DEVELOPMENT OF EVALUATION MODEL FOR MINI/MICRO HYDRO POWER POTENTIAL IN KENYA

by

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Declaration

This thesis is my original work and to my knowledge it has not been presented for the award of a degree in any other university.

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This thesis has been submitted for examination with my approval as the university supervisor.

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Signature : ....

Date : 25 05 1999.

Dedication

To my parents

For their love and endless efforts in educating me.

Acknowledgments

While I can take pride in completing this work, I would be deceiving both the world and myself to say that it was my lone effort that made it a success. I would therefore like to pay special tribute to all who in one way or another contributed to its successful completion.

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Notations and Symbols

A	-	Amperes
AC, DC	-	Alternating Current, Direct Current
ADB	-	Asian Development Bank
AVR	-	Automatic Voltage Regulator
ATDO	-	Appropriate Technology Development Organisation
ASEAN	-	Association of South-East Asian Nations
CB	-	Circuit breaker
CBS	-	Central bureau of statistics
CT	-	Current Transformer
Δ-Y	-	Delta-Star
ECC	-	Electronic Current Cut-out
E/F	-	Earth Fault
ELC	-	Electronic Load Controller
FKAT	-	Association for Appropriate Technology, Germany
GATE	-	German Agency for Technical Cooperation
GTZ	-	German Foundation for International Development
HRC	-	Hangzhou Regional Centre for Small Hydro Power
Hz	-	Hertz
IGC	-	Induction Generator Controller
ITDG	-	Intermediate Technology Development Group
kg	-	kilogram
KPLC	-	Kenya Power and Lightning Company (Ltd.)
Ksh.	-	Kenya shilling
KVA	-	kilovoltampere
kW, MW	-	kilowatt, megawatt
kWh	-	kilowatthour
LV, MV, HV	-	Low voltage, medium voltage, high voltage
MHP	-	Mini/micro Hydro Power
m/s	-	metres per second
m^3/s	-	cubic metres per second

mm, m, km	-	millimetres, metre, kilometre
MCB	-	Miniature Circuit Breaker
N/M^2	-	Newtons per square metre
NPW	-	Net Present Worth
NRECA	-	National Rural Electric Cooperative Association
O/C	-	Over Current
OLADE	-	Latin American Energy Organisation
PTC	-	Positive Temperature Coefficient-thermistor
PVC	-	Poly Vinyl Chloride
PW	-	Present Worth
RE	-	Rural Electrification
rpm	-	revolutions per minute
SEF	-	Sensitive Earth Fault
SHP	-	Small Hydro Power
SKAT	-	Swiss Centre for Appropriate Technology
SWER	-	Single Wire Earth Return
UN	-	United Nations
UNDP	-	United Nations Development Program
UNIDO	-	United Nations Industrial Development Organisation
US $	-	United States dollar
UV	-	Ultra Violet
V, KV	-	Volt, kilovolt

Abstract

As witnessed by the developed countries, rural electrification (RE) is of paramount importance for the development of a nation. It serves many social and economic purposes. Since the majority of the people in developing countries live in the rural areas, there is a need for these nations to address themselves to the real problems of rural electrification. The dominant method used for lighting up these areas is national grid extension which quite often proves to be very expensive due to the dispersed nature of rural population distribution and very low power consumption. Diesel generators have also been used to serve remote areas but these are not very appropriate because they require skilled maintenance and their running costs are very high especially where fuel is imported. Even the oil producing countries do seek alternatives due to the realization that oil is a depletable resource. Cheaper and more appropriate technologies for lighting up the rural areas must therefore be sought and most countries are turning to renewable resources. Of all the renewable sources, mini/micro hydroelectric power (MHP) has been found to be the cheapest and moreover, it raises very little environmental concern.

In this study an evaluation model for MHP has been developed for applications in Kenya. This model performs the technical design of plants of capacity up to 500kW. It is based on relevant mathematical formulae and engineering considerations applicable to hydro power plants of this range. The power demand of the potential consumers should be estimated as a pre-condition for the use of the model. The model matches the discharge rate corresponding to the potential power demand and the river discharge rate to determine the design discharge rate. Where the demand surpasses the supply, a 70 percent exceedance design discharge rate is recommended. Storage reservoirs have been found to increase the project cost drastically due to the fact that a dam would have to be constructed and the excavation work involved. They should therefore be avoided.

The study concentrates on A.C. generation, single phase for plants upto 10kW and three phase above this rating. The choice of an induction generator can be made whenever it

costs less than the equivalent synchronous generator which has been found to be upto 25kW. For plants of capacity up to 200kW, Electronic Load Controllers (ELC) may be used with synchronous generators and beyond 200kW a speed governor is recommended. The use of a step-up transformer is only considered when the power to be transmitted exceeds 40kW.

The effect of interest rate charged on capital and discount rate have also been investigated and it has been found that the higher these rates are, the lower the Net Present Worth (NPW) of a project becomes. The unit cost of generation of power decreases as the annual capacity factor improves and as the useful life of a project increases. Unit cost of diesel generation was found to be higher than MHP for values of capacity factor above 17.5% for the plant studied. Although the unit cost of generation for both MHP and diesel decreases individually as the annual capacity factor improves, the difference in cost between the two sources widens as the annual capacity factor improves.

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CHAPTER 1

GENERAL INTRODUCTION

1.1 RURAL ELECTRIFICATION (RE)

As experienced by the developed countries, the implementation of Rural Electrification programs is a very slow and time consuming process, no matter the efforts and financial input (Saunier & Mohanty, 1992). For example in the USA, it took half a century to complete the electrification of the rural areas. Developing countries account for 75% of the total world population, and more than 50% of this population live in the rural areas yet, electricity for lighting is only available in the capital city, large provincial towns and a few other cities. In particular in Kenya, 82% of the total population live in the rural areas, but rural electrification only accounts for slightly over 3% (CBS, 1996) of the national electricity supply. This imbalance is partly due to the investment criteria in electrical generating systems i.e. only large centralised generation is efficient, and thus restricting power generation to very large hydro electric schemes and thermal/diesel power plants.

The population distribution in rural areas is sparse and most of the populace are low income earners. The electrical load in rural areas is characterised by poor load factor, low levels of demand, low load density and high power line losses due to long lines. These factors make the cost of supplying electricity by grid extention quite high.

Electricity in rural areas is primarily used for:-

i) Lighting

ii) Commercial and social amenities like hospitals and trading centres.

iii) Economic development i.e. pumping of water and irrigation, small scale agro and village industries.

Energy in one form or another has been found to be a pre-requisite for rural development thus making RE a very critical subject. RE on its own does not cause an area to develop but only acts as a stimulant. Other necessary conditions for economic take off have to be available. However, there is a direct relationship between efficient and productive RE and economic development of a country.

Electricity in rural areas serves many social objectives and helps in reducing the imbalances between rural and urban settings. The main benefits associated with RE include :-

i) If productive use of electricity is enhanced, it encourages modernisation of agriculture and development of agro and cottage industries hence

ii) Creating employment. This improves the income of the rural community thus closing the gap between the rich and the poor.

iii) Better standards of living are enjoyed due to the higher income levels. This has been observed in a study carried out in Peru (Smith, 1995).

iv) Social equity: With electricity in the rural areas, social amenities improve thus providing an environment almost equal in comfort and convenience as that enjoyed in the urban areas thus mitigating the drift to urban centres.

v) With clean energy available in rural areas, there is less use of fuel wood and hence less degradation of the natural environment.

In a country like Kenya with agriculture as the backbone of the economy, the rural population gets a very disproportionate share of the benefits accrued from the foreign exchange earnings of their agricultural produce. There is no clean energy in these areas and fuel wood accounts for more than 80% of the total fuel consumption (Mbuthia, 1981). The clearing of forests for planting of more cash crops to meet the ever increasing demand for foreign exchange and the pressure on land due to increase in population, has deprived the rural community of their major source of energy and cannot comfortably meet the very basic necessities of life like cooking. This makes the areas unattractive resulting in a population drift to the urban centres. This could eventually lead to the stagnation or decline of the contribution of agriculture to the country's economy, while on the other hand urban slums will be on the increase. There is therefore, need to redistribute the foreign exchange expenditure by providing better services to the rural areas.

The use of electricity instead of kerosene for lighting and refrigeration in the villages results in substantial fuel savings to the economy. Fielder and Berrie (1982) observed that for the same brightness of lighting, fuel cost of a power station, after allowing for distribution losses, is much less than the cost of kerosene. They note that the savings are sufficient to pay for power station and distribution system particularly if the electricity is used productively.

Utility companies however do face some constraints in connection with RE which include:-

i) *High capital cost*: This is due to the characteristics of rural load highlighted earlier. Substantial savings in investment and maintenance costs can be achieved by careful selection of maintenance, reliability and technical standards that are appropriate for the unsophisticated rural load.

ii) *High revenue collection costs*: The cost of meter reading, billing, revenue collection and administration are more than the revenue collected due to the dispersed nature of the rural load.

iii) *Low income from existing operation*: In some countries the tariff systems are constrained by historical and political factors (Smith, 1995). The tariffs are low thus necessitating reduction of operation & maintenance costs and system up-grade. This results in poor quality supply and a reduction in revenue.

iv) *Theft and vandalism*: Illegal connection to the supply and by passing of meters. This reduces the return on investment. There is also theft of conductors and equipment.

On the other hand, rural consumers have their own share of problems. These are:-

i) *High charge for initial connection*: The utility companies impose high initial connection charges in order to recoup part of the investment. Highest charges are encountered when all or part of the cost of the distribution transformer is met by the consumer.

ii) *High cost of house wiring*: Most of the rural population are low income earners who can barely afford the cost of wiring their houses.

iii) *Distance to payment centre:* Due to the dispersed nature of the rural load, utility companies tend to have payment centres that serve very large geographical areas. This discourages potential consumers from obtaining a connection while on the other hand it encourages default on payments.

iv) *Poor quality/reliability of supply:* Utility companies try to keep the RE costs low by having simple line designs and protection schemes. Often there is only one line supplying an area and in case of outage the area is left with no alternative route of supply. Voltage regulation in most rural areas is also poor.

The diseconomies of electricity distribution have prevented power from large centralised generation from reaching large rural population and there is evidence to indicate that (Walkade, 1986) these generating plants can never be economically applied to serve the very low consumer density of demand in the rural areas. The slow pace of implementation of RE programs has partly been attributed to the over reliance on the centralised grid supply to the exclusion of several decentralised technologies which could make a significant difference. These decentralised power supply sources are diesel stations, wind, solar photovoltaic and mini/micro hydro power (MHP). Of all these sources MHP has been found to produce electricity more cheaply than all other competing sources (Chullakesa, 1992). It is therefore important to look into ways and means of harnessing this renewable source of energy. Initial returns from these projects hardly cover project costs, but the indirect benefits in saving foreign exchange on food imports and in generating wealth and employment go a long way to make up for this loss. The unquantifiable social benefits enjoyed as a result of RE can not also be ignored. Therefore, RE should not just be looked at from the point of view of direct returns on invested capital, but must also be seen to have an overall major positive impact on the national economy.

1.2 PROBLEM STATEMENT

Having appreciated the problem of RE by grid extension and the importance of lighting up the rural areas for the growth of the national economy, and realising that MHP is a cheap and viable alternative, it is the task of this research project to design the most suitable evaluation model for mini/micro hydro power schemes for Kenya. This is in line with the current trend in the world of Small Hydro Power technology of design standardization in order to achieve cost savings in terms of both specialised engineering time and equipment. MHP is site specific and hence the need to have a model that is suitable for Kenya.

The model is to be based on mathematical formulae and engineering considerations found to be applicable to MHP. It should determine the power potential of a site and match it with the demand, then come up with the technical design of the various main components of the MHP plant i.e. civil works and the electrical design. Finally the financial analysis of the proposed plant and comparison of the cost of generation using MHP and an alternative source should be carried out.

1.3 RESEARCH OBJECTIVE

The objective of this study is to design the most suitable evaluation model for MHP plants for use in Kenya.

1.4 REASONS FOR THE PROJECT STUDY

This study is a rural electrification project using a renewable energy resource. Rural electrification by grid connection is prohibitively expensive and so it is very important to explore the alternative of mini/micro hydro power which is the cheapest known way of generating power for rural areas (Walkade, 1986). MHP installations have been found to be economically feasible (Mbuthia, 1981; Blankenberg & Hulscher, 1990). Thus the main reasons for this study include-:

1. The trend in the world of MHP is design standardisation. However, MHP is very site specific and a design that may be quite good for one country may be a total failure if used in another. The outcome of this project would therefore go a long way in facilitating the fast design of MHP sites in Kenya. In addition to this, the power industry is in the process of being liberalised and the developed model will be very useful to private site developers who need not have thorough enginee ıg knowledge when they have the model.

2. Kenya is already experiencing a power deficit and mini/micro hydro power technology would come in handy to close the energy gap.

3. Rivers and streams are found in large portions of the country and if their energy potential can be exploited -which is the main aim of this study-, then the living standards of the rural population would be improved. If electricity replaces wood fuel which accounts for more than 80% of the total fuel consumption in rural areas, there will be less degradation of the natural environment.

4. The rural community will leap the benefits resulting from mini/micro hydro power development such as employment opportunities created by having the plants run by the local people.

5. Unlike large hydros, mini/micro hydro power plants need not be donor funded. They do not require skilled labour for operation & maintenance and they are cheap to maintain. The main reason to prefer mini/micro hydro power plants over diesel generators is that, often the donor provides the generator but not the diesel oil which is a more urgent problem and especially in Kenya where it has to be imported.

CHAPTER 2

LITERATURE REVIEW

2.1 MINI/MICRO HYDRO POWER (MHP)

Mini/micro hydro power is a mature technology. It usually refers to a hydraulic turbine-generator installation for the production of hydro electricity at low power levels (Monition et al., 1984). The power from such installations ranges between 5 and 5000 kW for heads of 1 5 - 400 metres and flows ranging from several hundreds of litres per second to several tens of cubic metres per second. There is no universal definition of these small scale plants and different organisations and countries have different classifications which reflect the degree of rural industrial development and the proportion of hydro power in the whole power sector of a country. Table 2.1.1 gives the classification used by some organisations and countries.

Table 2.1.1.: SHP Definition and classification.

UNIT: KW

Name of country or organisation	Micro	Mini	Small
UNIDO	100	101-1000	1001-10000
HRC	100	101-500	501-10000
OLADE	50	51-500	501-5000
China	100	101-500	501-25000

Source: SHP NEWS, No. 1, 1993

However, a common definition uses micro when the power is less than 100 kW and mini when it is between 100 and 500 kW (Monition et al., 1984). This research project is on plants of up to 500kW capacity.

Mini/micro hydro power plants are used for providing electricity to locations that are not served by transmission from larger or conventional generation of which most of these locations are the rural areas. It has been estimated that (Manwell, 1988), 26% of all global technically developable sites have capacities less than 1000 kW. The amount of power generated by a MHP installation depends on the site selected, topography and the hydrological conditions. The potential output is a function of available head and water flow rate but is also a result of an optimisation process based on economic and technical parameters (Shanker & Krause, 1992). The cost of MHP is site specific and therefore proper site selection is very important.

The factors influencing the feasibility of a MHP plant site include

i) Available head of water.

ii) The river flow rate and its distribution throughout the year.

iii) Potential electricity demand in the surrounding area.

iv) Distance between (a) the plant site

(b) the nearest existing grid supply

and the load centre.

v) Existing infrastructure.

MHPs have some advantages over both fossil based and large scale hydro power stations. These exclusive advantages include:-

i) The technology of engineering and construction is relatively simple and they do not require elaborate civil works. The power generating equipment is simple and can be manufactured locally.

ii) The small size of individual plants creates widespread potential for MHP schemes in terms of the number of sites which can be exploited. The decentralised nature of MHP resources coincides more closely with the dispersed nature of rural population.

iii) Most of the sites are near the load centre and so the transmission distances are short.

iv) MHPs require limited funds and a short period of time for implementation.

v) They rarely raise environmental concern and their interference with the natural ecosystem is very small.

vi) Due to their small size, they permit local villager involvement in the full range of activities from initiation and implementation to operation, maintenance and management.

2.2 COMPONENTS OF A MHP PLANT

To harness the energy in water flowing in a river/stream, there are various components that must be provided. The principal ones include a weir, intake, power conduit, forebay, penstock, power house and the tailrace. Others such as spillway, gates, trash racks & skimmers and settling basin may be incorporated depending on the conditions at the MHP site under consideration. The inclusion of unnecessary components leads to an increase in project cost and complexity of implementation and operation of the scheme. On the other hand, if necessary components are omitted, the problems that these components should address persist. It is important therefore, that only those components that are necessary at a specific site are incorporated for an efficient and cost effective scheme. The following gives a brief description of the main components of MHP plants.

1. *Weir*

Most MHP installations are run-of-river type and they do not have storage. A weir is a structure constructed across a part or all of the stream to divert the required flow towards the intake.

2. *Intake*

This permits a controlled flow of water from a river/stream into a conduit which eventually conveys it to the turbine. The intake should be placed as high as possible above the turbine to maximise the head. It is normally equipped with a trash rack which filters out large debris.

3. *Power Conduit*

The power conduit conveys water a relatively long distance from the stream to the inlet of the penstock with minimum loss of head and at minimum cost. It is most frequently a canal excavated in earth which is sometimes lined with concrete, stone masonry or wood. The canal should very nearly be along a contour line.

4. *Forebay*

Before descending to the turbine, the water passes through the forebay. This serves as a settling basin, where suspended particles settle at the bottom, and also as storage to cope with water demand due to sudden increase in turbine loading. Its size may vary depending on the quality of water and whether it serves as storage.

5. *Penstock.*

This is a pipe which conveys water under pressure from the forebay to the turbine. Some of the materials used for penstock pipe are steel, PVC, polyethylene and fibre-glass reinforced polyester.

6. *Power House*

This houses the turbine, generator and other electro-mechanical equipment.

7. *Tailrace*

It is a short open canal that guides the water from the turbine back into the river. It is a component of every scheme except for low head plants where the water emerges from a draft tube directly into the river.

2.3 DEVELOPMENTS IN MHP TECHNOLOGY

Globally, small scale hydro power has been in use for thousands of years with the earliest form being waterwheels with a mechanical output. These were used for grinding grain and raising water to higher elevation for irrigation and water supply. In the 1880's, hydro turbines were first used to generate hydroelectric power and this took over the waterwheel. Mini/Micro hydro power technology was developed up to the 1930s.

Thereafter until 1970's, there was a steady trend away from the technology as diesel generators and subsidised grid electricity provided cheaper alternative supply to the rural areas. It was not until the first oil crisis of 1973 that both the developed and developing countries started seeking the alternatives of indigenous energy resources for electricity generation. Both grid electricity and oil based fuels became increasingly expensive in most countries and governments encouraged the development of small hydro resources - being one of the most practical renewable energy technology - thereby reviving the industry.

The sharpening of ecological issues, improvement of design methods and modernized equipment have all led to the new development of small scale hydro power technology which is neither a scale-down of large hydro nor a simple repetition of the original technology, but a higher type under new economic and technical situation. So small scale hydro power has received more attention and has been revived after a long period of negligence. In some countries like China, mini/micro hydro power plants have been used for flood control and reclamation of the semi-arid and arid land through irrigation and electricity generation is secondary (Jiandong, 1993). Another example of a project that did not have electricity generation as the main objective is the Matutinao mini hydro scheme in the Phillipines. It was built to improve the livelihood of the people and to retain the scenic beauty of the area (Small Hydro, 1990).

Some of the developments that have come with the renewed interest in mini/micro hydro power are discussed below.

2.3.1 Design standardization

The costs of specialised engineering time can be very significant in small schemes. Due to the fact that mini/micro hydro power is site specific by nature, software packages that have been developed for the design of MHP plants only act as design tools thus saving on design time and hence cost. One such software package is the MICROHYP (Kahn et al. 1992). It helps the designer come up with the least-cost design of a micro hydro plant (its use is limited to plants of capacity up to 100kW). It allows the user to study a wide range of schemes giving alternative layout and component sizes. However, when tested the model was found to have some short comings. It declared some sites which had been working satisfactorily for years to be infeasible. This was due to some built-in constraints like on the penstock sizing and power canal dimensions. The model does not include the mini hydro plants i.e. plant capacity between 100-500kW. Although it comes up with the least cost design, it does not include an economic/financial analysis of the plant which is very important in determining the feasibility of a project.

Standardization of equipment has also received considerable efforts to achieve cost savings on engineering input, manufacture and the provision of spare parts. China's success in developing small hydro sites has been partly due to standardization of equipment and its quality (Metzler, 1982). She manufactures high quality low-cost equipment and conducts centralised research and development of turbines. This avoids the high capital expenditure and personnel requirement that an individual turbine manufacturing company would require. These designs offer lower costs and machines of guaranteed quality and reliability.

2.3.2 Electronic Load Control (ELC)

Mini/micro hydro power installations are normally stand-alone plants and they require a speed governor so as to maintain the frequency of generated voltage within acceptable limits when the electrical load is varied. Previously, mechanical and electro-hydraulic speed governors were used to control the water flowing into the turbine. The speed governor is the single most expensive unit in a hydro electric installation and it is quite sophisticated.

The load controller is an electronic device that maintains a constant electrical load at the generator terminals inspite of changing useful load. Solid state electronic voltage or frequency sensing causes power to be diverted to or from a ballast load connected in parallel with the main electrical load. This maintains a balance between the total electrical load torque and the hydraulic input torque thus keeping the water flow and hence the speed of the turbine-generator set constant. It dispenses the need for a water regulating device and allows simpler turbine designs. This means that the turbines can be produced in mass at low unit cost and also permits manufacture in a developing country's workshop using local labour and readily available materials. Typically, the cost of an ELC is about one tenth that of the speed governor (Henderson, 1993).

There are basically two commonly used techniques of load governing:-

1. ***Phase control*** - In this method, a single resistive load equal to the generator rating is connected to the generator via thyristors connected to a control circuit. The firing angle of the thyristors is varied according to the user load connected to the system. Current flows to the load for a specific period of the voltage cycle and when it is off

current flows to the ballast load. The average dumped power is the product of the voltage and the current during the interval when the thyristor is ON divided by the total cycle length. Hence by varying the thyristor firing angle, the dumped power can be varied between zero and full load.

This method however, suffers the disadvantage of introducing harmonic distortion in the current waveform and radio interference. It is possible to introduce filters to suppress the harmonics although distortion gets worse with increased load current thus making suppression more difficult and expensive. In addition the distortion is increased when the load has a longer time constant such as an electric heating element, which is a common form for the ballast load. Fraenkel et al. (1991) however observes that the above drawbacks have not restricted the widespread use of this type of ELC. It is now used in over 30 countries.

2. ***Stepped dump load*** - Four resistive loads are connected to the generator via four independent electronic switching circuits. The control circuit has a frequency comparator which compares the frequencies of the generated voltage with that of an internal crystal after which an appropriate signal is sent to the switching circuits. The resistances are in the ratio 1:2:4:8. By appropriate switching, the dump load can be varied between zero and full load in fifteen discrete steps and frequency kept to below ±1.5% within the whole range of variation (Inversin, 1986). Switching is done at the zero crossing of the voltage waveform and all the connected ballast loads are subjected to the full cycle. This method eliminates harmonic distortion experienced in

the phase control method. It however suffers the drawback of less accurate regulation and voltage flickering (Fraenkel et al., 1991).

