should be the only one to report to the semi-political body. Such a procedure would minimize interruption to the essential work of operation of the scheme by consumers or others telephoning or visiting the power station with complaints. However, it is also suggested that the consumers be invited to inspect the works on a particular day each year, with modest refreshments available.

F. PROGRAMME FOR THE PROJECT

100. It is suggested that instead of setting out an over-all programme for the project, with deadlines set for actions which would not be under the control of the project organizers, the project should be programmed in stages, for instance, as follows:

Stage 1

(i) Semi-political body considers the possibility of constructing a project - no fixed deadline;

(ii) Semi-political body hires investigator for preliminary study;

(iii) Investigator works for one month and issues preliminary report to the semi-political body;

(iv) Within two weeks, semi-political body approves further work by the investigator;

(v) Investigator works for three months and issues detailed layout report to the semi-political body. Investigator remains available for two weeks for discussion on technical matters.

Stage 2

(i) Semi-political body considers financial and social aspects - no fixed deadline;

(ii) Semi-political body submits layout report and its recommendations to authority concerned;

(iii) Authority concerned deliberate - no fixed deadline;

(iv) Authority concerned issues approval in principle.

Stage 3

(i) Semi-political body appoints Chairman of the project committee;

(ii) Chairman selects committee members, with agreement of the semi-political body;

(iii) Committee hires two detail designers, with agreement of the semi-political body;

(iv) Designers work for six months and prepare for issue detailed drawings and specifications, with recommendations on procedure;

(v) Committee reports to semi-political body;

(vi) Semi-political body requests authority concerned to provide limited funds for issue of documents;

(vii) Designers remain available for two weeks for discussions;

(viii) Authority concerned approves issue of documents - no fixed deadline;

(ix) Documents issued with deadline of four months for bids;

(x) Designers recalled when bids received for one month for analysis of bids;

(xi) Committee recommends to semi-political body that contracts be let;

(xii) Semi-political body requests authority concerned to allocate funds according to a schedule;

(xiii) Authority concerned deliberates - no fixed deadline;

(xiv) Two members of committee keep track of validity of bids;

(xv) Authority concerned allocates funds.

Stage 4

(i) Committee lets contracts and issues notices to proceed;

(ii) Committee hires construction manager;

(iii) Construction manager appoints three inspectors with agreement of committee;

(iv) Construction proceeds for 12 months;

(v) Semi-political body appoints Chairman of utility;

(vi) Chairman of utility appoints permanent staff with agreement of semi-political body;

(vii) Commissioning proceeds for three months.

Stage 5

(i) Chairman of utility takes over all works;

(ii) Project inaugurated;

(iii) Chairman of utility proceeds with operation and maintenance;

(iv) Construction manager remains available for one month for discussions;

(v) Committee finalizes payments to contractors, finalizes balance sheet, submits to semi-political body (copy to Chairman of utility) and disbands;

(vi) Semi-political body issues final statement to authority concerned.

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