An automatic voltage regulator (AVR) must be provided in addition to the ELC except in cases where the useful load is purely resistive. If a load with power factor less than unity is connected to the generator, it draws reactive current and if the excitation is fixed, the a.c. output voltage decreases if there is no AVR.

When an ELC is employed, the generator must be oversized by 60% of the normal requirement. In a phase controlled ELC, when conduction is retarded, the ballast load is seen by the generator and supply system as a load with lagging power factor (Harvey, 1993). A user load of low power factor combined with the switching effect of the ballast load require excessive reactive power from the generator in which case the large currents may damage the AVR or the generator windings. This is avoided by oversizing the generator rating.

At El Dormilon in Colombia (Kristoferson & Bokalders, 1986), heat storage cookers have been used as ballast load in conjunction with MHP installations. Other ballast loads that have been used else where are space heaters, water heaters, crop drying and refrigeration.

As observed from the foregoing discussion the value of C has to be as close to C_{min} as possible to avoid:-

i) Low frequency and efficiency

ii) High terminal voltage which can damage machine

iii) High stator and rotor currents which cause overheating of the windings.

It is evident that it is not an easy task to determine the precise value of C required for a self-excited generator to operate satisfactorily under varying load conditions. This would require an accurate knowledge of the electrical parameters of the machine, and their variation with voltage.

Another earlier hindrance to the use of the induction generator for plants working in isolation from the grid was lack of suitable excitation capacitance control mechanism. The load on the generator had to be maintained constant or very nearly so at all times to avoid the need for varying the capacitance. This has however, been overcome by the development, in recent years, of the Induction Generator Controller (IGC) (Hydronet, 1995). Its operation is similar to that of an ELC. Unlike in the ELC operation which senses frequency changes, the IGC operation senses variation of voltage thus dispensing the need of an Automatic Voltage Regulator (AVR). When the useful load on the generator increases, the voltage falls. The IGC senses the drop and compensates by diverting the power dissipated in the ballast thus maintaining the effective generator load constant. The use of IGC dispenses the need for varying the excitation capacitance for varying load conditions on the generator. Only one value of capacitance is needed i.e full load value.

2.3.3 Induction Generators

The synchronous generator has traditionally been used for hydroelectric installations of all sizes. The induction generator however, has several advantages over the synchronous generator which include:-

i) It is cheaper

ii) It is very rugged and less prone to failure

iii) Can handle prolonged overspeed with reduced risk of damage

iv) In case of a short circuit the voltage and hence the excitation collapse rapidly thus limiting the current.

The induction generator is now being used more frequently in small scale hydro power plants that are connected to a much larger electric grid (SHP, 1993) and is normally chosen when it is cheaper than the equivalent synchronous generator. When such a plant is connected to the grid, the generator draws excitation current from the system and the frequency is automatically regulated by the system hence there is no need for a speed governor. On the other hand, when used in stand-alone plants, the induction generator must be supplied with reactive power for it to excite. This can be achieved by the connection of a capacitor [C] across the machine terminals as shown in fig. 2.3.1.

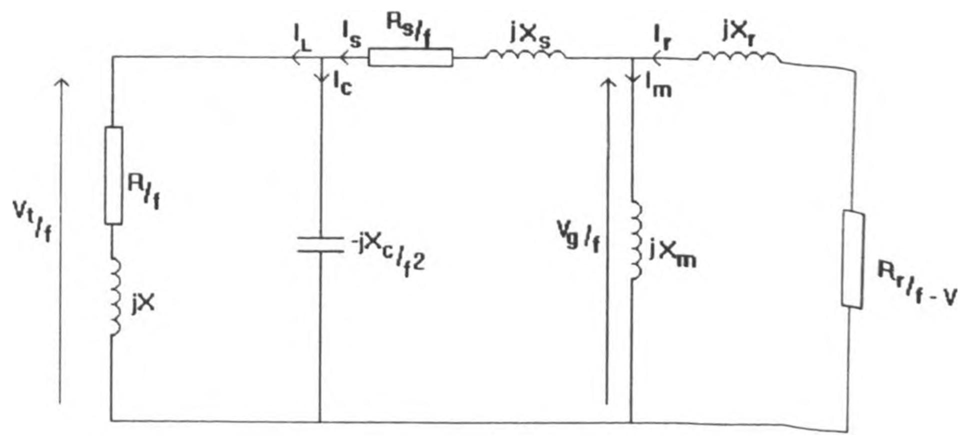


Fig 2.3.1: Steady state equivalent circuit of the induction machine with load

Where

R_s, R_r, R	- Stator, rotor (referred to stator) and load resistances respectively.
X_s, X_r, X_m, X, X_c	- Stator, rotor (referred to stator), magnetising, load and excitation reactances at base frequency respectively.
I_s, I_r, I_m, I_L, I_c	- Stator, rotor (referred to stator), magnetising, load and excitation capacitor currents respectively.
f,v	- Per unit frequency and speed respectively.
V_t	- Terminal voltage.

However, sizing the suitable capacitor presents problems because its value is tied to very many factors. The value of capacitor must be within certain limits ($C_{min} \leq C \leq C_{max}$) to sustain self-excitation in which case, outside the specified range the machine cannot excite. This range is dependent on machine parameters, speed, power factor and load

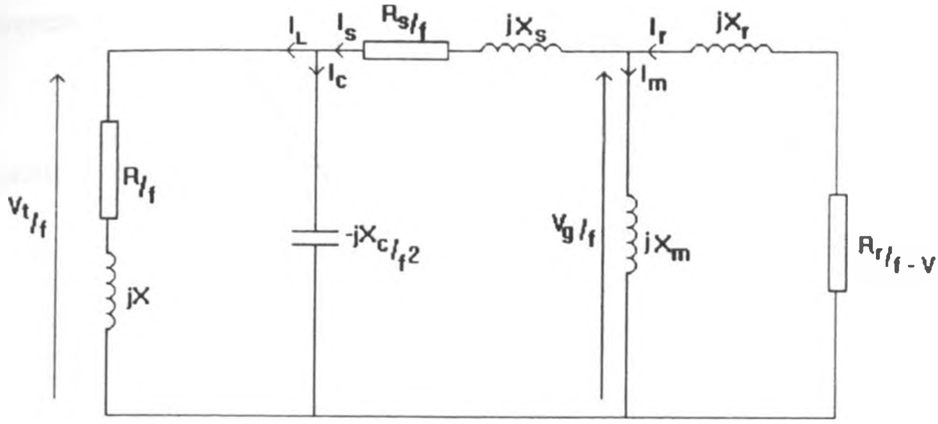


Fig 2.3.1: Steady state equivalent circuit of the induction machine with load

Where

R_s, R_r, R	- Stator, rotor (referred to stator) and load resistances respectively.
X_s, X_r, X_m, X, X_c	- Stator, rotor (referred to stator), magnetising, load and excitation reactances at base frequency respectively.
I_s, I_r, I_m, I_L, I_c	- Stator, rotor (referred to stator), magnetising, load and excitation capacitor currents respectively.
f,v	- Per unit frequency and speed respectively.
V_t	- Terminal voltage.

However, sizing the suitable capacitor presents problems because its value is tied to very many factors. The value of capacitor must be within certain limits ($C_{min} \le C \le C_{max}$) to sustain self-excitation in which case, outside the specified range the machine cannot excite. This range is dependent on machine parameters, speed, power factor and load conditions. In order to reach a steady state generating mode, some remnant magnetism must be present in the machine core initially (Elder et al., 1984, Tripathy et al, 1993).

The magnetising reactance varies non-linearly with the terminal capacitance and load. To maintain self-excitation under steady state conditions, $X_m \leq X_{max}$ (maximum saturated magnetising reactance of the machine). There is a minimum load impedance below which the machine cannot excite irrespective of the value of excitation capacitance. This happens when X_m is greater than X_{max}.

The magnitude of the steady state generated voltage is determined by the value of the terminal capacitance and the non-linearity of the magnetising inductance. If the voltage is to remain constant under varying load conditions, then the capacitance must be varied and this affects other factors differently. If a capacitor of a higher value than is required is connected, the terminal voltage rises above the rated value.

Malik & Al-Bahrani (1990) in their study of the influence of the terminal capacitor on the performance characteristics of the self-excited induction generator point out that the frequency of the generated voltage decreases as the capacitor value increases. They further note that when the machine is on no-load and $C \cong C_{max}$, $f \cong v/2$. Under this condition the rotor circuit impedance $[R_r/(f-v)+ jX_r]$ becomes small and the machine looses excitation. The stator, rotor and capacitor currents (I_s, I_r, I_c) are strongly influenced by C, rising to a maximum and then falling off as C increases. This causes increased machine losses (hence poor efficiency) and consequential heating of the windings.

If the load has an inductive component, the frequency increases to compensate for this load but the rise is typically less than 10% for an overall load power factor of 0.9 (Smith, 1994). Reactive loads may be supplied provided the load power factor is not below 0.8 lagging.

In Nepal alone, more than 100 induction generators on micro hydro schemes had been installed in 1994 (Smith, 1994) and they had proved to be considerably more reliable than synchronous generators.

Harvey (1993) gives two methods of calculating the approximate value of capacitance required which have been found to be sufficient (section 3.8.3.2) for MHP installations. The turbine speed is adjusted until the required voltage is obtained.

2.3.4 New materials

For heads below 150m, high density PVC and polyethylene pipes are commonly used to replace the more expensive and heavier steel penstocks which were formerly used (SHP News, 1993). They also have good corrosion resistance. Fibre-glass reinforced polyester has also been successfully used as a penstock pipe material.

Research is underway on the use of bursting discs for surge attenuation in the penstock (Hydronet, 1995). This is a barrier between the pressurized penstock and the atmosphere, designed to rupture at a pressure typical of that caused by a jet blockage or excessively fast valve closure. The potential benefit to be accrued from the use of this simple but effective form of surge attenuation, is cost reduction without compromising the performance or reliability of the penstock. Penstock material cost can be reduced by reducing the safety factor and even the penstock thickness as the disc offers reliable protection.

2.4 OBSTACLES TO VIABLE MHP SCHEMES

There are many obstacles that hinder the development of viable MHP schemes most of which have been overcome through innovative designs and proper dissemination of the technology. These obstacles include:-

2.4.1 High capital cost per kW of installed capacity

Inversin (1986) sites the employment of engineering firms engaged in large hydro power projects to implement small schemes as one of the causes of high capital costs. These firms simply scale down the large hydros instead of considering the unique aspects of small hydro power thus resulting in excessive increase in costs due to economies of scale. He however notes that a growing awareness of the problem and the availability of more cost effective designs and approaches to construction make MHP development an attractive alternative. Capital costs may be reduced by having MHP installations that do not require elaborate construction works or expensive power houses and highly optimised electromechanical equipment. A good example is Pakistan which produces the cheapest MHP in the world at US$ 350-500 per kW of installed capacity (Kristoferson & Bokalders, 1986) - 1981 figures. This very low cost has been attributed to the utilisation of local materials, designs suited to local situations and community involvement at all stages of implementation and utilisation.

Blankenberg & Hulscher (1990) report that the feasibility of MHP plants is not only a comparison with other alternatives but also the analysis of the elements that influence the price of the plant. These elements in order of importance include:-

i) Load factor

ii) Economic lifetime of the plant

iii) Operation and maintenance cost

iv) Capital cost.

They found that an improvement of the load factor from 19% to 35% and prolonging the economic life from 20-30 years reduces unit cost by 70%. In addition if capital and operation & maintenance costs are reduced by 50% and 60% respectively, it results in a 17% cost reduction, thus making it possible to reduce costs by 87%.

2.4.2 Effects of Seasonal River Flow Variation

The plants that have a design flow rate equal to or lower than the annual minimum river flow rate have power supply to meet the demand throughout the year resulting in the best solution. However, this is not always possible because most rivers/streams have very high flow during the wet season and low flow in the dry season. This leads to a demand/supply mismatch during the dry season. This has in some cases hindered the harnessing of potential MHP sites. However, it can be remedied by a load management program and a suitable power utilisation schedule can be worked out. Since rural electrification by grid connection is expensive, and diesel generators require highly skilled maintenance rendering them inappropriate. Therefore all year round supply requirement should not hinder the installation of MHP schemes.

2.4.3 Attitude/policy of lending agencies

Lending institutions/agencies -the World Bank being one of them- tend to favour investment in a few large hydro power schemes rather than in many small ones. Where loans are available, Santos (1992) highlights that the numerous bank requirements and bureaucracy result in increased project costs and delay in implementation. If the policies of self-construction -capital investment, material, labour and land are locally supplied- and self-management -plant run by local authority or organisation that built it- are adopted, these projects being of harambee/co-operative nature may not require donor funding. These policies have been adopted in China which has been very successful in SHP development.

2.4.4 Lack of good hydrological data

Santos (1992) notes that in most developing countries, hydrological data is either unavailable or unreliable. This results in poorly designed schemes with under-estimated project costs and over-estimated energy potential in the early stages of planning. Going by this kind of misleading data may result in flooding and submergence of the power plant and/or closure during the dry season.

The government could play a major role in the promotion of these programmes by giving special grants/subsidies, tax benefits and low-interest long-term loans. This would go a long way in making MHP affordable even by the very poor of the society.

2.5 DISTRIBUTION SYSTEM AND COST REDUCTION OPTIONS FOR RURAL ELECTRIFICATION PROJECTS

2.5.1 Introduction

As earlier discussed, the overall cost of MHP - including cost of the plant, transmission & distribution and revenue collection- should remain as low as is practically possible. This ensures that MHP remains competitive against other alternatives and affordable. The main problem faced by utility companies in connection with rural electrification is the dispersed nature of the rural load resulting in unusually long lines. This makes the cost of the transmission & distribution systems and revenue collection very high. This section discusses some of the factors that may be considered to reduce these costs.

2.5.2 System Configuration

Since the rural load is simple, the distribution system used should be a simple radial system to reduce on costs. Wyatt and Dingley (1995) in their report on the financial comparison of 3-phase and 1-phase rural electricity distribution note that the costs of medium voltage (MV) lines may be reduced by using 1-phase instead of 3-phase lines. The system configurations in use are

I. <u>*3-phase. 3-wire system*</u>

In this system, all the distribution lines and transformers are 3-phase. The low voltage (LV) lines are also 3-phase and customers are supplied with either 3 or 1-phase depending on their preference. This system has the advantages of availing the consumer with a choice between 1- and 3-phase, the load is well balanced amongst the phases of the MV lines and it supports sensitive earth fault (SEF) protection (Wyatt & Dingley, 1995). It is however quite expensive.

2. *3-phase with 1-phase, phase-to-phase lines*

The backbone system is a 3-phase 3 wire system with single phase lines taken between two phases of the 3-phase lines. Loads are supplied via single phase distribution transformers e.g. 11/.24kV, 33/.24kV. This system is cheaper than the 3-phase system but suffers the disadvantage of unbalanced loading of the 3-phase lines from which it is tapped and customers can not make their own choice as regards the number of phases required.

3. *3-phase, 4 wire system*

The backbone distribution system is Y-connected with three phase conductors and a neutral. One phase conductor is extended from the main system with a neutral conductor which has multiple connections to earth. The cost of such a system is low because the single phase lines only require protection equipment for the single phase conductor and the use of the neutral conductor reduces the earthing costs. The main disadvantage is that this system does not support SEF protection and must rely on earth fault (E/F) and overcurrent (O/C) protection. Loads are supplied via single phase distribution transformers e.g 6.35/.24kV.

4. *Single Wire Earth Return (SWER) system*

A single phase conductor is used with the earth providing a return path. SWER lines can not make up an entire distribution system and have to be used in conjunction with any of the other systems (Wyatt & Dingley, 1995). The SWER lines are supplied from an isolating transformer to restrict the extent of earth return currents and to allow freedom in the choice of SWER line voltage. The transformer must be well earthed and must be capable of carrying the full load current while ensuring step potentials remain within safe limits. O/C protection is the only applicable scheme and the relay setting must therefore be sufficiently low to detect all faults.

In a study carried out in Kenya to determine the best electrical system configuration for application in the rural areas (McCall, 1989), it was found that the single phase, phase-to-phase provides a viable and economic alternative. The use of single phase motors up to 20HP was recommended in the study but was found to be unsuitable by KPLC. The latter gave 7.5HP as the maximum single phase rating that is acceptable and which it uses citing the following reasons.

a) Beyond this limit there is too much voltage dip at motor starting thus reducing the distribution radius to contain the voltage dip.
b) Single phase motors require bigger transformers
c) Single phase motors require heavier conductors due to the high current drawn
d) In Kenya single phase motors are more expensive than the equivalent 3-phase units.

However, single phase motors available in the market are of capacity upto 3HP thus rendering this system unsuitable where motors above this rating are required.

The cheapest system as regards cost of the line only is the SWER system. However, this requires expensive distribution transformer earthing and isolating transformers thus making the fixed costs high but with low cost per km of line construction (Wyatt & Dingley, 1995). The viability of this system in a given situation is therefore dependent on the number of distribution transformers to be supplied and the total line length. The total cost (fixed cost + cost of line) per km decreases as the line length increases. In the Kenyan study (McCall, 1989) in which conclusions were drawn in favour of the single phase phase-to-phase system, this may hold only because the area studied already had the MV network in place. For a new project, factors like the length of the line and number of distribution transformers ought to be addressed. Some of the requirements used in the study to rate the various system configurations, like safety of the system, if well addressed can be solved. Pabla (1981) recommends the application of SWER as a means of meeting basic energy needs and promoting productivity in sparsely populated and isolated villages where the load is scattered, small and unlikely to increase substantially in 5-10 years time.

2.5.3 System cost reduction

In a study carried out by the Asian Development Bank (ADB) in Asian and Pacific countries (Chullakesa, 1992), it was observed that the cost of RE can be reduced by altering engineering design standards and design criteria. These observations were on RE by grid extension and the percentage savings were as shown in table 2.5.1.

Table 2.5.1 Percentage savings in RE by altering the engineering design

Item	Potential saving as a % of total RE cost
Distribution substation	10
Distribution line	
- Correct selection of system voltage	30
- Economic design of line supports	10-20
Distribution transformer	15
Service quality and reliability	
- Lowering voltage regulation	8-25
- Lowering reliability level	10-15
Meter installation	10

Source: (Chullakesa, 1992.)

Distribution substation cost can be brought down by use of a simple bus arrangement such as the single bus, avoiding duplication of transformers and correct choice of substation equipment and design.

A correct choice of system voltage is important as this determines the size of conductor to be used. This also affects the mechanical design of the line e.g pole height & size and size of insulators to be used.

Voltage regulation can be optimised by a trade off between the incremental investment to improve regulation and the loss of life of electric appliances in the consumer premises. Over-voltage often shortens the life of most appliances, e.g tungsten bulbs, coils and transformers, while under-voltage shortens the life of standard motors. The stipulated voltage regulation at the consumer premises is ±6%. Chullakesa (1992) argues that since there are very few motors in most rural supply systems, it would be cheaper to specify and procure motors that can cope with -10% voltage regulation at an extra cost of 10%. He further notes that in the ADB survey it was observed that RE systems designed for -8 to -12% regulation can save on investment by 15-25%. He gives power factor correction as the most economical means of improving voltage regulation.

For MHP plants working in isolation from the grid supply, Harvey (1993) recommends a voltage tolerance of ±7% for an all purpose electrical supply system. These limits may be exceeded when loads are switched on and off for as long as the fluctuations are not excessive and do not last more than two or three seconds. The Kenyan utility company, KPLC, allows a voltage dip of 10% during motor starting in the rural areas.

The costs of RE may also be cut by reducing the distribution line losses which are both technical and non-technical (theft by illegal connection). It can be very expensive to reduce these losses and therefore the lowest possible losses may not necessarily be the most economical. Optimal levels depend on the load density and for a given loading the technical losses will depend on the power factor, conductor size, system voltage, length of the line and load factor. Of all these factors, loss reduction by power factor correction has been found to be the most cost effective (Chullakesa, 1992). Pabla (1981) notes that the power factor of rural loads without compensation is about 0.7 and an improvement to 0.85 may reduce the losses by as much as 22.5%. Induction motors commonly used for agricultural pumping and industrial loads are normally designed for a power factor of 0.8-0.85 at full load. This falls appreciably when the motors are run on part load e.g for lightly loaded motors power factor can be as low as 0.4. In practice most motors are run on part load due to over sizing of motors because most people fear it may burn out if they purchase the exact rating required for a given purpose. To attain the full benefit from the investment, power factor correction should be done at the consumer end.

2.5.4 Metering and billing techniques

One of the problems faced by utility companies in connection with RE is the high cost of revenue collection. This includes meter reading, billing and administration costs. On the other hand the consumer faces the constraint of high charge for initial connection which includes the cost of the meter. It is therefore important to try and come up with a scheme which harmonises the two sides.

Pre-payment meters

The pre-payment meter provides almost an ideal solution to the utility company's problem. The consumer purchases the units of electricity from the supply authority in advance in as much the same way as filling up a car with petrol. This dispenses the need for meter reading, billing and default on payments. However, the main drawback with these meters is the high cost which makes them non-starters for rural areas where most of the population are low income earners. They have been used extensively in South Africa principally in townships (Smith, 1995).

Load limiters

The use of load limiters is a more promising solution for both the consumer and the utility company. It limits the amount of current drawn by a consumer to a prescribed value and if it is exceeded, the load limiter trips. Some load limiters require manual reset while others will automatically reset once the overload is removed. The consumer pays a fixed monthly fee depending on his size of load limiter, no matter the amount of energy consumed (peak demand based tariff system).

There are three types of load limiters

i) Miniature circuit breaker - MCB

ii) Positive Temperature Coefficient Thermistor - PTC

iii)Electronic Current Cut-out - ECC

The MCB is the most widely used because it is produced in mass, robust and is cheap. It uses thermal or magnetic sensing mechanism with some incorporating both. The thermal and thermal-magnetic are more common. It has to be reset manually after the overload is cleared. The standard current rating is from 1A to 100A.

The PTC uses semiconductor technology. They are mass produced for overload protection in telecommunications. It has not been widely used for domestic electricity connection due to its low current rating - typically 20mA to 500mA.

The ECC is a very recent development which is still at the field trial stage (Smith, 1995). It uses thyristor switching to cut off the supply in case of overload. The range currently being developed is between 500mA and 3A.

The load limiter has the disadvantage that it is prone to illegal connection by by-passing it or connecting a higher rated one than what is actually paid for. This is because unlike the metered supply it gives no indication of the energy consumed in a given period. This kind of theft can be checked by connecting a group of consumers to a common load limiter, in addition to the individual ones, installed at the top of a pole to avoid tampering. It then becomes a communal responsibility to ensure that the common load limiter does not trip. Load limiters have been successfully used in Nepal, Zimbabwe and Sri Lanka. Consumers may be given the option of getting a metered supply.

2.6 MINI/MICRO HYDRO POWER IN KENYA

2.6.1 MHP in Kenya

In the Kenya National Paper published by the Ministry of Energy for the United Nations Conference (UN, 1981), the author outlines some of the government's objectives for the development of new and renewable energy sources as:-

* Increase the supply of energy to meet the requirements of the economy.
* Lessening dependence on imported fuels through vigorous conservation measures aimed at increasing productivity of such fuels and utilization of new and renewable sources of energy to the extent possible.
* Developing indigenous resources

The author further points out that the sources currently being used are hydro and fuel wood and the development of mini/micro hydro power potential is under investigation. However, as of today very little if anything has been done in this direction. The first objective which is the most urgent has also not been realized and the energy deficit is becoming worse by the day. Perhaps unlike in China where these projects have been very successful, the government has not given them much backing by way of subsidies or preferential loans and even dissemination of the technology (Jiandong, 1993). It has been found that (Santos, 1992) micro hydro power programmes only have a future if the governments of developing countries show a real and enduring interest in rural and village development and it is important that their development is integrated with the country's general development plan.

In a study carried out by Mbuthia (1981) he found out that the number of small scale hydro schemes in Kenya had not increased since 1956 (as of 1981) and that some existing ones had infact been closed down in favour of the formerly cheap grid supply and oil-based stations. He further points out that for those that were abandoned, it was not due to poor performance or uneconomic operation, but they were simply regarded as an unnecessary bother and were replaced with energy tapped from the national grid. He writes that, for the survival of small hydro power (SHP), the attitude towards them must change especially where a large organisation is involved in their management.

Kenya has mainly concentrated on exploiting the large hydro sites while leaving the many small rivers and streams found in many parts of the country untouched. Muchiri (1980) reports that small hydro electricity has not received much attention in Kenya and only exists in isolated places such as ranches and estates, in spite of the fact that they might even be cheaper as has been demonstrated by Brooke Bond (K) Limited in Kericho. The company runs four hydro power stations, some diesel generators and is connected to the Kenya Power and Lighting Company (KPLC) grid supply. The total hydro generation is 2030 kW (Henya, 1995) which contribution to the peak demand is about 65%. In a wet month, the hydro stations supply 81% of the total power requirement while during the dry spell they account for about 30% of the supply. The economic comparison of the three sources is as shown below for the unit cost.

Source	Unit cost (Ksh./kWh)
Hydro	1.22
Diesel	10.10
KPLC	8.10

Source: Henya (1995)

From this, it can be seen that MHP supply is the cheapest, followed by KPLC and the most expensive being diesel generation. The electricity generated is mainly for productive use in the tea factories with domestic supply accounting for only 14 5% of the peak demand.

Another successful installation is the Tenwek mission hospital in Bomet District. This has a 320 kW hydro generator supplying a 300 beds hospital, church, school and staff houses. Generation has been limited to 280 kW to discourage expansion of the plant for unproductive purposes. To ensure that the domestic load remains low, staff houses have been fitted with solar panels for water heating and the hospital encourages its staff to use gas cookers by providing them with free gas cylinders. The hospital also has a standby diesel generator of 292 kW capacity rating.

Fielder & Berrie (1982) in their study on the energy resources of Kenya concluded that the fuel cost savings achieved by use of electricity instead of kerosene for lighting, and the secondary benefits resulting from rural electrification may justify the large capital costs of MHP developments. It has also been found that although small hydro plants may be considered marginal as regards their contribution to the total power supply, they are important for political and sociological reasons. These projects harness both small hydro power and "small people's power" in the sense that, the people who participate are small income earners, with low education level and a small amount of technical skill.

2.6.2 MHP sites in Kenya

A desk study had previously been carried out (Ewbank, 1979; Finnconsult, 1981) that used topographical maps -1:50000 scale- with rivers' main course and aerial photographs, to identify potential MHP sites. Hydrological and geological data was also used for the investigation of the site power potential and assessment of site suitability for putting up a power plant. The sites that are within the scope of this study are those that

i) Have hydrological data available

ii) Where there is no grid supply

iii) The site power potential i.e. power input to the turbine, is not more than 650 kW.

iv) Site is accessible.

v) Load centre is not more than 10km away from the MHP site.

The site power potential is estimated using the following equation

$$P = 9.81 \times h \times Q \times 0.9$$

where the multiplying factor 0.9 is the estimated combined efficiency of the civil works, power conduit and the penstock.

P - Estimated power potential of site (kW)

h - Gross head (m)

Q - Average river flow rate (m^3/s).

The identified MHP sites in Kenya and the estimated power potential for each are as given in table 2.6.1 below.

Table 2.6.1 Existing and Potential MHP Sites in Kenya.

	River/Tributary	Location (1:50,000 map)		Annual Mean Discharge (m^3/s)	Max. available head / river section (m/km)	Maximum mea capacity (kW)
		Sheet No.	Reference			
1.	Arror	90/1	8608	2.12	28 / 0.05	525
2.	Arror	76/3	8321	1.53	60 / 0.4	810
3.	Arror	75/4	7829	0.45	60 / 0.4	238
4.	Muruny	75/4	5535	0.40	100 / 1.0	354
5.	Muruny	75/4	5733	0.40	40 / 0.5	141
6.	Perkerra	104/3	0511	2.20	30 / 0.7	582
7.	Nzoia/Kuywa	88/1	8091	0.30	110 / 0.5	292
8.	Nzoia/Moyben	89/2	7590	0.92	20 / 0.2	162
9.	Nzoia/Moyben	90/1	7800	0.65	20 / 0.5	114
10.	Nzoia/Moyben	75/4	7414	0.25	60 / 0.6	132
11.	Nyando	118/1	8378	1.50	30 / 1.0	397
12.	Nyando	118/1	8680	1.40	30 / --	370
13.	Kuja	130/3	9112	11.80	6 / --	626
14.	Kuja/Mogunga	130/3	9311	4.20	16 / 0.2	594
15.	Mara/Amala	131/4	7607	4.60	20 / 1.2	813
16.	Mara/Amala	132/3	8312	4.10	20 / 1.0	725
17.	Mara/Amala	132/3	8412	4.00	20 / 1.0	707
18.	Migori	144/2	0874	4.50	20 / 1.0	795
19	Muruny	75/4	5436	0.40	250/1.0	883
20.	Thingithu	122/1	5293	2.80	20 / --	494
21.	Thingithu	122/1	4195	1.60	20 / --	283
22.	Maranene	122/1	4876	1.20	60 / --	636
23.	Thuchi	122/4	6360	4.50	15 / --	595
24.	Ena	136/1	4343	2.40	20 / --	424
25.	Ruamuthambi	121/3	0048	0.40	20 / --	71
26	Kabingashi	135/2	2943	0.90	30 / --	239
27.	Thaina	120/4	5259	0.85	70 / --	525
28.	Kathita	122/2	8780	14.00	5.0 / --	618
29.	Mutonga	122/1	4580	3.80	14 / --	504
30.	Kaanja	134/4	6214	0.55	24 / --	122
31.	Gathika	134/4	6409	0.61	25 / --	135
32.	Thika	134/4	6308	1.67	15 / --	221
33.	Gathika	134/4	6309	0.41	20 / --	72
34.	Ruarai	135/1	8535	0.90	23 / --	198
35.	Rutune	135/1	9429	3.40	20 / --	600
36.	Sara saba	135/3	9611	3.40	20 / --	600
37.	Kaanja	134/4	6513	0.60	15 / --	80
38.	Ruarai	135/1	8536	0.80	20 / --	141
39.	Gathika	134/4	6309	0.41	18 / --	66
40.	Kazita	122/2	8587	14.00	6.5 / --	618
41.	Maragwa	Mesco*		1.91	40 / --	675 (380)

Table 2.6.1 cont'd

42.	Jamji	Kericho	0.17**	18 / --	771
43.	Sagana	Sagana Falls*	1.10	37 / --	359 (240)
44.	Liki	Nanyuki	0.11**	26 / --	129
45.	Sosiani	Selby Falls*	0.04**	43 / --	- (360)
46.	Uaso Narok	Thomson Falls	0.40**	73 / --	643
47.	Nyangores	Mau Forest Falls*	4.5	14 / --	557 (320)
48.	Muani	Londiani	0.45**	100 / --	450
49.	Galana	Lugard Falls	1.42**	15 / --	219
50.	Gura	Above forest line	-	120 / --	257
51.	Gura	Sagana-Gura confluence	0.79**	20 / --	489
52.	Kimugung	Kerenga*	-	-	- (400)
53.	Chemogo	Chemosit*	-	-	- (90)
54.	Sondu	Sondu	0.45	90 / --	357
55.	Kapchura	Nandi	0.14	110 / --	136

Source: Extracts from Njau (1976), Ewbank (1979) and Finnconsult (1981)

* - Existing power station

** - Minimum flow

( ) - Installed Capacity

As given in table 2.6.1. the estimated MHP power potential of the identified sites in Kenya totals to 22,394kW. Of this, only 2,087kW (about 9.3%) has been harnessed. This list is however not exhaustive as some sites were left out on the basis of lack of sufficient population density near the potential MHP sites i.e. inadequate power demand, and lack of roads, which may not be the prevailing situation today - 16/18 years later.

Other potential sites were left out due to their proximity to the existing grid supply. Harnessing MHP sites that are close to the grid still remains a controversial issue as the social and economic benefits accrued from the development of micro hydro plants have sometimes been found to outweigh the fact that they are more expensive than grid extension. This is evident from Brooke Bond Company which is supplied by the national grid but has continued to run and expand her mini hydroelectric plants. Another good example is the Mau Forest Falls scheme (Tenwek Mission Hospital) which was developed against the finding that it would have been more economical to extend the grid supply (Finnconsult & Imatran, 1982).

Other MHP sites have not been accorded any meaningful attention because their power potential is below 50kW In other countries where MHP has been popularised plants of capacity as low as 10kW have been installed.

CHAPTER 3

DESIGN MODEL COMPONENTS

TECHNICAL DESIGN & FINANCIAL ANALYSIS

3.1 INTRODUCTION

This chapter discusses the main components of a MHP mainly in the areas of civil engineering, penstock design and electrical equipment. The design steps suggested and use of alternative materials whenever possible are all directed towards reducing the project cost. A guide to the choice of equipment to be used is given. A financial analysis of the designed plant is then carried out. A comparative analysis with an alternative source, in this case diesel, is done.

A load demand survey should be carried out in the feasibility study to assess the power demand in the area. It was not possible to come up with a mathematical model for predicting this given the available time and resources. Site visits should therefore be made to assess the potential demand in the area to be served by the MHP plant.

Some of the main factors considered in the assessment of household power demand include:-

i) Family income

ii) Preference that the consumer gives to electricity with respect to other needs e.g. food, clothing, transport

iii) Literacy level

iv) Awareness of the uses of electricity

v) Quality of housing.

Non-household use:-

i) Extent of local commerce

ii) Type and growth of local agriculture

iii) Development of local agro-industries

iv) Quality and extent of local infrastructure e.g. roads, railway, schools, water, health facilities

v) Any government plans for the area.

A study of the consumption of the fuel used in place of electricity e.g. kerosene, would give a good guideline for the prediction of the domestic power requirement. The growth in consumption must also be considered and it depends on the population growth and income level.

A good load estimation is necessary for the planning of the generation plant capacity and distribution system. These should be planned to serve an optimum period of time which depends on maintenance costs of the distribution system, annual load growth and the capital cost of the system. A period of ten years has been found (Mevon & Rao, 1986) to be acceptable on all counts.

3.2 MODEL DESCRIPTION

3.2.1 Site Hydrology and Geology

Separate hydrological and geological studies of the proposed site should be carried out as it is not covered in this study. Hydrological daily data taken for a period of 15 years or more should be used so as to come up with a good model. Kenya has quite a good number of gauging stations across the country and the data is available at the Ministry of Water Development. This data is used to assess the power and energy potential of a site and its seasonal variation throughout the year. It is also used in the design of civil works. The most cost-effective site is one with the highest head concentrated over a short distance.

The geological survey helps in assessing the best location for proposed civil works and in estimating their construction and future maintenance costs. Such a survey should aim at assessing the future surface movements, -marked by loose slopes, storm gullies, flood pla...- future sub-surface movements, -marked by land slides, layer faulting- and soil & rock types at the site.

3.2.2 Matching Power Demand and Supply

Opportunities to develop small hydro power plants are often found in remote rural areas where there is no grid supply This model is therefore designed for isolated operation.

The power potential at a hydro site is determined from the relationship

$$P = g \times H \times Q \times 0.46\text{kW} \quad \text{......} \quad 3.1$$

where

P - power (kW)

g - gravitational acceleration (m/s^2)

Q - average discharge flow rate (m^3/s)

H - gross head (m)

The constant 0.46 is the approximated efficiency of the whole scheme which includes 51% for the electromechanical equipment (Martinez, 1987) and 90% for the civil works i.e only about 46% of the power available at a hydro site gets to the consumer. It is therefore important to match the power requirement to the power supply. The power demand may vary seasonally during the year especially where it is put into some agriculture based productive use. For example a tea factory's demand is higher during the wet season when tea harvest is high. During the dry season, the harvest is low and hence the demand is also low. On the other hand, where there is irrigation pumping, the power demand is higher during the dry season than during wet season. The design should cater for the peak demand.

3.2.3 Civil Works

In this study, only a skeleton design of the civil works has been presented. To reduce on costs, the civil design should be as simple as is practically possible. The important data that has to be available include the flow duration curve for the potential site, gross head of water and the design discharge flow rate. There is a great variation in the design of intake, weir and power canal to suit a wide range of natural conditions. This study only gives a guideline to the design.

3.2.3.1 Intake location

For the small schemes considered in this study, it is recommended that a storage reservoir is not included unless it is extremely necessary. This is because a reservoir highly inflates the cost of the plant. Therefore only a simple diversion weir should be built across the river. In locating the intake care must be taken to find a position which is least likely to be a position of sediment deposition. The intake mouth should be placed some distance behind the weir to allow sediment and debris to build up downstream of the mouth. Other factors that should be considered include

* The nature of the stream bed
* Bends along the stream
* Natural features along the stream
* Competing uses for water
* Ease of accessibility.

Having identified the intake location, the data required for its design include the largest river flow rate (m^3/s) for each year recorded, length and height of weir crest (m).

3.2.3.2 Intake dimensions

The intake is dimensioned using the orifice discharge equation.

$$Q_{design} = A_i V_i \quad \text{......} \quad 3.2$$

$$V_i = C_d \sqrt{[2g(h_r - h_h)]} \quad \text{......} \quad 3.3$$

Where

Q_{design} - Design discharge flow rate

A_i - Area of the orifice which from fig. 3.2.1 (a) = d x w

V_i - Velocity of water passing through the intake orifice

C_d - Coefficient of discharge of the intake orifice

= 0.6 for sharp edged, roughly finished orifice

= 0.8 for a carefully finished aperture.

h_h - depth of water in the headrace channel

h_r - head of water in the river upstream of the weir under normal conditions.

In this study a rectangular shaped orifice has been adopted but other shapes may also be used and the same dimensioning procedure followed but making changes to suit the particular shape chosen. The velocity of water in the headrace channel must not be excessively fast as this erodes the channel while on the other hand it must not be too slow as this would result in silt deposition. The lower limit for silty water and water carrying fine sand is 0.3m/s and 0.3 - 0.5 m/s respectively while for clear water is 0.1 m/s. The upper limit of velocity depends on the type of canal used and table 3.2.1 gives the values for different types of canals.

Table 3.2.1.: Allowable maximum flow velocity to avoid erosion (m/s)

Material	Less than 0.3m deep	Less than 1m deep
Sandy loam	0.4	0.7
Loam	0.5	0.8
Clay loam	0.6	1.5
Clay	0.8	2.0
Masonry	1.5	2.0
Concrete	2.0	2.2

Source : Fraenkel P. et al (1991)

Wood and quality concrete have been found to withstand velocities of up to 4 m/s while for thin metal flumes the maximum is 2-3 m/s.

3.2.3.3 Worst Flood discharge flow

The useful life of large hydro civil works is between 50 and 60 years. Due to the very simple design and materials used in mini/micro hydro schemes, their life is reduced to about 35 years. Therefore to take care of flood discharges, civil structures should be designed to cope with the highest flood discharge predicted in the next 40 years. Very small schemes may be designed for a life of between 20-30 years. Gumbel distribution method of flood prediction is recommended because it is simple and easy to use. The description of this method is given in Appendix B. The flood discharge $Q_{(river\ flood)}$, is used to design suitable heights of intake barrier walls and wings.

The conditions at the intake during both normal and flood conditions are as shown in figure 3.2.1.(a), (b), (c).

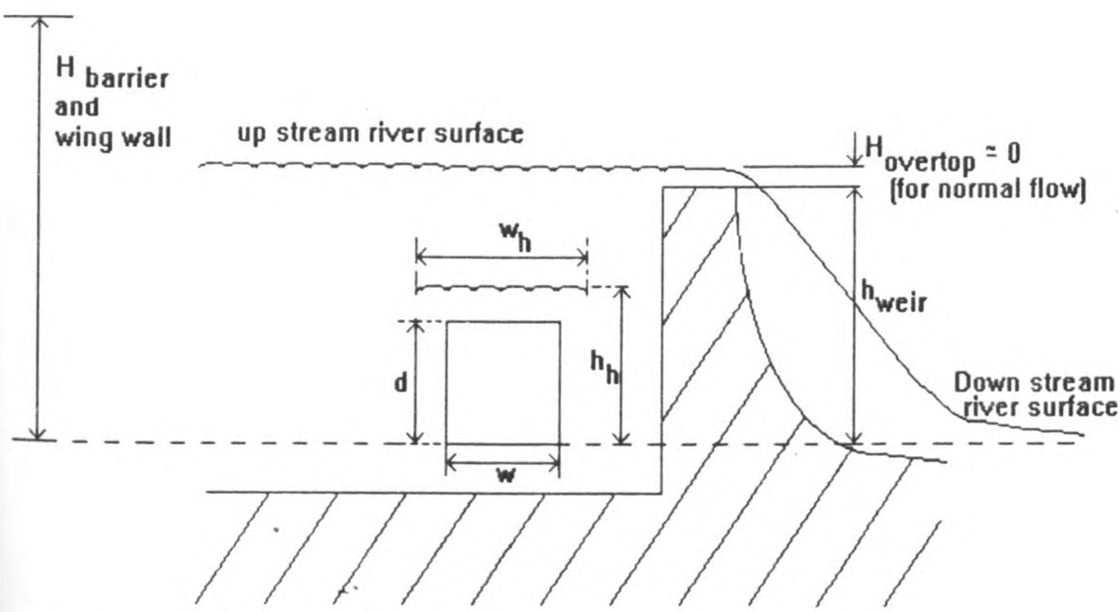


Fig. 3.2.1.(a) : River in section during normal flow

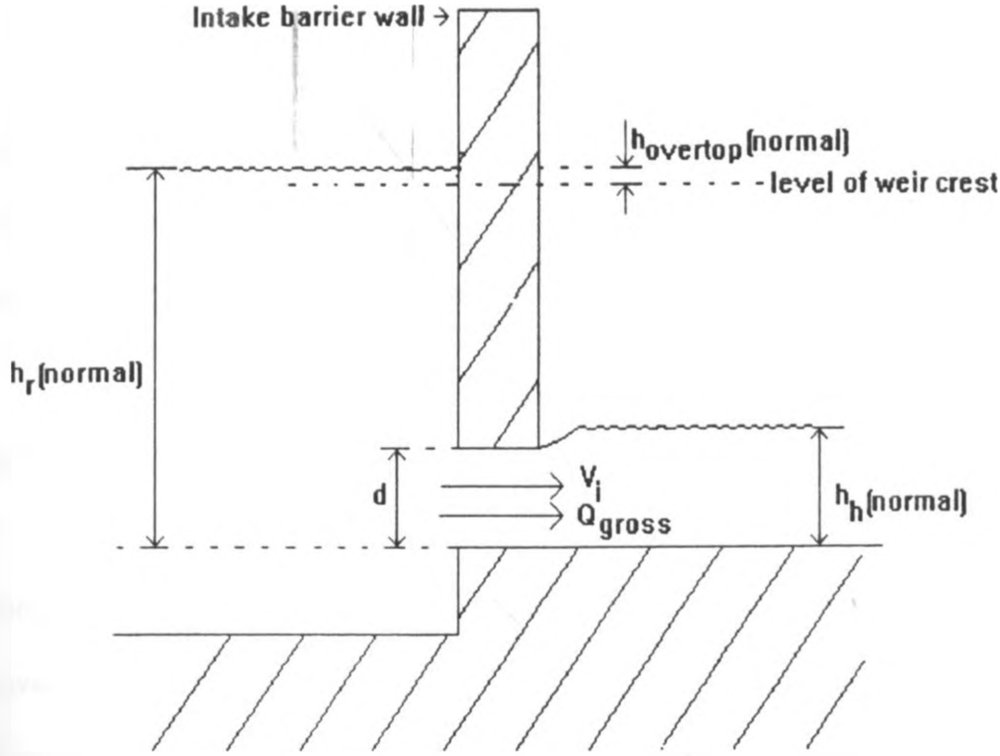


Fig.3.2.1.(b) : Side view section through the intake during normal flow

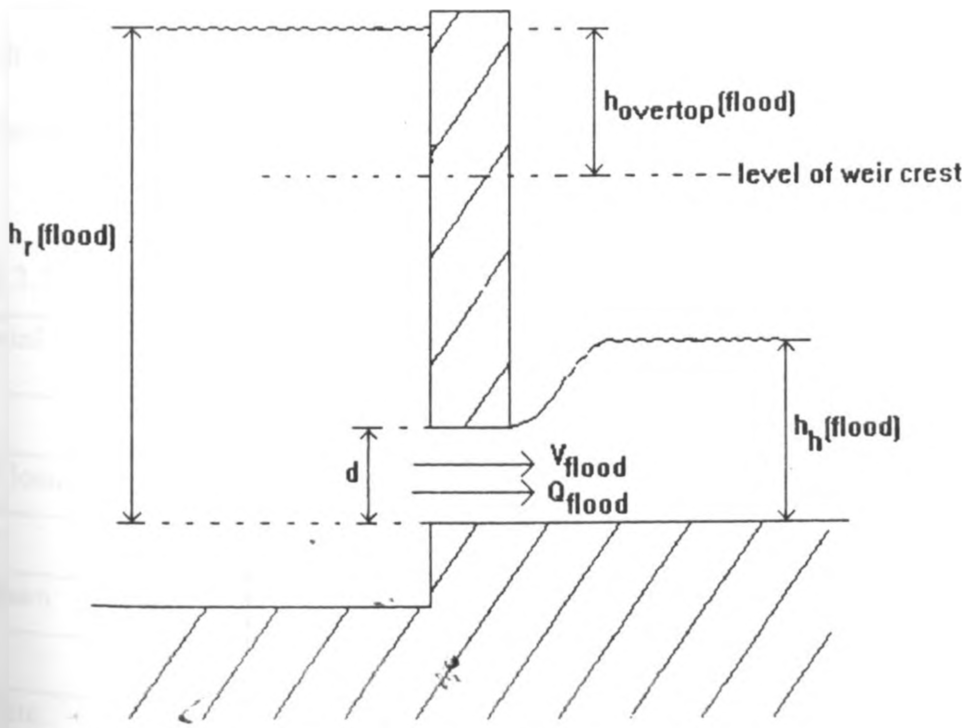


Fig. 3.2.1. (c) : River section during flood flow

3.2.3.4 Headrace channel slope and width

In most MHP schemes, the power canals are often unlined because of the cost savings that result. An appropriate velocity flow rate is chosen and the headrace must slope downwards sufficiently to maintain this velocity and the depth of water in the headrace h_h at the chosen value. The channel should very closely follow a contour line.

Optimizing channel dimensions

The material in which the canal is excavated or of which it is constructed dictates the cross-sectional profile. A semi-circular cross-section is the most efficient but it is impractical to excavate. It is therefore used with materials which lend themselves to this shape e.g. pre-fabricated concrete, sheet metal and wood stave sections.

A trapezoidal section is more practical and is the most commonly used. T' nature of the soil in which the canal is excavated determines the maximum side slope. Table 3.2.2. gives the recommended side slope angles for different channel materials.

Table 3.2.2.: Recommended side slope angles for trapezoidal channels

Material	Angle of inclination measured from the horizontal, 'α' (°)
Sand	18
Sandy loam	27
Loam	34
Clay loam	45
Clay	60
Concrete	60

Source : Fraenkel P. et al. (1991)

Rectangular cross-section is used where excavation is undertaken in firm rock. This study only looks at the trapezoidal cross section because it is hoped that earth canals will be used for the MHP schemes to reduce costs. The canal dimensions are as shown in figure 3 2.2.

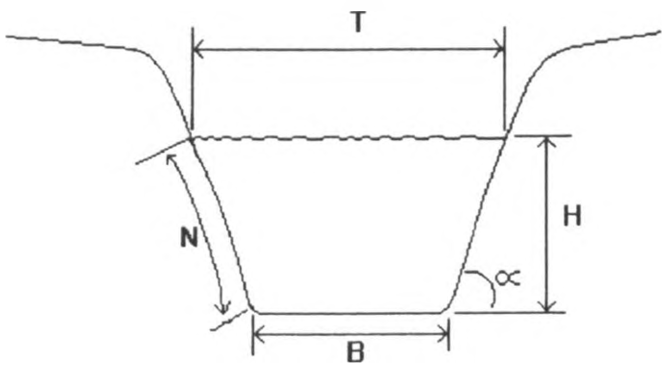


Fig 3 2.2 : Canal dimensions

In optimizing the channel design, a compromise between channel head loss and channel size has to be struck: The hydraulic radius gives a measure of channel efficiency and the higher the radius, the more efficient the channel is. The hydraulic radius is given by

$$r = 0.5\sqrt{\frac{A\sin\alpha}{2-\cos\alpha}} \qquad \text{3.4}$$

where

α - side slope angle measured from the horizontal

A - wetted cross-sectional area given by

$$A = Q / V \qquad \text{3.5}$$

3.2.4 Penstock

The penstock, being more expensive than an open channel, should be kept as short as possible. It must be strong enough to withstand surge pressure which results from sudden shut down. The penstock pipe must also not collapse inwards at times of negative pressure. A design for the worst positive surge is sufficient for both positive and negative surges. A safety factor of between 2 - 3 is adopted.

3.2.4.1 Penstock Material

The factors that determine the material to be used for a particular project include

* Surface roughness
* Design pressure
* Weight and ease in handling and accessibility of the site
* Nature of terrain to be traversed
* Expected life and maintenance requirements
* Local availability of pipe
* Relative cost
* Likelihood of structural damage
* Method of jointing
* Effect of water quality, climate, soil and possible tampering on the pipe

If the materials used for penstock, this study recommends the use of either poly vinyl chloride (PVC) or mild steel because both are locally available and are relatively cheap. It is also commended that except where the terrain to be traversed is rough and rocky or where the pe is exposed to destruction by either human beings or wildlife, PVC pipes be used where pressure rating allows. High density PVC has been used for heads upto 150m. However, PVC pipes must be protected from ultraviolet (UV) radiation primarily from sunlight which kes it deteriorate fast. This may be done by either burying the pipe, covering with foliage or ting.

3.2.4.2 Penstock sizing

3.2.4.2.1 Choosing penstock diameter.

Selecting penstock diameter is a trade-off between higher costs for larger diameter and higher frictional loss for smaller diameters. The acceptable diameter is one that results in losses between 2 - 10% and 5 % loss is a good balance.

3.2.4.2.2 Choosing Penstock Thickness

If mild steel is used for penstock material, a safety factor of 2 can be used. For PVC penstocks it is recommended that a safety factor of 3 be adhered to due to the fact that it is weaker and is bound to deteriorate due to UV radiation even when protected from direct exposure.

The young's modulus of elasticity E, and the ultimate tensile strength σ_T for the material must be known. A manufacturer's list giving the available thicknesses and corresponding internal diameters is also necessary.

3.2.5 Choice of Turbine.

For MHP schemes, the developer only need to give the necessary specifications and the turbine manufacturer/dealer is relied on to select the most appropriate components and ensure their compatibility as a part of a complete turbine-generator package. The selection of the best turbine for a particular hydro site depends on site characteristics the dominant ones being head and the available flow. Other necessary information include maximum output power needed, water quality, type of governing device required, required speed, altitude of powerhouse site and penstock diameter.

Turbines may be classified in two broad categories as either

1. Impulse turbines

In this type of turbine, the pressure energy in water is first converted to kinetic energy in the form of a high speed jet of water emerging from a nozzle. The water jet strikes the runner imparting its momentum to the surface it strikes and then drops into the tail water at atmospheric pressure.

These are generally more suitable for MHP applications because of the following advantages over reaction turbines.

i) They are easier to fabricate and maintain

ii) They are not subject to cavitation

iii) They have better access to working parts

iv) They have no pressure seals around the shaft

v) They have greater tolerance of sand and other particles in the water

vi) They have better part-load efficiency.

However, they are mostly unsuitable for low head sites because of their low specific speeds. The turbines that fall in this class are pelton, turgo and crossflow.

2. Reaction turbines

Water pressure exerts a force directly on the surface of the runner which imparts energy on it causing a corresponding energy or pressure drop in the water as it goes through the runner. Water leaves the distributor with energy in the form of both kinetic and pressure. Turbines in this class are francis, propeller and kaplan.

The actual type of turbine used is determined by the specific speed N_s, and the part load efficiency of the turbine if the demand is variable. The specific speed is given by

$$N_s = \frac{N_a}{G} \times \frac{\sqrt{(1.4 \times P_0)}}{H^{1.25}} \qquad 3.6$$

N_a - generator speed (rpm)

G - gearing ratio. Where there is direct coupling G = 1

P_o - Maximum Turbine output power (kW)

H - Head (m)

Whenever possible, direct coupling is recommended to avoid complexity and losses.

Table 3.2.3. : Specific speed for different types of turbines.

Type of turbine	*Specific speed (metric)*
Impulse	
1 - Jet pelton	10-35
2 - Jet pelton	10-45
3 - Jet pelton	10-55
4 - Jet pelton	10-70
6 - Jet pelton	10-80
Turgo	20-80
Crossflow	20-90
Reaction	
Francis	70-500
Kaplan	350-1100
Propeller	600-900

Source : Fraenkel et al. (1991)

Despite the complexity, higher cost and poor part load efficiency of the francis turbine, it is often a popular choice due to the fact that it is the only turbine suitable within a certain range of specific speeds.

For turbines smaller than 100 kW, fixed pitch propeller turbines for low head, cross-flow or turgo wheel turbines for medium head and multi-jet pelton wheels for high head are recommended (Holland, 1983) all either direct or belt drive coupled to the generator.

3.2.6 Choice of Governor

The frequency of the voltage generated by a synchronous generator depends on the rotor speed and the number of poles, the latter being fixed at machine construction. The speed is therefore the only variable parameter that affects the frequency and is directly proportional to it. Changes in frequency may cause damage to electrical appliances connected to the supply. For example, when frequency is too low, motor and transformer losses increase.

This study recommends the use of an ELC for plants of capacity less than 200kW except for cases where a storage reservoir is found to be extremely necessary, in which case a speed governor may be used. This allows the use of simpler turbine design and avoids the use of complex mechanical governors. Since an earlier suggestion of run-of-river schemes has been made, the fact that water is wasted to generate power supplied to the ballast becomes irrelevant as there is no provision for storage.

A deviation of ± 1% of the rated frequency is allowed by the Kenya Power & Lightning Company and has been adopted in this study.

3.2.7 Electrical Design

3.2.7.1 Supply system - AC or DC

In Kenya the grid supply system is AC. This study has been carried out with the background intentions of connecting the MHP plants to the grid once it has been sufficiently extended to the rural areas. Coupled with this, most of the electrical appliances in the Kenyan market require an AC supply. With these two dominating factors an AC system has been chosen for the MHP plants. DC generation may be used only where the plant is for battery charging - very common in Sri Lanka- which has not been discussed in this study.

3.2.7.2 Single phase or three-phase

Harvey (1993) gives an approximate rule of, systems up to 10 kW may be single phase while those over 5kW may be three phase. Three-phase generation has been recommended in this study for plants rated more than 10kW and 1-phase for smaller plants for the following reasons.

* Attaining a balance in all the three phases would be difficult at low power rating hence the use of 1-phase below 10kW.
* 3-phase generators and motors are more common, cheaper and smaller than their 1-phase equivalents.
* A 3-phase system delivers power more efficiently and the transmission line is cheaper per unit of power delivered.

This distinct grouping between 3-phase and 1-phase generation has been used by ITDG (Holland, 1996) in several countries all over the world.

3.2.7.3 Generator

Since Kenya does not manufacture her own generators, it is recommended that standard ones are used instead of custom built to suit a particular hydro site. This has the advantages of ready availability, costs less than a special made unit and spare parts can be easily found. The generator used can either be induction or synchronous type. Whatever choice of generator is made, the 3-phase and 1-phase generation voltage should be 415V and 240 V respectively at a frequency of 50Hz, these being the national standard values. In this study, induction generators have been recommended for use where they cost less than synchronous generators, both single phase and three phase, which is generally upto 25kW (Smith, 1994).

3.2.7.3.1 Synchronous generator

A synchronous generator with a revolving field and stationary armature is preferable due to the fact that it is more advantageous to have the more complex part being stationary. It is also easier with this arrangement to protect and insulate the stationary armature leads which carry current at high potential.

The self-excited generator makes a better choice and is recommended. The static excitation system has the advantage that it has no rotating parts and therefore requires less maintenance. They also have fast current response which contributes to improved transient stability. These have been used in MHP plants throughout Sri Lanka, Indonesia, Peru and Nepal (Holland, 1996). The DC power requirement of the field is generally much less than the machine rating and is typically less than 1%.

The generator speed, frequency and the number of poles are related by the following relationship.

$$f = \frac{np}{120}$$

where f - frequency (Hz)

n - generator speed (rpm)

p - Number of poles.

From this it can be observed that

$$p = 120f / n$$

Hydro generators are normally driven at low speed and hence the number of poles is high. They therefore have salient poles.

Voltage regulation

The machine terminal voltage changes as the load current varies. It is important that terminal voltage is maintained at the rated value because under-voltage and over-voltage have adverse effects on different electrical equipment connected to the system. An automatic voltage regulator (AVR) is used for the purpose of maintaining the terminal voltage very nearly equal to the rated value. This adjusts the field current of the generator accordingly thus bringing the terminal voltage back to the rated value.

AVRs designed for use with diesel generators which have lighter duty cycles tend to be highly unreliable when used with MHP installations which operate continuously (Fraenkel, 1991). The life of the AVR can be prolonged by removing the AVR from the generator and repositioning it to a neighbouring wall where there is less temperature variation and mechanical vibration.

3.2.7.3.2 *Induction Generator (IG)*

The induction generator is only used where it gives a cost benefit over the synchronous generator which generally tends to be up to about 25 kW. This must however be confirmed from the market.

The squirrel cage type is the most common and the simplest form and should always be selected because it is less expensive and more robust than the wound rotor type (Smith, 1994). For the plants under study that have been designed for isolated operation, excitation capacitors are a requirement. Harvey (1993) recommends a star connected generator with delta connected excitation capacitors (figure 3.2.3.) for a three phase supply because this arrangement requires less capacitance values.

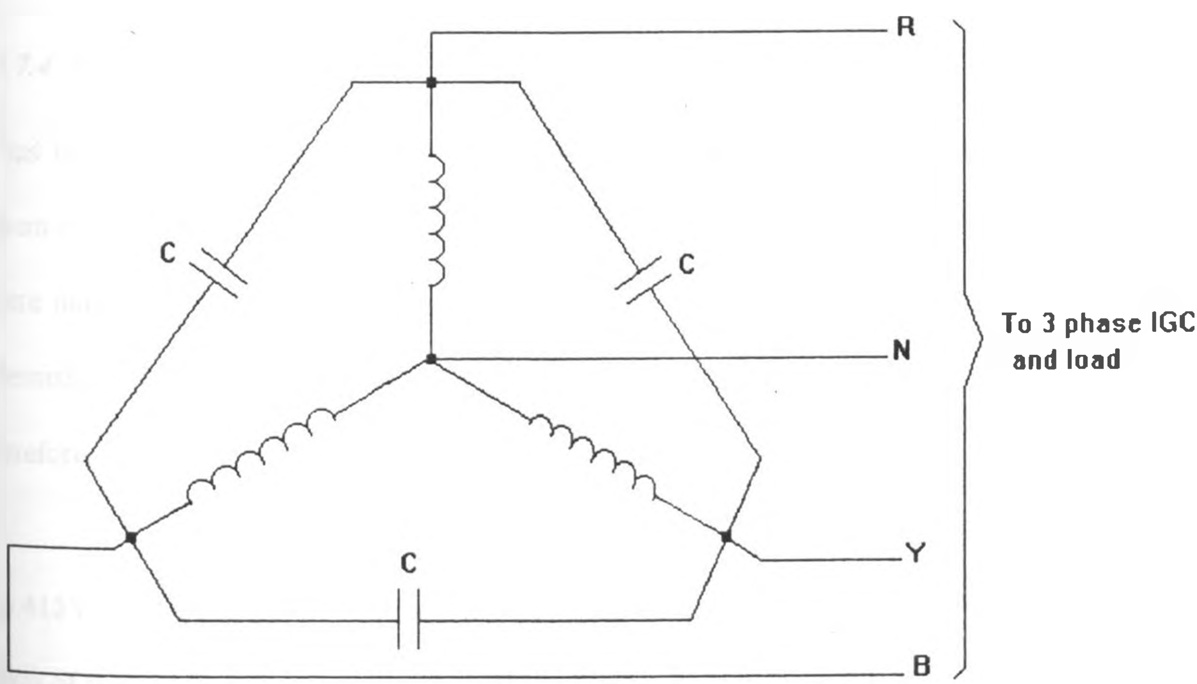


Fig. 3.2.3. A star connected IG with delta connected excitation capacitors

Single phase induction generators are not manufactured in sizes above 2 kW and they are more expensive than three phase motors. Single phase output may be obtained from a three-phase machine by using the 'C-2C' connection shown in figure 3.2.4. The unbalanced arrangement of capacitance helps to compensate for the unbalanced load on the generator. The value of 'C' calculated is that required for normal 3-phase 240V delta operation.

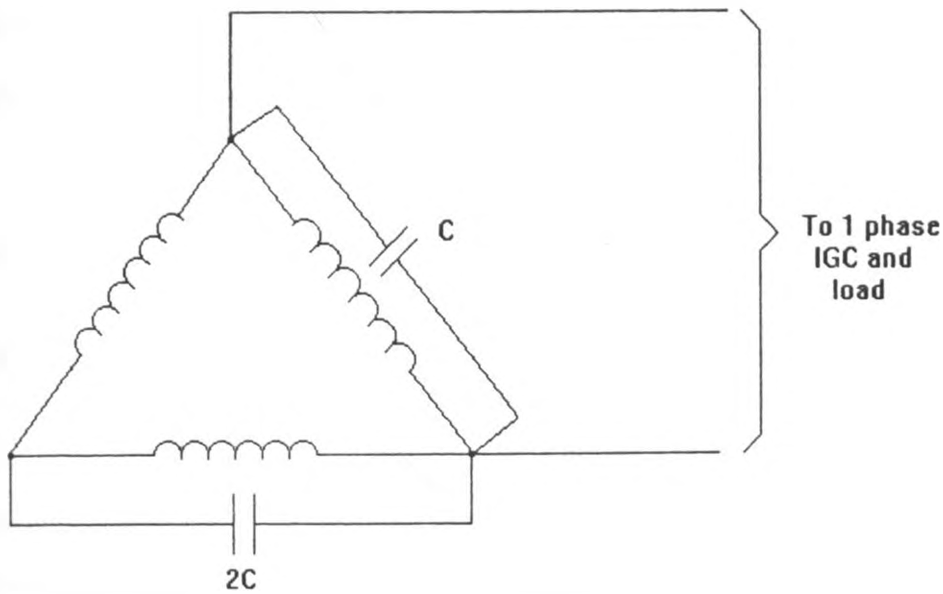


Fig. 3.2.4.: Single phase supply system using the 'C-2C' arrangement

3.2.7.4 Transformer

It has been found that (Walkade, 1986) to transmit power up to 10 kW, the distribution system required can use secondary voltage circuits so as to keep the unit cost low. The load centre must be within 1km of the generation station to limit the voltage drop. Sites with a potential of this size will most likely not be feasible if the load centre is more than 1km away. Therefore, for all the single phase units no transformer is required.

The 415V system voltage may be used for supplying loads not exceeding 40 kW in total within 0.8km of the generating station (Taylor, 1969). For loads exceeding this capacity and distance the voltage may be stepped up to 11kV or 33kV which are the standard voltage levels used in Kenya. For the purposes of this study, the 11kV system is considered to be adequate. Taylor (1969) recommends this voltage level for loads less than 5MW over distances of up to 8km.

In a study carried out in Malaysia (Shanker & Krause, 1992), the allowable distance between a micro hydro station and the load, and the associated voltage drops for various values of power transmitted on an 11kV system were found to be as given in table 3.2.4. These values have to be confirmed on a case by case basis.

Table 3.2.4. : Maximum allowable distance of transmission for various amounts of power at 11 kV.

Peak Load (kW)	Voltage drop (V) / km	Maximum distance (km)
500	40	22
350	28	16
200	16	11
100	8	7
50	4	4

Source: Shanker & Krause (1992)

A delta-star (LV/HV) connected transformer is the most suitable because it allows for the circulation of currents in the delta circuit in case of load imbalance.

In specifying the transformer rating, the power capacity is given in KVA. This must be capable of handling the rated generator output and its allowable overload. As much as possible, a standard rating should be chosen. The voltage rating required is 0.415/11kV.

3.2.8 Protection Scheme

A comprehensive protection scheme has been designed for both the generator and transformer because if any of the two units is damaged, this would cost a great deal both in financial terms and the inconvenience caused to the consumers.

3.2.8.1 Generator protection

1. Rotor earth fault (E/F) protection

The DC injection method is recommended for this fault protection with connections as shown in figure 3.2.5.

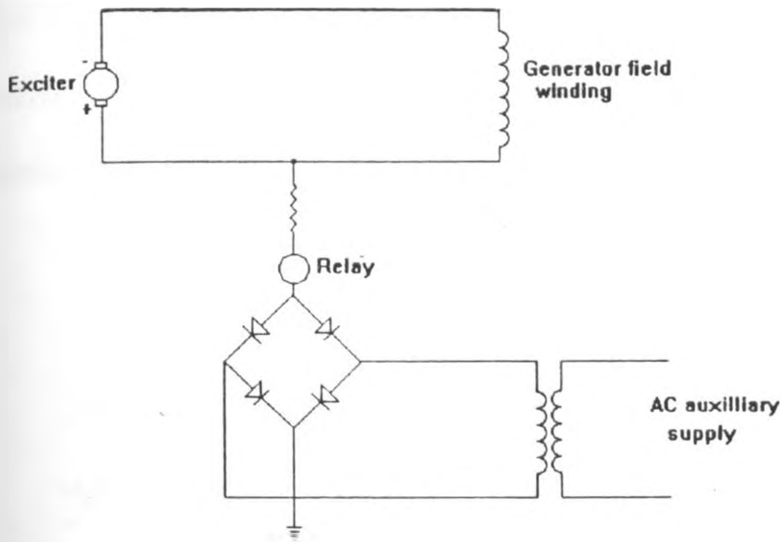


Fig 3.2.5 : Rotor E/F Protection

The field is biased by a d.c. voltage which causes current to flow through the relay for an earth fault anywhere on the field circuit.

2. Field Failure

This is a very rare occurrence (Mehta , 1982) and it cannot cause immediate damage to the machine. The station attendant can be relied on to disconnect the machine manually in case of failure.

3. Unbalanced stator currents

A negative sequence relay is connected in the stator circuit to detect imbalances which may be due to

i) Open-circuiting of one phase of a line or failure of one contact of a circuit breaker.

ii) Unbalanced fault near the station which is not cleared promptly.

iii) A fault in the stator winding.

These faults are protected by other relays and so the inclusion of the negative sequence relay is optional. The flow of unbalanced currents causes heating of the stator. The heating time constant of the machine is expressed by a rating equation.

$$K = I_2^2 t$$

K - Constant which depends on the method of stator cooling

I_2 - Negative sequence current in per unit based on the continuous maximum rating

t - Current duration in seconds.

The protective relay should have a time current characteristic ($I_2^2 t = K$) that closely matches that of the machine to avoid unnecessary disconnection.

When an induction generator is used, a derating factor is applied to allow for load imbalance. However, to protect against severe overload on a phase, miniature circuit breakers (MCBs) rated for 1.5 times the rated full load generator output can be used (Smith, 1994).

4. Overload protection

Sets below 30 MW are usually provided with a thermal relay that detects overheating of the stator windings (Ravindranath & Chander 1977; Wadhwa, 1983). Thus no extra protection is required.

The excitation of the induction generator collapses when the machine is overloaded thus limiting the winding currents to safe values.

5. Prime mover protection

In case of prime mover failure, the generator starts motoring and draws power from the system. For the purposes of this study where the plants have been designed for isolated operation, the question of reverse power flow does not arise. However, protection may be achieved by providing mechanical devices to disconnect the generator when the water flow drops to an insufficient rate

6. Overvoltage/Overspeed protection

An overvoltage may result due to

(a) A faulty voltage regulation system

(b) Sudden loss of generator load with consequent overspeed.

An overvoltage relay is used for the protection against these fault conditions. It has two units; an instantaneous unit (inserts resistance in the exciter field circuit) set to operate at 140% of the rated voltage value and an inverse time unit (if the overvoltage persists, it shuts down the generator) with a pick-up setting of 110% (Warrington, 1968, Wadhwa, 1983). The relay must be compensated for frequency and energised from an unregulated voltage supply.

On loss of load, an induction generator draws current from the capacitors hence increasing the winding current above the rated value. To protect the capacitors and the windings against damage, a three-pole MCB should be fitted in series with the capacitors. Its current rating should be between 1.2 and 1.5 times the capacitor current under normal conditions (Smith, 1994). Magnetic MCBs are preferable to thermal ones because they are more accurate and are unaffected by temperature variations.

3.2.8.2 Generator - Transformer Protection

Whenever a transformer is used, it is recommended that the generator and transformer units are directly connected so that the two are protected as one unit by a biased differential protection scheme. This has been chosen because it is cheaper to protect the two as one unit and biased differential protection is more reliable than simple differential relay during through faults. This scheme detects phase-to-earth faults and the arrangement is as shown in figure 3.2.6.

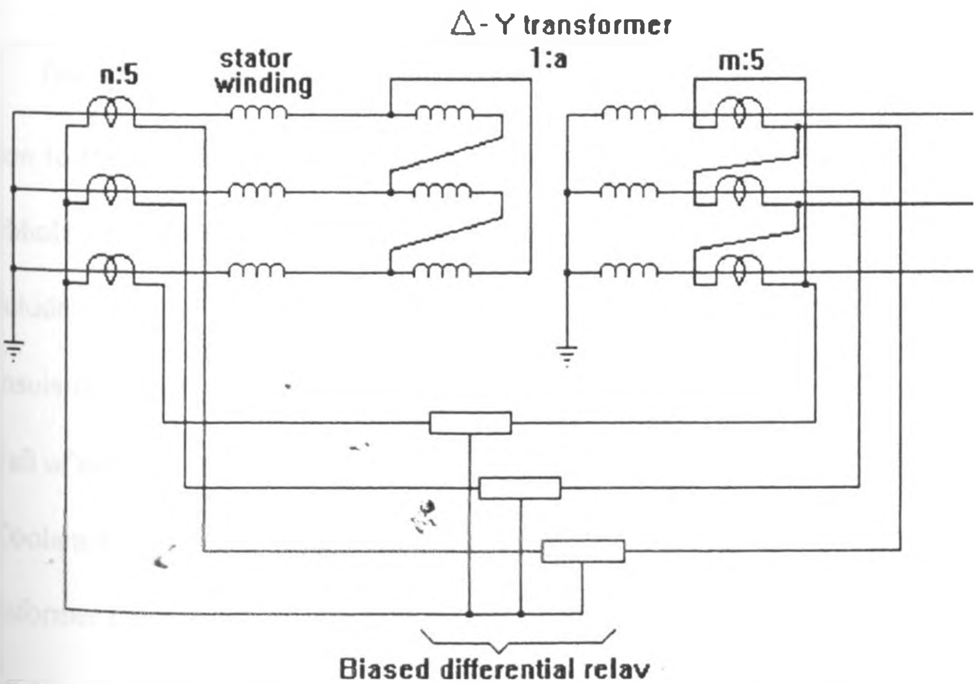


Fig. 3.2.6. : Biased differential protection for the generator-transformer unit

CTs on the delta side of the transformer are connected in star while those on the star side are connected in delta. This is to counter the 30° phase shift of currents in a Δ-Y transformer. This connection also eliminates zero sequence component of current on the wye side which might otherwise upset stability due to lack of corresponding component on the delta side and thus prevent tripping on an external fault on the wye side (Warrington, 1968). Alternatively, interposing CTs may be used to correct the phase shift.

No appreciable magnetizing in-rush current is produced when the transformer is magnetised near a voltage zero and therefore harmonic restraint is not necessary.

Typical values of bias are 10 to 40% and pick-up setting of 50-100%. A pick-up setting of 20% and 20% bias has been found to be satisfactory (Rushton 1986, Ravindranath & Chander, 1977).

3.2.8.3 Transformer protection

In addition to the biased differential protection, the transformer has other protection schemes. The Buchholz relay is recommended for the detection of incipient faults.

These include:-

(a) Insulation failure of windings

(b) Fall of oil level due to leakage

(c) Coolant failure which causes temperature rise.

The transformer must have a conservator for this relay to be fitted.

3.2.9 Switchgear

Circuit breaker rating

It is recommended that a CB be located after the transformer just before the bus-bar and immediately after the bus-bar on each feeder as shown in figure 3.2.7.

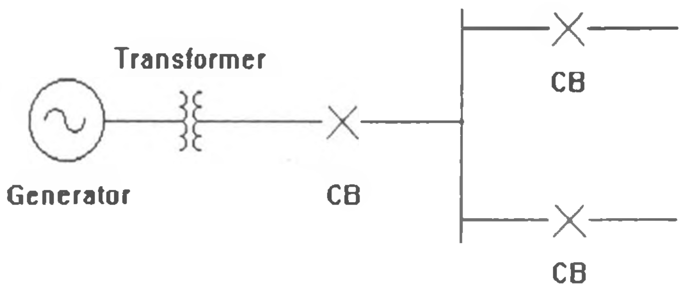


Fig. 3.2.7.:Circuit breaker locations

The following CB ratings must be given in specifying the required breaker.

(i) Breaking capacity

This is the rms current that the breaker is capable of interrupting at a given recovery voltage

The symmetrical breaking current is used to calculate the KVA rating.

$$KVA_{sc} = \sqrt{3} I_{sc} kV_{L-L}$$

$$KVA_{sc} = \frac{KVA_{base}}{Z_{pu}}$$

where I_{sc} = symmetrical short circuit current

KV_{L-L} = Line-line voltage

KVA_{base} = Base KVA

Z_{pu} = per unit impedance

(ii) Making Capacity

This is the peak value of current during the first cycle of current wave after the closure of CB contacts.

Rated making capacity $= 1\ 8 \times \sqrt{2} \times I_f$

$= 2.55 \times I_f$.

The factor 1.8 accounts for the asymmetry present in the short circuit current.

$I_f =$ rated breaking current (rms)

(iii) Short-time rating

This defines the time for which the CB is able to carry fault current without damage while remaining closed. The rating is based on thermal limitations and the breaker's ability to withstand the electromagnetic force effects.

(iv) Normal current rating.

RMS value of current that the CB can carry continuously at rated frequency under specified conditions.

Since the maximum system voltage will be 11kV either air or oil break type of CB may be used.

3.3 TECHNICAL DESIGN

3.3.1 Matching Demand and Supply

Whenever conditions allow, the choice of turbine and generator made should be one which can provide the peak power demand predicted in the load survey. The discharge flow rate required to generate this power is calculated from equation 3.1 as

$$Q_{calc} = \frac{P}{g \times H \times 0.46} \text{ m}^3/\text{s} \qquad \text{3.7}$$

P is the maximum demand predicted in the load survey.

If this flow is less than the minimum river flow rate, then the plant can supply the required power throughout the year. The design discharge (Q_{design}) will be equal to the value calculated (Q_{calc}) in 3.7 above. On the other hand, if Q_{calc} is more than the minimum river flow, then the demand cannot be met all the year round and some load management measures have to be taken to suit the power supply pattern. In such circumstances, a design discharge corresponding to 70% exceedance (Q_{70}), which has been used in India (Kedia, 1986), has been adopted in this model. However, if Q_{calc} is less than Q_{70} i.e. the percentage exceedance of Q_{calc} is more than 70%, then the value of Q_{calc} becomes the design discharge. A turbine with adjustable blades is recommended for such cases so as to give a reasonable part load efficiency.

3.3.2 Civil Works

3.3.2.1 Intake dimensions

The procedure followed for dimensioning the intake orifice is iterative adjusting various factors so as to achieve a suitable flow velocity.

The data required includes depth of water upstream of the weir h_r and design discharge flow rate, Q_{design}.

Steps for determining orifice dimensions

1. Choose a value for the depth of water in the headrace channel, $h_{h(normal)}$, e.g. $h_h = d$

2. Under normal conditions $h_{overtop} \approx 0$

   $h_{r(normal)} = h_{weir} + h_{overtop}$

   $\Rightarrow h_{weir} = h_{r(normal)}$

3. Calculate the velocity of water through the orifice using equation 3.3

   $V_i = C_d \sqrt{[2g(h_r - h_h)]}$

   If the value of velocity is outside the set limits, adjust the most appropriate factor and repeat steps 1 to 3.

4. Calculate the value of the width of the intake orifice from equation 3.2

   $Q = d \times w \times V_i$

   $$w = \frac{Q}{d \times V_i}$$

The velocity may be altered by

(a) Adjusting the weir crest height, h_{weir}. Increasing this value while holding all other parameters constant increases the velocity while reducing it has the opposite effect.

(b) Adjusting the depth of water in the headrace, h_h. Increasing this height reduces the velocity while reducing it results in a faster flow.

(c) Adjusting the intake position from the river-bed so as to adjust the head of water in the river upstream of the weir, h_r. Reducing h_r by raising the intake position results in a lower flow velocity while lowering it has the opposite effect.

The choice of the factor to be altered depends on the economics involved and the seasonal variation of the river flow.

3.3.2.2 *Height of flood barrier and wing walls*

The value of predicted flood flow rate is used to calculate the flood level, $h_{overtop}$, during worst flood. The standard weir equation is used i.e.

$$Q_{river\,(flood)} = C_w \times L_{weir} \times (h_{over\,top})^{1.5} \quad \text{.......................................} \quad 3.8$$

where

$Q_{river\,(flood)}$ - river flow during worst flood (m^3/s)

C_w - Coefficient of discharge which depends on the weir crest profile. Values for different profiles are given in table 3.3.1.

L_{weir} - weir crest length (m)

$h_{overtop}$ - flood level to be calculated.

From equation 3.8

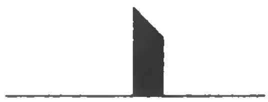
$$h_{overtop} = \left[\frac{Q_{river(flood)}}{C_w L_{weir}}\right]^{0.667} \quad \text{.......................................} \quad 3.9$$

As can be observed from this relationship, $h_{over\text{-}top}$ is inversely proportional to the length of the weir crest. It is therefore advisable to choose a high value of weir crest length.

The height of the barrier wall should be 0.5m higher than the predicted flood level.

$$h_{barrier} = (h_{weir} + h_{overtop} + 0.5)\ m \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ 3.10$$

Table 3.3.1. : Coefficient of discharge C_w for different weir profiles.

Profile of crest of weir		c_w	Profile of crest of weir		c_w
	broad; sharp edges	1.5		sharp-edged	1.9
	broad; round edges	1.6		rounded	2.2
	round overfall	2.1		roof-shaped	2.3

Source : Harvey (1993)

3.3.2.3 *Headrace channel slope and dimensions*

Steps for calculating channel dimensions

Decide upon the length of the channel L and have a record of rated channel flow Q.

Choose a suitable velocity that is within the limits for the particular type of channel.

Deduce the value of wetted area from equation 3.5.

From table 3.2.2. choose the most efficient side slope angle 'α' and calculate the hydraulic radius using equation 3.4. If the angle is not practically achievable, choose a suitable value.

Estimate the value of manning's roughness coefficient 'n' from table 3.3.2. then calculate the slope using Manning's equation.

$$S = [\, n\, V / r^{2/3}]^2 \quad \text{.......................................} \quad 3.11$$

If this slope is not practically achievable, give the maximum slope attainable, SFIX, and calculate the hydraulic radius using the equation

$$r = 0.46 \times \frac{Q_{des}^{0.38}}{SFIX^{0.19}}$$

6. Determine the channel headloss ; HL = L x S.

   If the headloss is more than 5%, repeat steps 2 to 5 using a lower value of velocity. If on the other hand this loss is too small, increase the velocity - which results in a smaller channel size - and repeat steps 2 to 5.

7. Calculate the channel dimensions as shown in figure 3.2.2 from the following:-

   wetted height H = 2 r.

   wetted top width T = 4 r/sinα

   Bottom width B = T - 2H/tanα

8. Find the channel width and depth by multiplying T and H by the freeboard allowance F (usually 1.2) which ensures that the channel does not overspill when carrying a flow in excess of the design discharge flow.

Table 3.3.2. : Manning's Roughness Coefficient 'n'.

Earth canals	
Clay	0.0130
Solid material, smooth	0.0167
Sand with some clay or broken rock	0.0200
Bottom of sand & gravel, with paved slopes	0.0213
Fine gravel, 10 - 30mm	0.0222
Medium gravel, 20 - 60mm	0.0250
Coarse gravel, 50 - 150mm	0.0286
Cloddy loam	0.0333

Lined with coarse stones	0.0370
Sand, loam or gravel, strongly overgrown	0.0455
Rock canals	
Medium coarse rock muck	0.0370
Rock muck from careful blasting	0.0455
Very coarse rock muck, great irregularities	0.0588
Masonry canals	
Brickwork, bricks, also clinker, well pointed	0.0125
Ashlars	0.0133
Thorough rubble masonry	0.0143
Normal masonry	0.0167
Normal (good) rubble masonry, hewn stones	0.0167
Coarse rubble masonry, stones roughly hewn	0.0200
Rubble walls, paved slopes, sand and gravel bed	0.0213
Wooden channels	
Planed, well-joined boards	0.0111
Unplaned boards	0.0125
Older wooden channels	0.0149
Natural water courses	
Natural river bed, solid and no irregularities	0.0244
Natural river bed, weedy	0.0313
Natural river bed with rubble and irregularities	0.0333
Torrent with coarse rubble (head-sized stones), bed load at rest	0.0385
Torrent with coarse rubble, bed load in motion	0.0500

Extracted from Fraenkel et al. (1991)

3.3.2.4 Headrace flood flow

Flood conditions increase the flow in the headrace and hence the need for a spillway to get rid of the excess discharge flow To determine the depth of water in the headrace during a flood ($h_{h(flood)}$), several guesses of this value must be made and each time calculating the flood discharge rate in the channel using both

Discharge orifice equation

$$Q_{flood} = d \times w \times C_d \sqrt{[2 g (h_{r(flood)} - h_{h(flood)})]} \quad \text{.......... 3.12}$$

and

Manning's equation

$$Q_{flood} = h_{h(flood)} \times T \times \frac{\sqrt{S}}{n}\left[\frac{T \times h_{h(flood)}}{T + 2h_{h(flood)}}\right]^{0.667} \quad \text{.......... 3.13}$$

The correct value of $h_{h\ (flood)}$ is the one that gives approximately the same result for both equations 3.12 and 3.13.

It can be concluded that

i) The wall height upstream of the spillway must be slightly more than $h_{h(flood)}$.

ii) The spillway must be capable of removing an excess flow of $Q_{flood} - Q_{design}$.

3.3.3 Penstock sizing

3.3.3.1 Choosing penstock diameter.

The procedure is iterative beginning with a first estimate for the penstock internal diameter chosen from the available choices from manufacturer's list.

The data required include penstock length (L), design discharge flow rate (Q_{design}), gross head (H_{gross}) and the number of bends along the penstock profile, n.

Steps for determining penstock diameter

1. Estimate penstock diameter, D, in metres
2. Calculate the velocity of flow in the penstock using

$$V = \frac{4Q_{design}}{\pi D^2}$$

3. Determine the frictional headloss

   a.) If a pipe manufacturer's friction loss chart is available, read h_f.

   b.) If the chart is not available

   (i) calculate Reynold's number Re = V x D x 10^6

   (ii) Find the ratio ε = k/D where k is the equivalent grain size and values for different materials are given in table 3.3.3.

   (iv) Deduce the friction factor f from moody's chart fig. 3.3.1.

   (v) Calculate the frictional headloss

$$h_f = \frac{2V^2 Lf}{gD}$$

4. Deduce the headloss coefficients for each of the bends from table 3.3.4.

   Turbulence headloss

$$h_t = \frac{V^2}{2g}\sum_{i=1}^{n} K_i$$

where n - total number of bends

K_i - head loss coefficient for the i^{th} bend.

5. Determine the percentage headloss

$$\%HL = \frac{h_f + h_t}{H_{gross}} \times 100$$

(i) If this value is more than 10%, increase the diameter size and repeat steps 2 to 5.

(ii) If the value is less than 2%, reduce the diameter and repeat steps 2 to 5.

Table 3.3.3. : Roughness values, k mm for different materials.

Material	k mm
Smooth pipe PVC	 0.01
Concrete	0.15
Mild steel Uncoated Galvanised	 0.10 0.15
Cast iron New Old - Slight corrosion Moderate corrosion Severe corrosion	 0.30 1.50 3.00 10 0

Source : Harvey (1993)

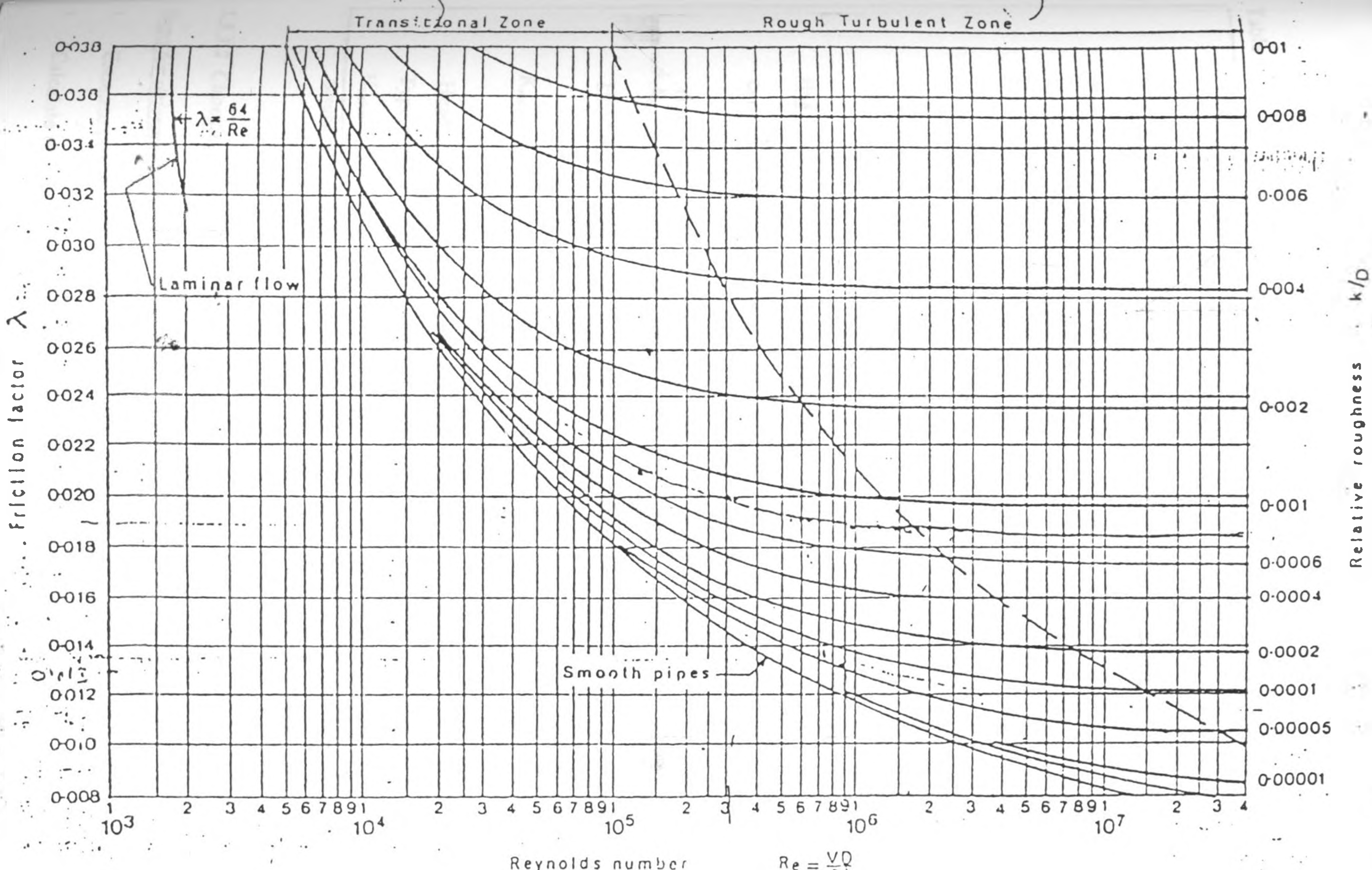
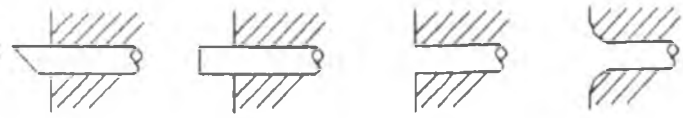


Figure 3.3.1 Moody diagram

Table 3.3.4. : Turbulence Headloss Coefficients

Head loss coefficients for intakes (K_{intake})

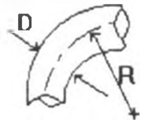
Entrance profile:



$K_{entrance}$	1.0	0.8	0.5	0.2

Head loss coefficients for bends (K_{bend})

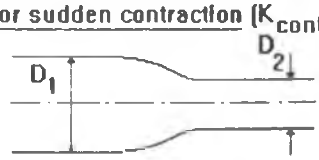
Bend profile :



R/D		1	2	3	5
K_{bend}	$\theta = 20^0$	0.36	0.25	0.20	0.15
	$\theta = 45^0$	0.45	0.38	0.30	0.23
	$\theta = 90^0$	0.60	0.50	0.40	0.30

Head loss coefficients for sudden contraction ($K_{contraction}$)

Contraction profile :



D_1/D_2	1.0	1.5	2.0	2.5	5.0
$K_{contraction}$	0	0 5	0.35	0.40	0.50

Head loss coefficients for sudden enlargements ($K_{enlarge}$)

	0.2	0.4	0.6	0.8	1.0
$K_{enlarge}$	0.9	0.7	0.4	0.1	0

Head loss coefficients for valves (K_{valve})

Type of valve	spherical	gate	butterfly
K_{valve}	0	0.1	0.3

Source : Fraenkel et al. (1991)

3.3.3.2 *Choosing Penstock thickness*

Steps for determining penstock thickness.

1. Estimate penstock thickness t (m)

2. Calculate the pressure wave velocity

$$C = \frac{1}{\sqrt{\rho\left(\frac{1}{K} + \frac{D}{Et}\right)}}$$

where

C - wave velocity (m/s)

ρ - Density of water (1000 kg/m^3)

K - Bulk modulus of water (2.1 x 10^9 N/M^2)

D - Internal pipe diameter (m)

E - Material young's modulus of elasticity (N/M^2)

t - pipe wall thickness (m)

3. Calculate surge pressure in terms of surge head

$$h_s = \frac{CV}{g}$$

Where V - flow veloc

g - gravitational acceleration

4. Calculate maximum expected pressure head

$$h_{max} = h_s + H_{gross}$$

5. Calculate the minimum allowable pipe thickness

$$t_{min} = \frac{\rho g h_{max} D}{\left(\frac{2\sigma_T}{S}\right)}$$

S - Safety factor

6. Check if the estimated thickness is less than t_{min}. If yes, increase t and repeat steps 2 through 5.

If the estimate is more than t_{min}, check from the manufacturer's sizes whether this value can be closer to t_{min}. If yes, repeat steps 2 to 5.

3.3.4 Choice of Governor

When the plant size is less than 200kW, an ELC is preferable. For bigger plants, the conventional speed governor may be used.

3.3.5 Electrical Design

3.3.5.1 Generator

(i) Synchronous Generator

Electrical specification

The power generated must be sufficient to supply the load demand and transformer & distribution line losses. It is also important to ensure that the voltage reduction due to motor starting is minimised. To cater for all these factors the generator is normally over-rated by 25% and by 60% if a phase controlled ELC is used. This is due to the fact that when conduction is retarded, the generator sees the ballast load as a load with a lagging power factor (Harvey, 1993). In this study, ELCs are recommended for plants of capacity up to 200kW. The appropriate generator rating is given by:-

$$KVA = \frac{P_{demand}}{pf} \times 1.6 \text{ for } P_{demand} \leq 200\text{kW}$$

$$KVA = \frac{P_{demand}}{pf} \times 1.25 \text{ for } P_{demand} > 200\text{kW}$$

where

P_{demand} - estimated demand in kW

Pf - rated power factor

Other important specifications that must be made when ordering a generator are voltage rating which in this case is 415V and 240 V for 3-phase and 1-phase respectively at a frequency of 50Hz.

The ambient temperature and humidity of the powerhouse should be given as these can affect the insulation of the generator windings. It is also important to know the overspeed capability of the generator.

Some generators have built-in protection schemes against underspeed, overload and short circuit.

(ii) Induction Generator (IG)

Selection of suitable induction motor for use as a generator

Harvey (1993) gives a derating factor of 0.8 to be applied on the generator rating required e.g. if the power demand is 20 kW, choose a motor of 20/0.8 = 25 kW rating. If the rating calculated is not standard, get the closest rating that is higher than this value. This simple derating rule has been found to be sufficient in almost all cases. It compensates for possible load imbalance in the phases and also caters for the generator losses which must be supplied from the mechanical input power.

Capacitor sizing

Having identified the size of motor required, the machine's data can be obtained from the manufacturer giving its characteristics. If such information is available, the rated full load current and corresponding power factor are necessary for the determination of the approximate capacitance required for self-excitation. The magnetising current component of the full load current (I_{fl}) may be estimated by

$$I_{mag} = I_{fl} \sin\left(\cos^{-1} pf\right)$$

where

I_{mag} - magnetising current

I_{fl} - rated full load current

pf - power factor at full load

The magnetising reactance -which is the capacitive reactance required for excitation- is given by

$$X_c = \frac{V_{rated(L-L)}}{I_{mag}} \times \sqrt{3}$$

where $V_{rated(L-L)}$ - rated line-line voltage

Therefore the capacitance required per phase is

$$C = \frac{1}{2\pi f X_c}$$

However, if the manufacturer's data is not available, then a no-load test has to be performed on the motor. The line current is measured when the motor is supplied at rated voltage and frequency. The measured current is the magnetising current drawn by the motor and the capacitance required is calculated as in the previous case. Under normal circumstances a value within 10% of the calculated value is adequate (Harvey, 1993; Smith, 1994).

3.3.5.2. *Transformer*

A transformer is not necessary for all single phase plants ($P \leq 10kW$).

For the plants whose generation is three phase, if the load is less than 40kW and the transmission distance is less than 0.8km, no transformer is required. All other cases will have a 415V/11kV step-up transformer.

3.3.6 *Protection Scheme*

Settings of the relays discussed earlier in section 3.2 should be determined by the designer.

For the biased differential unit protection of the generator-transformer set, the CTs chosen must be capable of carrying the full load current. Hence the primary rating of the CT, n, at the generator neutral is given by

$$I_{gen} = \frac{KVA_{rating}}{\sqrt{3} \times V_{rated}} \times C$$

C	- generator overload capability
I_{gen}	- generator full load current rating after allowing for overload tolerance.
KVA_{rating}	- generator KVA rating
V_{rated}	- generator rated voltage

The rating of the CT, m, on the transformer HV side is given by

$$I_{HV} = \frac{I_{gen}}{\sqrt{3} \times a}$$

Where

a - Transformer turns ratio as marked on Fig. 3.2.6.

The values of n and m (fig. 3.2.6) are chosen from available standard CTs closest to the calculated values. In some cases, the standard values chosen may not exactly match due to the transformation ratio. The ratio of the ratings of the CTs should be $I_{gen}/I_{HV} = 1/\sqrt{3}$. Auxiliary CTs may be used to achieve this ratio but adjustment of tap-settings on the relay coil is a better alternative. This provides an adequate margin to correct for most practical ratio mismatches.

Table 3.3.5 Summarised Design

ITEM	DESCRIPTION
Civil Works	
- Dam	- Use a simple diversion weir
- Reservoir	- Not necessary for plants below 200kW using ELC. May be considered for higher capacities using a speed governor
- Intake	- designed to satisfy allowable water flow velocity both minimum and maximum.
- Flood discharge rate	- Cater for worst flood predicted in 40 years
- Power canal	- use earth canal - Maximum headloss of 5%
- Penstock	- Headloss between 2 - 10% - safety factor - 2 for steel - 3 for PVC
Turbine	- Determine the specific speed
Governor	- ELC for plants ≤ 200kW - Speed governor for plants > 200kW
Electrical Design	- All AC generation - 1 - ϕ for plants of capacity ≤ 10kW at 240V - 3 - ϕ for plants of capacity > 10kW at 415V
Generator	- For plants less than 25kW capacity the induction generator when chosen may provide a better option to reduce the generation equipment cost.

Table 3.3.5 cont'd

	For higher capacities self-excited synchronous generator is recommended.
- Transformer	- Not necessary for all 1 - ϕ plants and 3 - ϕ loads less than 40kW transmitted within a distance of 0.8km. All other cases require a 415V/11kV step-up transformer.
Protection	
- Generator Protection	
- Rotor earth fault	- DC injection method
- Field failure	- not necessary
- Unbalanced stator currents	- not necessary
- Overload	- thermal relay fitted by manufacturer
- Prime mover protection	- not necessary when plant is run in isolation from the grid.
- Overvoltage/Overspeed	- use overvoltage relay
Generator-transformer protection	- Biased differential protection

3.4 FINANCIAL FEASIBILITY OF MHP PLANTS

3.4.1 Introduction

Financial feasibility determines whether the tangible value of project output is sufficient to amortise the project loan, pay operation and maintenance costs and meet other financial obligations. Economic feasibility on the other hand involves the analysis of both tangible and intangible benefits and costs of an investment from the point of view of society as a whole. A project that is economically feasible may not necessarily be financially feasible and vice versa.

This study only gives the financial analysis of MHP plants as it is hard to quantify the intangible costs and benefits required for economic analysis. Moreover, it is more important to have the schemes being first and foremost financially sound for self-sustenance.

MHP schemes are characterised by high initial capital cost and low operating costs thus making them very sensitive to interest rate. They are to some extent inflation proof because the energy costs are very low. The capacity factor is also a critical consideration as it directly affects the price of electricity.

The Net Present Worth (NPW) method of financial feasibility analysis is chosen. Other methods include benefit/cost ratio (B/C), payback period, Life Cycle Costing (LCC) and Internal Rate of Return (IRR). The NPW offers the following joint advantages over other methods.

i) It gives a monetary indication of the project feasibility.

ii) It recognises time value of money.

iii) It takes care of the opportunity cost of capital.

3.4.2 *Financial Analysis*

The necessary parameters for project analysis are -:

a) Plant installed capacity, P

b) Annual energy production, E

c) Plant capacity factor, CF

d) Capital cost including cost of distribution, C

e) Annual operation and maintenance cost, OM

f) Discount rate, r

g) Interest rate, i

h) Construction period, t

i) Financing period, k

j) Plant's useful life, n

Operation and maintenance of MHP plants has been found to account for 3% of the plants initial capital cost per annum (Harvey, 1993).

The interest rate charged on borrowed capital is used to calculate the annuity. The analysis covers the life span of the project, n.

<u>*Steps for determining the NPW of a project.*</u>

1. Calculate the value of annuity

$$A = \frac{C \times i(1+i)^k}{(1+i)^k - 1}$$

2. Calculate the annual operation and maintenance costs

$$OM = 0.03 \times C$$

3. Calculate the annual revenue from sale of energy

B = UCE x CF x P x 8760

where UCE is the unit price of energy

4. Calculate the present worth of costs and benefits

$$PWC = \sum_{i=1}^{k} \frac{A}{(1+r)^i} + \sum_{i=t+1}^{n} \frac{OM}{(1+r)^i}$$

$$PWB = \sum_{i=t+1}^{n} \frac{B}{(1+r)^i}$$

5. Calculate net present worth

NPW = PWB - PWC

The project is only feasible if NPW is positive.

3.4.3 Comparative analysis between mini/micro hydr and diesel generation.

To ascertain the economic feasibility of MHP for a given situation, it is necessary to compare the cost of generating each unit of power with an alternative source. In remote rural areas of developing countries, the most commonly used alternative is the diesel generator.

Cost of electricity generation (cost of generating a kWh of energy) depends on both the fixed and variable costs. Fixed costs comprise of loan repayment including interest charged on capital, insurance and in some cases government taxes. The variable costs include cost of fuel, maintenance costs and wages. The cost of generation also depends on technical factors like plant capacity factor and the power factor.

A diesel plant's capital cost is less than the equivalent hydro plant but it has a shorter useful life than the hydro plant (Fritz, 1984). For the purposes of this study, loan repayment has been spread over the plant's useful life.

The described evaluation model is developed in the next chapter following the technical design outlined in this chapter.

CHAPTER 4

MODEL DEVELOPMENT AND TESTING

4.1 INTRODUCTION

The design model developed in this chapter gives the dimensions and rating of the main components of a MHP plant. It is based on the technical design discussed in chapter three. The designer should have some knowledge of the potential site.

The model has two main parts, one for the civil components and the other one for the electrical components design. A financial analysis of the proposed plant and generation cost comparison with a diesel plant are also carried out.

4.2 COMPUTER PROGRAM

The model is implemented in FORTRAN language and is user friendly. It prompts the user for design data and offers available alternatives where there are options. It has been structured into four subroutines all called in the main program as shown on flow chart in fig 4.2.1 (a).

As described in section 3.1, the potential power demand is taken to have been estimated. atching this with the available site power potential, the design discharge rate is determined which leads to the subroutine CWORKS for the civil design. This performs the tasks of determining the weir and intake dimensions, sizing of the power canal and computes its efficiency.

Subroutine PENDIM leads to the choice of penstock material, pipe diameter and its thickness using manufacturer's standard tables and charts. Calculating the frictional headloss the subroutine further computes the penstock efficiency

Subroutine ELECT performs the electrical design of the plant. It determines the type of generation that is appropriate for a given site power rating i.e. 1-ϕ or 3-ϕ. Choice of synchronous generator as against induction generator with suitable capacitor for self excitation is decided. The type of turbine is based on the specific speed which depends upon the speed of the generator. Choice between ELC and the standard hydraulic governor depends upon the overall plant size. The need for the transformer is based on overall plant capacity and the transmission distance to the load centre. It however, does not carry out the design of the protection scheme and choice of switchgear.

Subroutine ECON performs the financial analysis of the MHP plant. It determines the net present worth (NPW) of the project, which gives the viability of the plant. This is done for various values of interest rate, discount rate, plant useful life and plant capacity factor. The estimated cost of the project must be known to perform this analysis. The user can also carry out a comparison between the designed MHP and an equivalent diesel plant. This compares the cost of generating a unit of electricity using MHP and using a diesel plant of the same power rating.

All the design output results are written to an output file.

A print out of the program is given in Appendix A and its operation is as given by the flow charts on fig. 4.2.1 (a), (b), (c), (d) and (e) below.

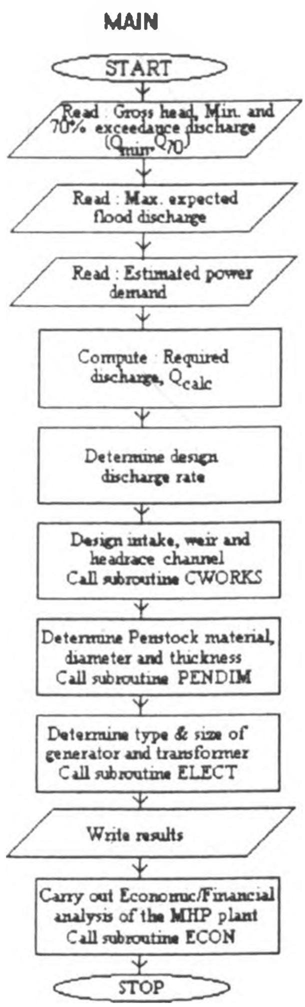


Fig. 4 2 1 (a) MAIN

Subroutine CWORKS for civil design

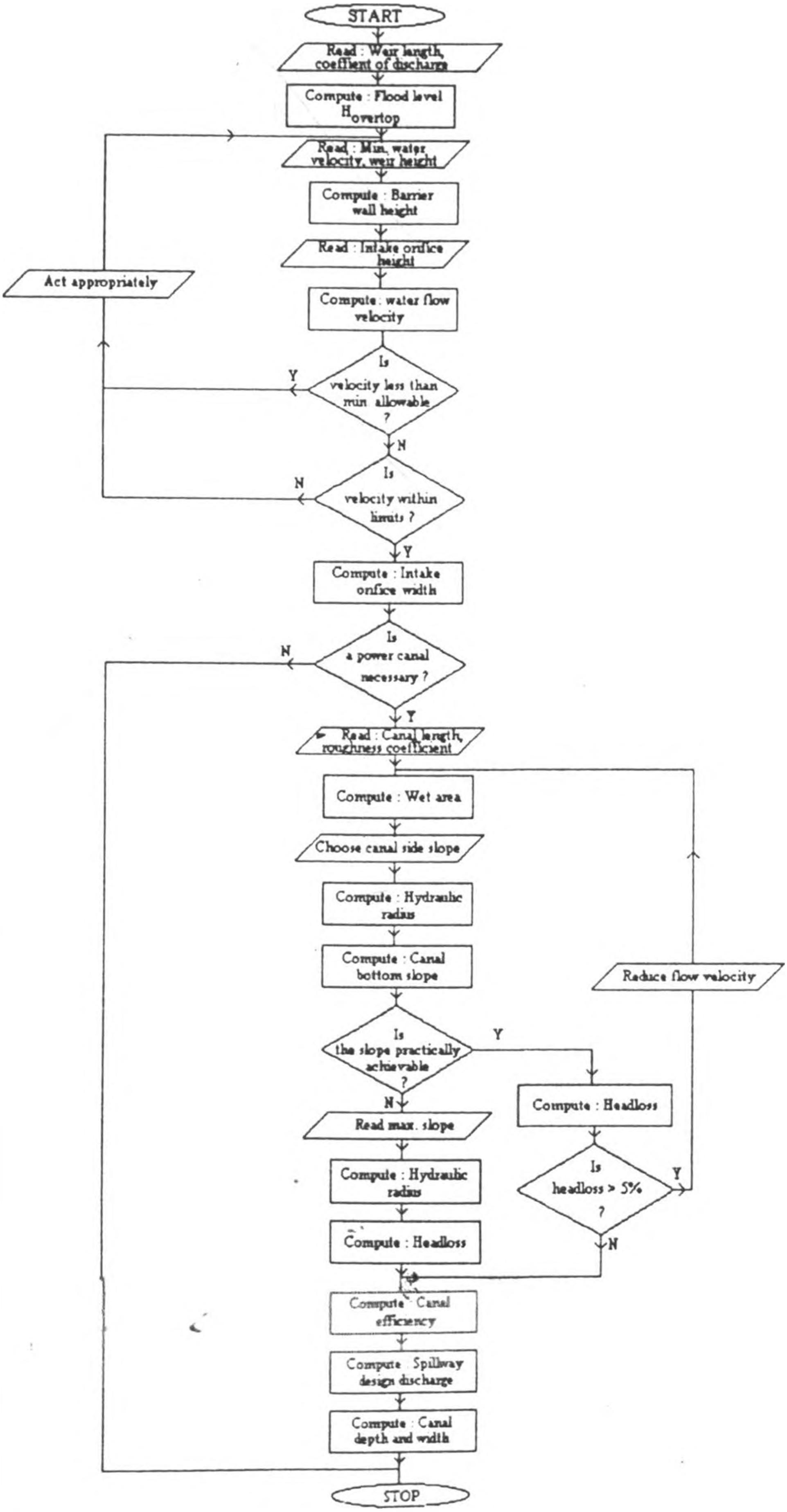
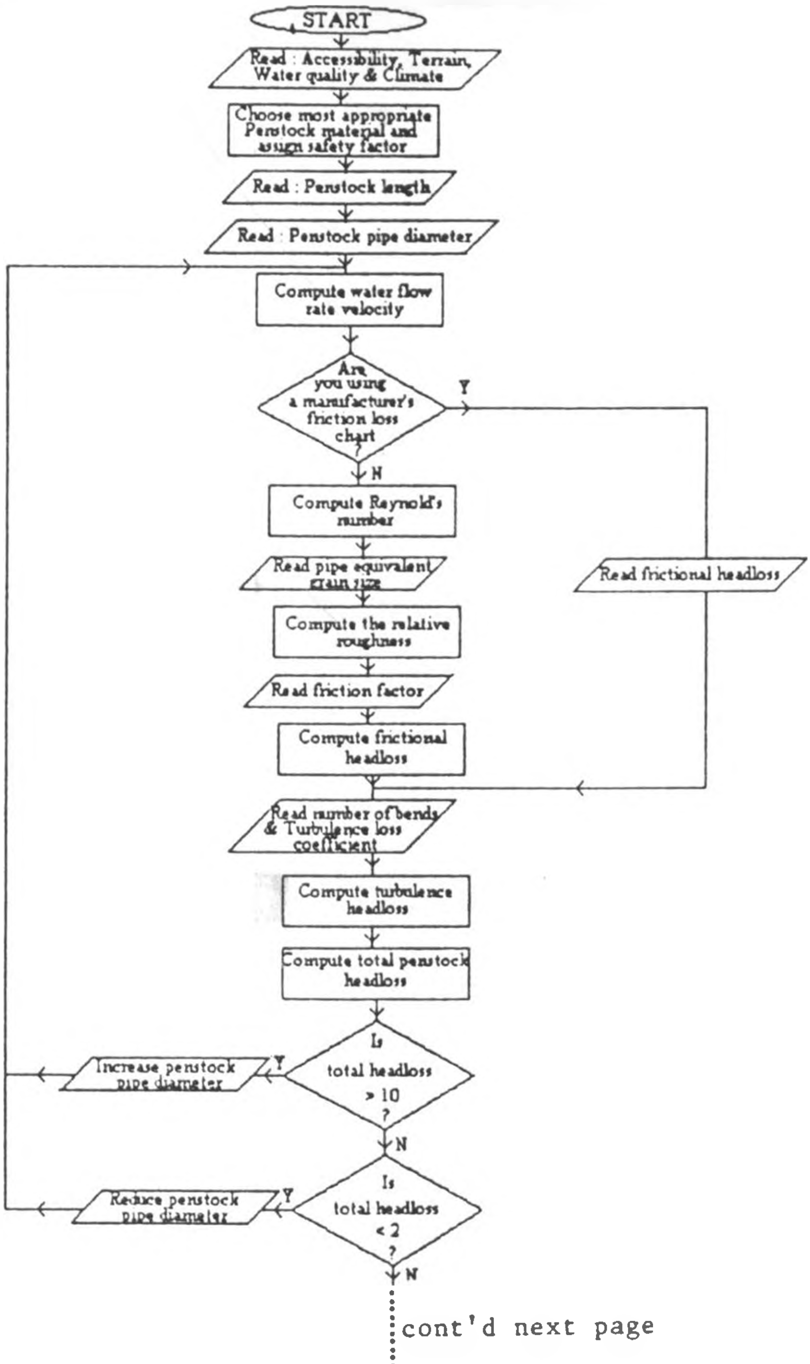


Fig 4 2 1 (b) : Subroutine CWORKS

Subroutine PENDIM for penstock design



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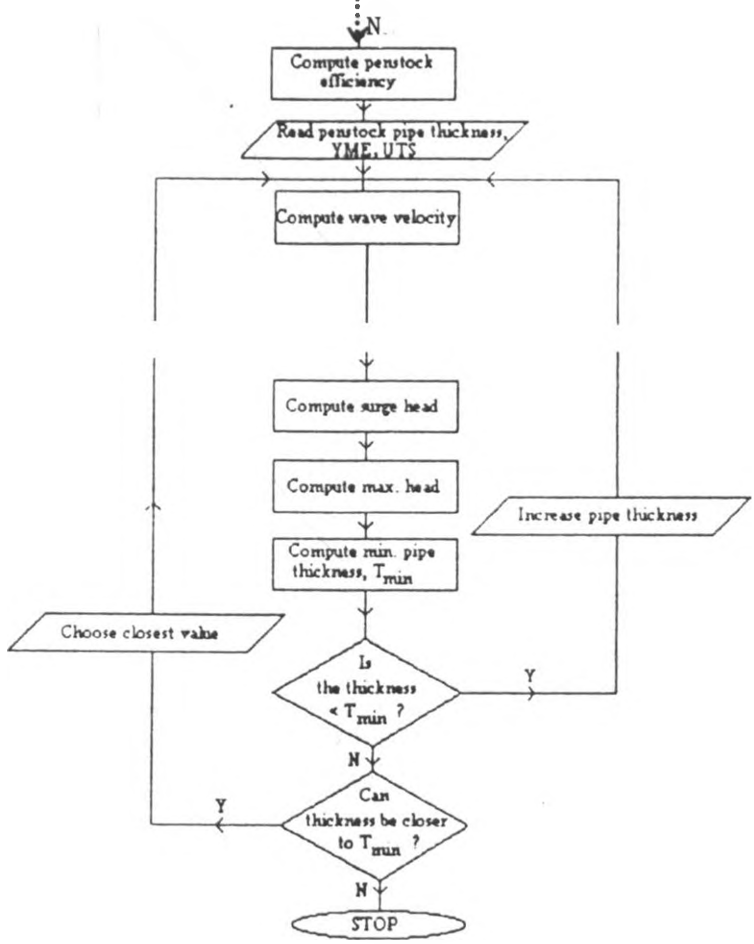

Fig. 4.2.1 (c) : Subroutine PENDIM

Subroutine ELECT for electrical design

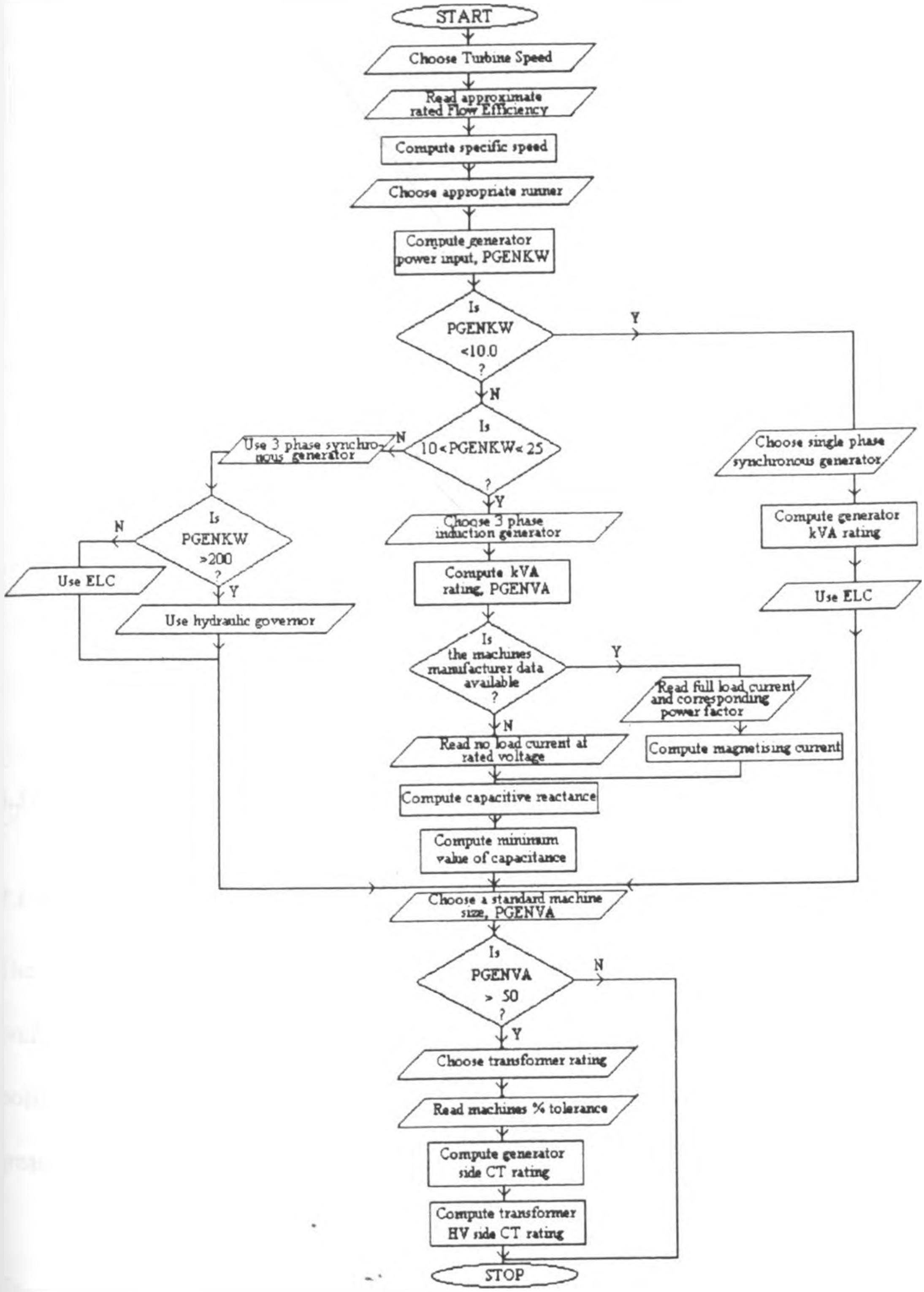

Fig 4 2 1 (d) Subroutine ELECT

Subroutine ECON for financial analysis

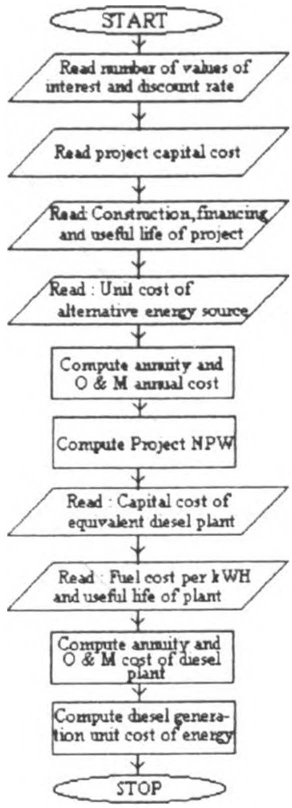

Fig 4.2.1 (e) Subroutine ECON

4.3 MODEL TESTING

4.3.1 Test Data

The model is tested using two plants because data for other existing stations was not available. This was due to lack of other plants known to the author which work in isolation from the grid and are within the model's range. The two plants have capacity greater than that considered in the study i.e. 500kW

The first plant is the Mau Forest Falls MHP plant (Tenwek Mission Hospital) on Nyangores river which is a privately owned generation station and it works in isolation from the national grid. It was commissioned in 1987 and has an installed capacity of 320kW. There is provision for the installation of a second turbine-generator set

Therefore when the second phase is implemented the plant will have a total capacity of 640kW. At the time of construction, the grid supply was more than 40km away (Kericho town) and the hospital's main supply was a diesel generator.

The generation cost averaged US$0.19/kWh (Mckay et al., 1990). This figure has been adopted in the financial analysis of this study as this was the cost of the alternative source at the time of project implementation.

The second plant is the proposed Terem Falls scheme which was designed by Finnconsult (1982). It is on Kuywa river which is a tributary of river Nzoia. There are three possible heads of 100m, 200m and 270m. The 200m head was found to be the most economic choice. Two designs were made, one with one machine (850kW) installed initially with provision for a second one at a later date and the other with two machines right fro the beginning. The design for the latter plan connected to the grid was also made.

For the purposes of this study, the single unit, isolated operation design has been preferred because it is closer to the designed model size limit (500kW).

Part of the data used for the Mau Forest Falls plant is for the design that was done in the feasibility study (Finnconsult & Imatran,1982) whose plant capacity was 740kW. The weir in both cases has been assumed to be wedge-shaped with a flat top and a discharge coefficient of 1.8. The intake orifice is also assumed to be sharp edged with coefficient of discharge equal to 0.6

The plant's construction time, useful life and loan repayment period used are one, thirty five and six years respectively but these may be varied. The opportunity cost of capital (discount rate) used is the interest rate paid on five years treasury bills. These are not fixed values but they are varied within a given range so as to observe their effect on the project viability. Other data used is given in table 4.3.1.

The comparison of MHP with an alternative source (i.e. a diesel plant) has been done for the Mau Forest Falls plant only because diesel plant data for the Terem Falls plant was not available. The diesel and MHP plants are assumed to have equal power rating. However, diesel plants have a shorter useful life than MHP.

The values of the parameters used in this study are as given below:

(I) Useful life - fifteen and thirty five years for diesel and MHP respecti ly (Fritz, 1984).

(ii) The cost of the diesel plant - US$800 per kW of installed capacity (Jabbal).

(iii) A diesel plant uses 0.33 litre (Fritz, 1984) to generate one kWh and the cost of diesel per litre at the time of project implementation was US$0 39 (McKay et al., 1990). Hence cost of generation per kWh is US$0.13.

(iv) Annual operation & maintenance costs - 3.5% (Fritz, 1984) and 3% (Harvey, 1993) of the capital cost for the diesel and MHP plant respectively.

Table 4.3.1. Design data

Description	Mau Forest Falls	Terem Falls
Gross head (m)	14	200
Average minimum discharge (m^3/s)	0.27	0.13
70% exceedance discharge (m^3/s)	2.85	0.55
Design flood discharge (m^3/s)	120*	120
Estimated power demand (kW)	450*	1000*
Length of weir (m)	30	35
Power canal length (m)	-	185
Minimum allowed water velocity (m/s)	0.3*	0.3*
Canal roughness coefficient	-	0.013*
Penstock length (m)	48	380
No. of bends on penstock (40°)	2	0*
Turbulence loss coefficient	0.30*, 0.30*	-
Turbine speed (rpm)	222	1500
Capital cost (US $ - 1987)	828,000♣ (676,000**)	1,163,000**
Rated flow turbine efficiency (%)	85*	
Generator overload tolerance (%)	15*	
Equivalent grain size for steel (mm)	0.1*	
Young's modulus of elasticity (N/M^2)	200×10^9*	
Ultimate tensile strength (N/M^2)	400×10^6*	

* - Estimated data

♣ - Actual amount spent on single unit with provision for a second machine.

** - Finnconsult estimate for single unit

4.3.2. Test Results

The model was tested with the input data given in section 4.3.1 above. The output results are as shown in tables 4.3.2 (a) and (b) along with the field data for the Mau Forest Falls and Terem Falls plants respectively has also been given. However unavailable field data has been put as dash.

Table 4.3.2 (a) : MHP plant design results - Mau Forest Falls plant.

Item	*Model Results*	*Field Data*
Intake and Weir		
Weir height (m)	2.0	2.0* (maximum)
Barrier wall height (m)	4.20	5.0*
Intake height (m)	0.750	0.75
Intake width (m)	1.28	-
Penstock		
Penstock material	steel	steel
Diameter (m)	1.2	1.4
Thickness (mm)	7.0	6.2
Minimum thickness (mm)	7.0	-
Flow velocity (m/s)	2.52	2.5* (max)
Design discharge (m^3/s)	2.85	2.5
Efficiency (%)	94	97.9*(max)
Runner specific speed	171.6	141.5
Generator		
Type	3-phase synchronous	3-phase synchronous
KVA rating	400 (330)	400
Frequency (Hz)	50	50
Rated voltage (V)	440	440
Transformer		
KVA rating	400	400
High voltage side max. current (A)	14	-
Generator side max. current (A)	604	-

( ) - calculated value

* - Finnconsult design values for plant with single unit.

Table 4.3.2 (b) : MHP plant design results - Proposed Terem Falls project.

Item	*Model Results*	*Field Data*
Intake and Weir		
Weir height (m)	2.0	2.0
Barrier wall height (m)	4.04	5.0
Intake height (m)	0.85	-
Intake width (m)	0.227	-
Power canal		
Concrete canal shape	Trapezoidal	Rectangular
Depth (m)	0.55	-
Top width (m)	1.28	-
Bottom width (m)	0.64	-
Flow velocity (m/s)	1.5	1.0
Canal efficiency (%)	99.75	90
Canal slope	0.0027	0.001
Spillway capacity (m^3/s)	0.35	-
Penstock		
Penstock material	Steel	Steel
Diameter (m)	0.5	0.5
Thickness (mm)	6.5	6.0,10.0 (upper, lower section)
Minimum thickness (mm)	6.2	5.4
Flow velocity (m/s)	2.8	2.6 (max)
Design discharge (m^3/s)	0.55	0.5
Efficiency (%)	91	-
Runner specific speed	68.2	-
Generator		
Type	3-phase synchronous	3-phase synchronous
KVA rating	1000	1000

Table 4.3.2 (b) cont'd

Frequency (Hz)	50	50
Rated voltage (V)	400	230/400
Transformer		
KVA rating	1000	1000
High voltage side max. current (A)	35	-
Generator side max. current (A)	1660	-

Table 4.3.3 below is a sample of the present worth table It shows the present value of both costs and benefits. The annuity is calculated up to the end of the loan repayment period which has been taken to be six years after which it becomes zero. During the construction period, assumed to be one year, operation & maintenance costs and benefits are zero.

The net present worth which is the difference between sum of present worth of benefits and that of costs -sum of column five less sum of column four- is given at the end of the table.

Table 4.3.3 Present Worth Table.

DISCOUNT RATE	=	10.00%	
INTEREST RATE	=	2.00%	
CAPACITY FACTOR	=	0.50	
CONSTRUCTION PERIOD	=	1 YEAR	
PLANT'S USEFUL LIFE	=	35 YEARS	
ANNUITY FOR 6 YEARS REPAYMENT PERIOD	=	US $147819.37	
ANNUAL O & M COST AT 3% OF CAPITAL COST	=	US $24840.00	
ANNUAL BENEFITS FROM SALE OF POWER AT US $0.19/KWH	=	US$266304.00	

YEAR	PW ANNUITY	PW O&M	PW COSTS	PW BEN.
1	134381	0	134381.25	0
2	122164	20528	142693.70	220085.94
3	111058	18662	129721.55	200078.12
4	100962	16966	117928.68	181889.20
5	91784	15423	107207.89	165353.81
6	83440	14021	97461.71	150321.64
7	0	12746	12746.85	136656.03
8	0	11588	11588.04	124232.76
9	0	10534	10534.58	112938.87
10	0	9576	9576.90	102671.70
11	0	8706	8706.27	93337.91
12	0	7914	7914.79	84852.64
13	0	7195	7195.26	77138.76
14	0	6541	6541.15	70126.15
15	0	5946	5946.50	63751.04
16	0	5405	5405.91	57955.49
17	0	4914	4914.46	52686.81
18	0	4467	4467.69	47897.10
19	0	4061	4061.54	43542.81
20	0	3692	3692.31	39584.37
21	0	3356	3356.64	35985.80

Table 4.3.3 :Present Worth Table.

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INTEREST RATE	=	2.00%
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CONSTRUCTION PERIOD	=	1 YEAR
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16	0	5405	5405.91	57955.49
17	0	4914	4914.46	52686.81
18	0	4467	4467.69	47897.10
19	0	4061	4061.54	43542.81
20	0	3692	3692.31	39584.37
21	0	3356	3356.64	35985.80

Table 4.3.3 cont'd

22	0	3051	3051.49	32714.36
23	0	2774	2774.09	29740.33
24	0	2521	2521.90	27036.66
25	0	2292	2292.63	24578.78
26	0	2084	2084.21	22344.35
27	0	1894	1894.74	20313.04
28	0	1722	1722.49	18466.40
29	0	1565	1565.90	16787.64
30	0	1423	1423.54	15261.49
31	0	1294	1294.13	13874.08
32	0	1176	1176.48	12612.80
33	0	1069	1069.53	11466.18
34	0	972	972.30	10423.80
35	0	883	883.91	9476.18

THE NET PRESENT WORTH IS = US $1465412.12

Table 4.3.4 shows the variation of net present worth (NPW) with average annual capacity factor at various discount rates and interest rates. The annuity remains constant for as long as the interest rate and loan repayment period remain constant. The NPW is calculated as explained above for each value of capacity factor.

Table 4.3.4 : Variation of net present worth with average annual capacity factor.

Int. rate / cap. fact.	Net present worth (US $)								
	Discount Rate = 10%			Discount Rate = 15%			Discount Rate = 20%		
	2%	4%	8%	2%	4%	8%	2%	4%	8%
0	-860771	-904896	-997046	-702176	-740519	-820592	-594865	-628557	-698919
0.1	-395534	-439660	-531809	-396084	-434427	-514500	-373395	-407088	-477450
0.2	69702.4	25577.1	-66573	-89992	-128335	-208408	-151926	-185619	-255981
0.3	534939	490814	398664	216100	177758	97684.6	69542.8	35850.4	-34512
0.4	1000176	956050	863901	522192	483850	403777	291012	257320	186958
0.5	1465412	1421287	1329137	828284	789942	709869	512481	478789	408427
0.6	1930649	1886524	1794374	1134377	1096034	1015961	733950	700258	629896
0.7	2395885	2351760	2259610	1440469	1402126	1322053	955419	921727	851365
0.8	2861122	2816997	2724847	1746561	1708218	1628145	1176888	1143196	1072834
0.9	3326358	3282233	3190083	2052653	2014310	1934237	1398357	1364665	1294303
1	3791595	3747470	3655320	2358745	2320402	2240329	1619827	1586134	1515772

Table 4.3.5 gives the average cost of generating a unit of energy using MHP at different average annual capacity factors while varying the plant's useful life. It also gives the average cost of unit generation using a diesel plant with a useful life of fifteen years. An interest rate of eight percent has been used.

Table 4.3.5 : Average cost of unit generation for MHP and diesel.

Average Unit cost (US $/kWh) Useful life (years)				
	MHP			Diesel
Cap. Factor	**25**	**35**	**45**	**15**
0.1	0.365	0.342	0.333	0.269
0.2	0.183	0.171	0.166	0.199
0.3	0.122	0.114	0.111	0.176
0.4	0.091	0.086	0.083	0.165
0.5	0.073	0.068	0.067	0.158
0.6	0.061	0.057	0.055	0.153
0.7	0.052	0.049	0.048	0.15
0.8	0.046	0.043	0.042	0.147
0.9	0.041	0.038	0.037	0.145
1.0	0.037	0.034	0.033	0.144

The above results are represented graphically by figures 4.3.1, 4.3.2, 4.3.3 and 4.3.4.

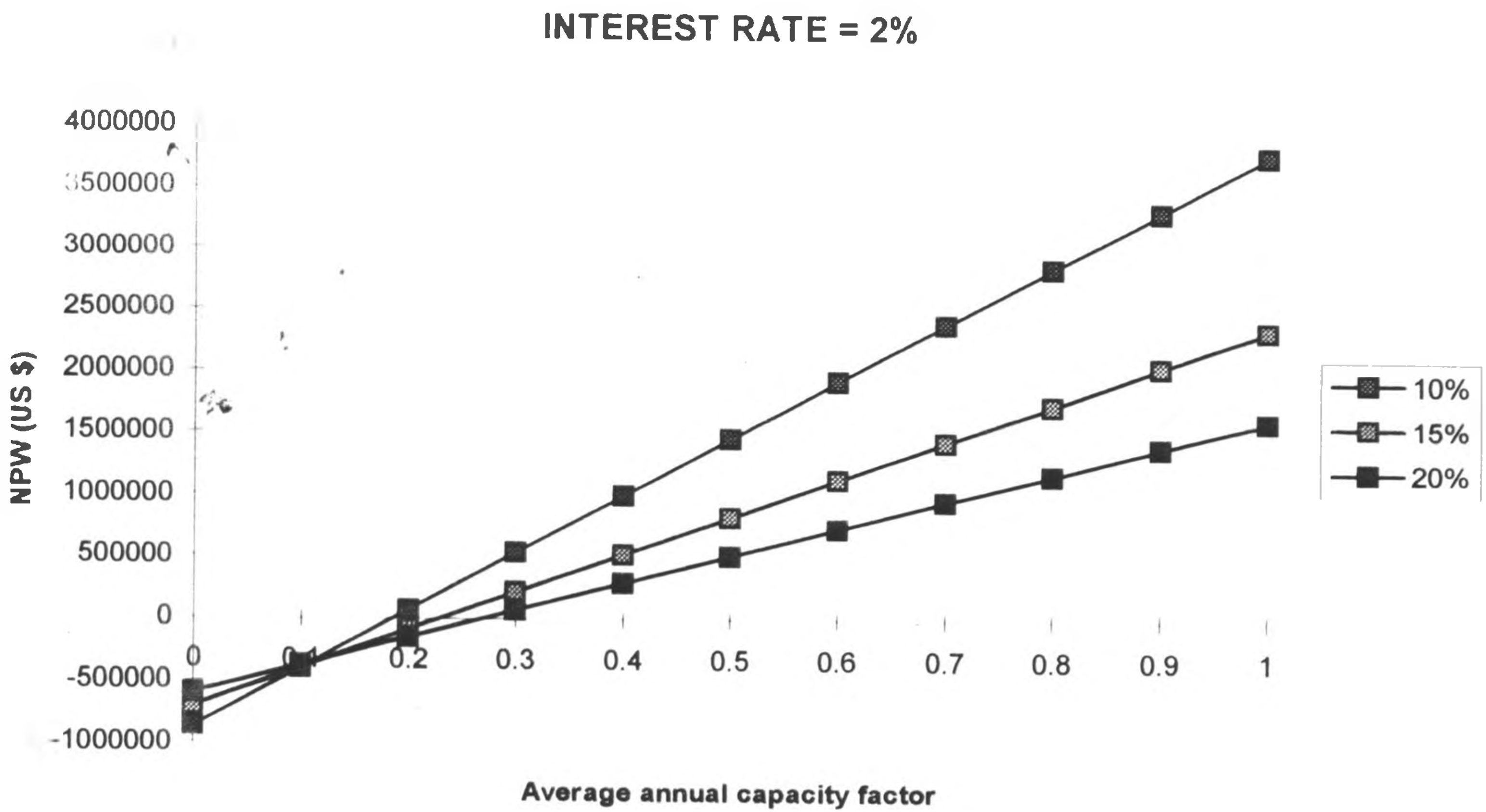

Fig. 4.3.1 : NPW Vs average annual capacity factor for various values of discount rate

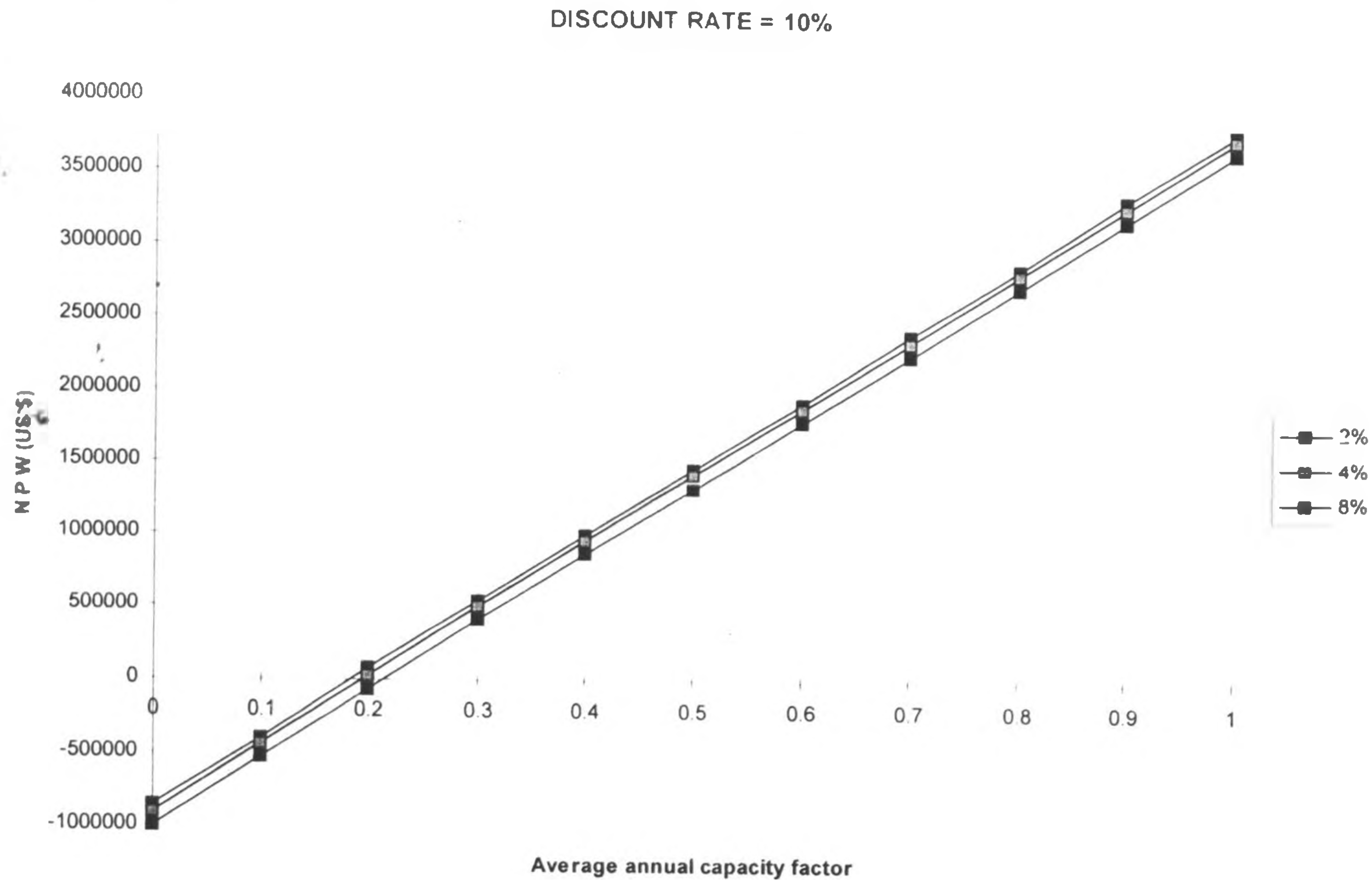

Fig. 4.3.2 : NPW Vs average annual capacity factor for various values of interest rate

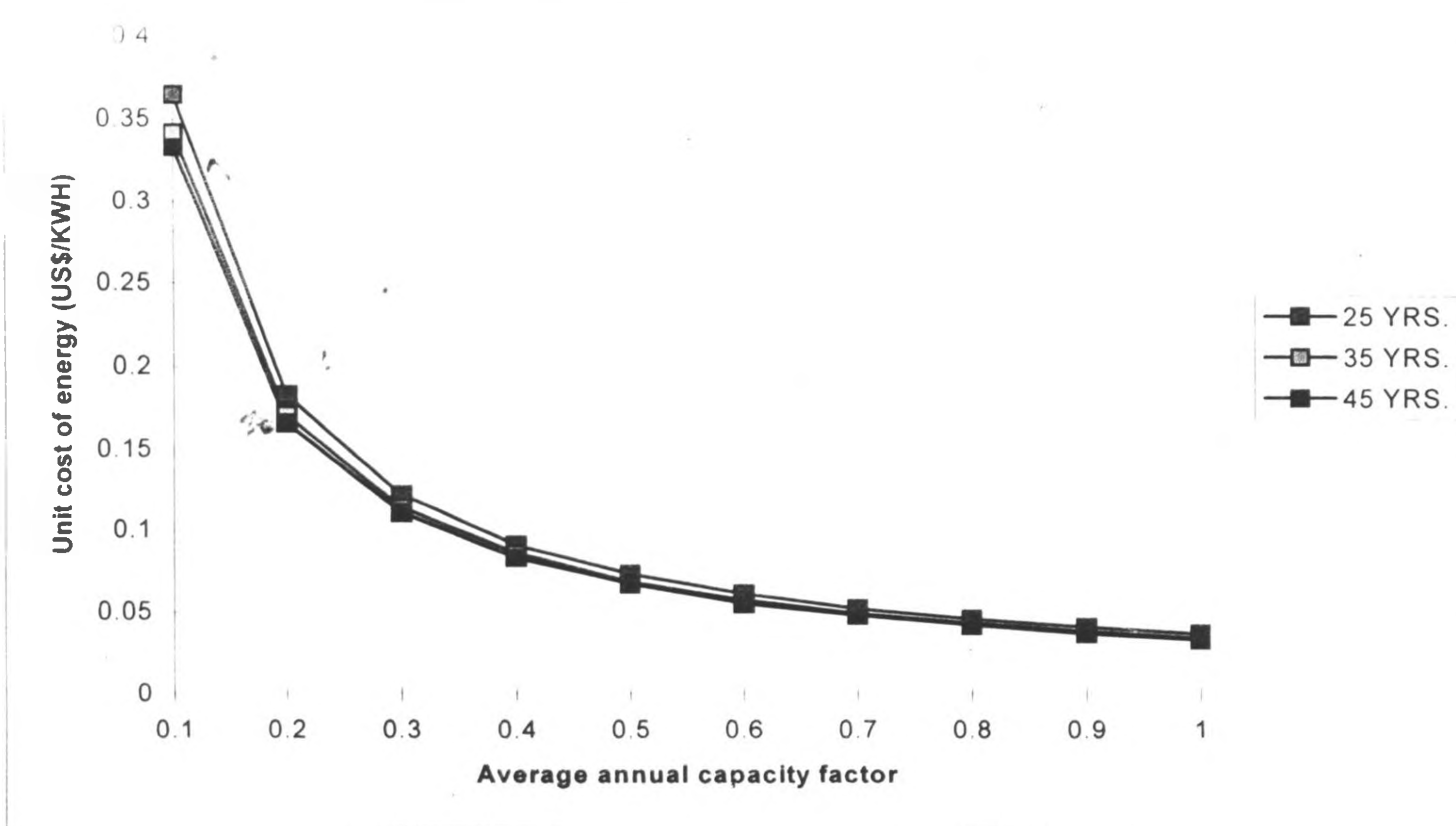

Fig. 4.3.3: Unit cost of energy Vs average annual capacity factor for varying MHP plant useful life

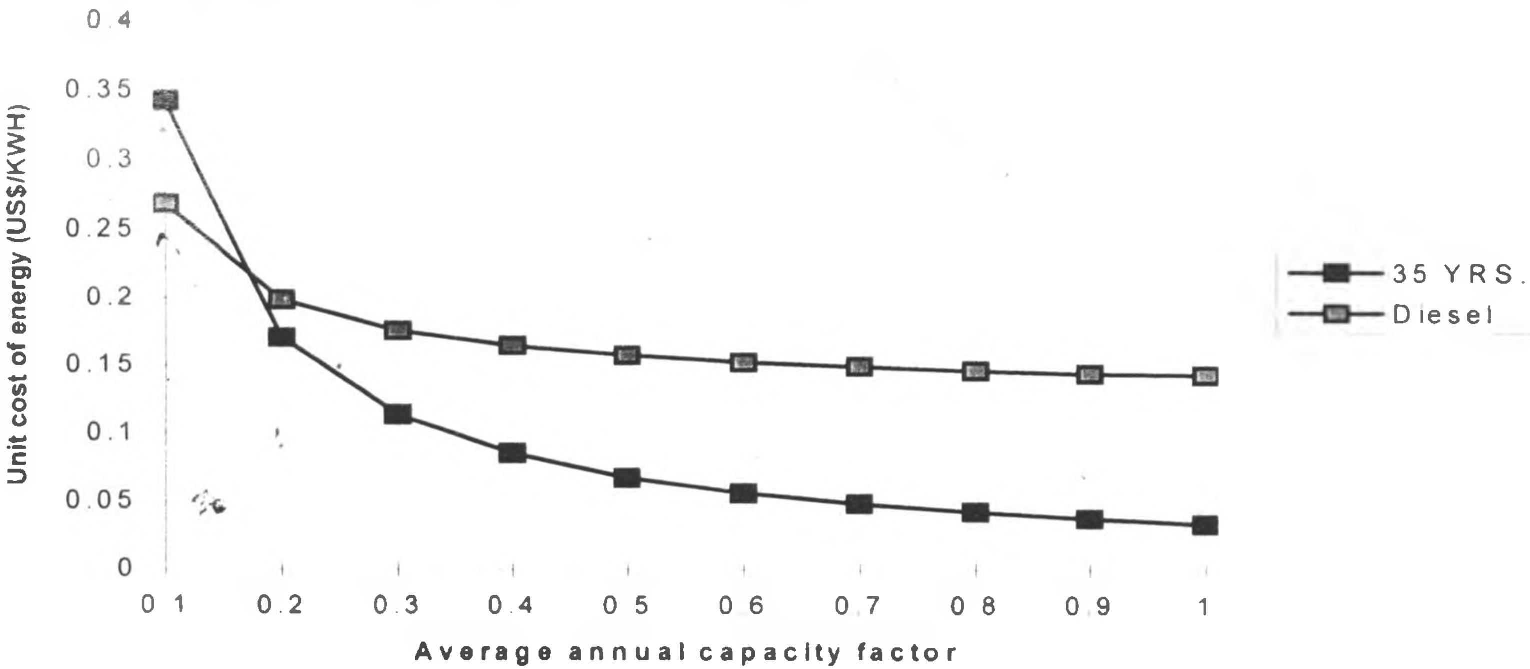

Fig. 4.3.4 : Unit cost of energy Vs average annual capacity factor for diesel and MHP plants

CHAPTER 5

DISCUSSIONS, CONCLUSIONS AND RECOMMENDATIONS

5.1 DISCUSSIONS

5.1.1 Model results

From the test results given in table 4.2.2(a) and (b), it can be seen that the penstock dimensions, generator and transformer ratings for the two plants tested are in very close agreement with the field data. The slight variations are attributable to the fact that the two test cases had been designed for plant capacities above 500kW which is the limit for this model. Lack of some crucial design data which had to be assumed also contributes to the deviations.

It is observed from figure 4.3.1 that for the same average annual plant capacity factor, the higher the discount rate the less attractive the project becomes i.e. the project returns are lower at higher discount rates. The higher the discount rate, the higher the minimum average annual capacity factor required to make project worthwhile i.e. to have a positive value of NPW. There is a linear relationship between NPW and the average annual capacity factor. However, it is observed that the graphs for the various values of discount rates transpose at low values of capacity factor. This is due to the fact that the gradient of each of the graphs is inversely proportional to the discount rate and hence the graphs are not parallel to each other. Thus leading to the transposition.

International lending interest rates used in the study are stable and thus as seen on figure 4.3.2, the interest rate variation does not affect the projects worth significantly. However, it must be noted that if the Kenyan commercial lending rates are used which are currently quite high (over 20%), then this would adversely affect the project's financial viability.

Both the discount and interest rate are factors that depend on the country's economic health and the organisation or person undertaking the project is a victim of it with no control over it. Hence a project's financial feasibility can only be improved by varying technical factors like the plant's capacity factor.

If the Mau Forest plant had been implemented as per the design for the single unit plant, the total capital cost had been estimated at US$676,000 giving an installation cost of US$2,200/kW. This figure rose to US$2,600/kW due to the fact that a second machine was provided for in the design but was not installed. The cost of the two machine design had been estimated at US$1,028,000 which reduces the unit capital cost to approximately US$1,400/kW. The unit cost of generation decreases with the unit capital cost.

The unit cost of generation using MHP decreases as the plant capacity factor increases. On figure 4.3.3 it can be seen that the drop in unit cost is very drastic as the capacity factor increases up to 0.4 and then reduces gradually as it tends to unity. If the capacity factor is improved from 0.2 to 0.5 when the plant's useful life is thirty five years, the unit cost reduces by about 60%. If further to this the plant's useful life is changed to forty five years the combined changes result in an overall unit cost reduction of about 61%. It must be noted that changing the economic life of the plant calls for sophisticated design and materials which may increase the project cost and this has not been taken into account in this test. Maximising on the plant's useful life may therefore not necessarily bring down the unit cost. It is therefore more advisable to improve on the plants capacity factor to achieve a significant cost reduction.

As observed on figure 4.3.4, MHP is cheaper than diesel generation only for capacity factors greater than 0.175. MHP becomes competitive when the capacity factor is higher than this value.

5.1.2 MHP Implementation

Mini/Micro Hydro Power is mainly meant for use in the rural areas most of which are characterised by low income earning population. These being schemes that require the participation of the local community in terms of both financial and labour input, a careful implementation process is worth considering. Introducing small scale hydro power involves more than just equipment installation. There are two methods of project implementation which may be used. One of these involves governmental or non-governmental organisations owning and managing the plant with the local people purchasing power from them. The local people usually have a passive attitude towards the project and it neither motivates them nor does it help to build their self confidence.

Klaus & Thomas (1992) regard it a fundamental mistake to induce a government to install and operate MHP plants of capacity under 100kW and plants under 1MW should be run by a public utility but never by the state. The other method is one where the local community implements the project through harambee/co-operative efforts. In this, they gain a sense of achievement and they want to identify with the project. With this approach, the project may be implemented in three stages where need be.

1. Start by creating irrigation canals

   This makes the area more productive and by sale of the agricultural produce, the rural community will gain a higher purchasing power meaning that they can make bigger financial commitments towards the project.

2. Once there is increased productivity and higher income, energy may be harnessed by introducing mechanical drive units. These can be used for agro processes like grain milling, rice hulling and oil pressing.

3. Having enhanced the financial capability of the local community, a turbine-generator set can be installed for electricity generation. By the time this stage is implemented, the local people can afford to pay for the installation, wire their houses and buy electrical appliances.

Initially, only one generator per scheme is recommended so as to avoid the need for synchronising equipment, load sharing, sophisticated protection schemes and to minimise on the operation and maintenance costs.

Where electronic load controllers are employed, the ballast can be put into some productive use. This increases the load factor, thus reducing the cost of energy significantly. It may be more advantageous to locate the controller away from the powerhouse so as to utilise the power diverted to the ballast more effectively. In such a case frequency sensing becomes more appropriate. This is due to the fact that system voltage fluctuation could be due to line impedance, power factor or action of the voltage regulator rather than only change in the system loading, resulting in erroneous ELC response.

5.2 CONCLUSIONS

The evaluation model developed reduces the engineering design time and also cuts overall project cost due to the simplified design. The potential power demand is taken to have been estimated as a pre-condition for the use of the design model as sizing of the plant capacity depends on it. To attain good results using the model, all the necessary data must be available. Manufacturer's data on the various components like penstock, generator and their characteristics must be obtained before hand.

The model was tested for the Mau Forest Falls plant (Tenwek Mission Hospital) and the proposed Terem Falls project. There was some missing data required in the design which had to be estimated and both plants were of higher capacity than the maximum limit of 500kW recommended for the model. Not withstanding these shortcomings, the test results were in good agreement with the field data.

Using the developed evaluation model quick comparison of different possible MHP plant locations on the same river/stream, so also the comparison of alternative designs for a specific site is possible. This if done manually would be time consuming. The model thus increases location choice and specific site design flexibility. A model user can also test the financial feasibility of the designed plant after costing has been done. Priority listing of sites based on the financial return can be concluded by re-running the program for the selected sites.

To make the project more attractive and to reduce the unit cost of generation the plant should be operated at high values of capacity factor. This may be attained by encouraging the consumers to make productive use of electricity like cottage industries and modernised farming methods.

The comparison between MHP and diesel generation done in this study shows that MHP only offers a better alternative when operated at capacity factor higher than 17.5%. This will vary depending on the capital cost of the plant with cheaper plants being more competitive. The plant's capital cost per kW of installed capacity must therefore remain as low as is practically possible.

In cases where MHP will be installed to replace an existing diesel generator and the power demand cannot be met all the year round, then diesel generation may be used to bridge the deficit.

The model is only a design tool and the user must have some engineering knowledge although not specialised.

5.3 RECOMMENDATIONS

1. The competitiveness of grid extension as against MHP supply as a means of rural electrification should be analysed from all angles and not just from the economic point of view.

2. Given that conditions, circumstances and attitude towards MHP have changed over the years, there is need to update the list of potential sites by visiting the sites in addition to the desk study.

3. Carry out a study for the development of a mathematical model for assessing the potential power demand in an area to be served by MHP site. This should take into consideration all the parameters that affect rural electricity demand.

4. Investigate the use of heat storage cookers as the ballast and assess their acceptability and affordability by the local community. If this can be incorporated, the plant capacity factor would improve.

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APPENDIX A

```
      PROGRAM MHP

      REAL HGROSS,QCALC,QMIN,Q70,N,QDES,G,PSITE,PDEMES,THICK,SPECSP,TX
      REAL HGTW,HGTWA,INHGT,INW,WETH,WETT,BOT,VEL,DIA,VELPEN,PI,PGENVA,D
      REAL EFC,SLOPE,EFP,QRF,VOLTRA,CTLV,CTHV,QSPILL,VC,THICKM
      INTEGER F,L,Q
      CHARACTER*1 ANSE,ANSCAN
      CHARACTER*10 PENSMA
      CHARACTER*30 GENTYP

      COMMON G,D,PI,EFP,EFC
      COMMON GENRAT
      COMMON / HYDRO / HGROSS,QDES, QSPILL,QRF,ANSCAN,VC
      COMMON / EPARAM / F,PSITE,PGENVA

      OPEN(30,FILE='A:DES.RES')
      REWIND(30)
5     FORMAT(' ',T20,'MHP PLANT DESIGN' / ' ',T20,16('=') / )
15    FORMAT(' ','THE DESIGNED PLANT FROM THE DATA GIVEN IS AS FOLLOWS'
     $// ' ',T10,'ITEM',T30,'SPECIFICATION' / ' ',T10,4('-'),T30,13('-')
     $ / ' ','INTAKE AND WEIR' / ' ',15('*') )
25    FORMAT(' ',  A,T35,F10.4 / ' ',A,T35,F10.4 )
35    FORMAT(' ',/ T10,A )
45    FORMAT(' ', A,T30,A / )
55    FORMAT(' ', A,T30,F10.2 / ' ',A,T30,I6 /)
65    FORMAT(' ', A /)
75    FORMAT(A1)
85    FORMAT(' ',A,T35,F10.3 )
95    FORMAT(' ',T20,A,/ ' ',T20,33('*') )
105   FORMAT(' ',T10,51('-')/ )
```

```
      PRINT 95,'WELCOME TO THE MHP DESIGN PROGRAM'
      PRINT 35,'Please type all the CHARACTER entries in UPPER CASE'
      PRINT 105
         G=9.81
         D=1000.0
         F=50
         PI=3.14

      WRITE(30,35)'MHP DESIGN DATA'
      PRINT 65,'ENTER THE VALUES OF GROSS HEAD, MIN AND 70% EXCEEDANCE R
     $IVER DISCHARGE'
      READ*, HGROSS,QMIN,Q70
      WRITE(30,85)'GROSS HEAD',HGROSS
      WRITE(30,85)'MINIMUM DISCHARGE RATE',QMIN
      WRITE(30,85)'70% EXCEEDANCE DISCHARGE',Q70
      PRINT 65,'WHAT IS THE MAXIMUM EXPECTED FLOOD DISCHARGE DURING THE
     $WORST FLOOD AT THE MHP SITE IN THE NEXT 40 YEARS'
      READ*,QRF
      WRITE(30,85)'DESIGN FLOOD DISCHARGE',QRF
         N = 0.46
      PRINT 65,'WHAT IS THE ESTIMATED POWER REQUIREMENT OF THE AREA,KW?'
      READ*,PDEMES

C   THE  POTENTIAL POWER OF THE SITE SO AS TO MEET THIS DEMAND SHOULD
C   BE

         PSITE = PDEMES/N
         QCALC = PSITE/(G*HGROSS)
         IF((QCALC.LE.QMIN).OR.((QCALC.LE.Q70).AND.(QCALC.GT.QMIN)))THEN
            QDES = QCALC
         ELSE
            QDES = Q70
            PSITE = G*HGROSS*QDES
         END IF
```

```
 CALL CIVIL(HGTW.HGTWA.INHGT,INW,WETH.WETT,BOT,VEL.SLOPE)
 CALL PEN(PENSMA.DIA.THICK,VELPEN,THICKM)
 CALL TURGEN(SPECSP.GENTYP,VOLTRA.TX,CTLV,CTHV)

 WRITE(30,5)
 WRITE(30,15)
 WRITE(30,25)'WEIR HEIGHT(M)',HGTW ,'BARRIER WALL HEIGHT(M)',HGTWA
 WRITE(30,25)'INTAKE HEIGHT(M)',INHGT,'INTAKE WIDTH (M)',INW
 IF(ANSCAN.EQ.'Y')THEN
     WRITE(30,35)'POWER CANAL'
     WRITE(30,25)'DEPTH (M)'.WETH,'TOP WIDTH (M)'.WETT
     WRITE(30.25)'BOTTOM WIDTH(M)'.BOT,'FLOW VELOCITY (M/S)'.VC
     WRITE(30.25)'CANAL EFFICIENCY',EFC,'CANAL SLOPE'.SLOPE
     WRITE(30.25)'SPILLWAY CAPACITY (CUBIC M/S)'.QSPILL
 END IF
 WRITE(30,35)'PENSTOCK'
 WRITE(30,45)'PENSTOCK MATERIAL',PENSMA
 WRITE(30,25)'DIAMETER (M)',DIA,'FLOW VELOCITY (M/S)'.V' _PEN
 WRITE(30,25)'THICKNESS (M)'.THICK,'MINIMUM THICKNESS'.THICKM
 WRITE(30,25)'DESIGN DISCHARGE (CUBIC M/S)',QDES,'EFFICIENCY',EFP
 WRITE(30,25)'RUNNER SPECIFIC SPEED',SPECSP
 WRITE(30,35)'GENERATOR'
 WRITE(30,45)'TYPE'.GENTYP
 WRITE(30,55)'KVA RATING'.PGENVA,'FREQUENCY (HZ)'.F
 WRITE(30,25)'RATED VOLTAGE (V)',VOLTRA
 WRITE(30,35)'TRANSFORMER'
 WRITE(30,25)'KVA RATING'.TX
 WRITE(30,25)'GENERATOR MAXIMUM CURRENT (A)',CTLV,'HIGH VOLTAGE MAX
$IMUM CURRENT (A)'.CTHV
 PRINT 65,'DO YOU WANT TO CARRY OUT AN ECONOMIC ANALYSIS OF THE PRO
$JECT? (Y/N)'
 READ 75,ANSE
 IF(ANSE.EQ.'Y')THEN
     CALL ECON
 END IF
```

```
      CLOSE(30)
      STOP
      END


************************************************************************************

        SUBROUTINE PEN(PENMAT,B,T,VP,TMIN)

************************************************************************************
*     THIS SUBROUTINE SELECTS THE MOST SUITABLE PENSTOCK PIPE MATERIAL  *
*     FOR A PARTICULAR SITE.CALCULATES THE DIAMETER AND GIVES THE APP-  *
*     ROPRIATE THICKNESS FROM WHAT IS AVAILABLE IN THE MARKET            *
************************************************************************************

      INTEGER ACCESS,TERAIN,PH,TEMP,N
      REAL L,B,E,F,K(20),SUMK,HLF,HLT,T,YME,UTS,HS,HMAX,TMIN
      REAL HLP,X,Y,EFP,SAFE,VP
      INTEGER I
      CHARACTER*6 PENMAT
      CHARACTER*1 ANST,ALT,ANSFRI,ANSVP

      COMMON G,D,PI,EFP,EFC
      COMMON / HYDRO / HGROSS,QDES,QSPILL,QRF,ANSCAN,VC

5     FORMAT(' ',A /)
15    FORMAT( A1 )
25    FORMAT(' ',A, A6/)
35    FORMAT(' ',A,E12.5/)
45    FORMAT(A6)

      PRINT 5,'HOW IS THE SITE ACCESSIBILITY?'
      PRINT 5,'1=GOOD, 2=AVERAGE, 3=BAD'
```

```
READ*,ACCESS
PRINT 5,'HOW IS THE TERRAIN TO BE TRAVERSED?'
PRINT 5,'1=ROUGH, 2=GENTLE'
READ*,TERAIN
PRINT 5,'WHAT IS THE QUALITY OF WATER/SOIL IN THE AREA?(ACIDIC, AL
$KALINE)'
PRINT 5,'1=CORROSIVE, 2=NEUTRAL'
READ*,PH
PRINT 5,'HOW IS THE CLIMATE IN THE AREA (TEMPERATURE)?'
PRINT 5,'1=TEMPERATE,2=HOT'
READ*,TEMP
IF((TERAIN.EQ.1).OR.(TEMP.EQ.2).OR.(ACCESS.EQ.3))THEN
    PENMAT='STEEL'
    SAFE = 2.0
ELSE
    PENMAT='PVC'
    SAFE = 3.0
END IF
PRINT 25,'THE APPROPRIATE PENSTOCK PIPE MATERIAL IS ', PENMAT
PRINT 5,'DO YOU WANT TO USE ANOTHER MATERIAL? (Y/N)'
READ 15,ALT
IF(ALT.EQ.'Y')THEN
    PRINT 5,'ENTER THE MATERIAL YOU WANT TO USE(MAX. 6 CHARACT
$ERS)'
    READ 45,PENMAT
    SAFE = 3.0
END IF
PRINT 5,'ENTER THE PENSTOCK LENGTH L, IN METRES'
READ*,L
PRINT 5,'ESTIMATE THE DIAMETER B,IN METRES'
READ*,B
10      VP=4*QDES/(PI*(B**2))
PRINT 5,'ARE YOU USING A PIPE MANUFACTURER''S FRICTION LOSS CHART?
$(Y/N)'
READ 15,ANSFRI
```

```
 IF(ANSFRI.EQ.'N')THEN
      RE=VP*B*10**6
      PRINT 35,'THE REYNOLD"S NUMBER RE = ',RE
      PRINT 5,'ENTER THE VALUE OF EQUIVALENT GRAIN SIZE,k,METRE'
      READ*,Y
      E= Y/B
      PRINT 35,'THE RELATIVE COEFFICIENT E = ',E
      PRINT 5,'DEDUCE AND ENTER THE VALUE OF FRICTION FACTOR, F,
   $ FROM MOODYS CHART'
      READ*,F
         HLF=2*(VP**2)*L*F/(G*B)
 ELSE
      PRINT 5,'READ OFF THE FRICTIONAL HEAD LOSS FROM THE CHART'
      READ*,HLF
 END IF

 PRINT 5,'HOW MANY BENDS DOES THE PENSTOCK PIPE HAVE?(NUMBER)'
 READ*,N
 IF(N.NE.0)THEN
      PRINT 5,'ENTER THE VALUES OF THE LOSS COEFFICIENTS AT EACH
   $ BEND FROM THE TURBULENCE LOSS TABLES'
         SUMK=0
      DO 20 I=1,N
         READ*,K(I)
         SUMK=SUMK+K(I)
20    CONTINUE
 END IF
 HLT=(VP**2)*SUMK/(2*G)
 HLP = (HLF+HLT)/HGROSS
 IF(HLP.GT.0.10)THEN
      PRINT 5,'INCREASE PIPE DIAMETER'
      READ*,B
      GOTO 10
 ELSE IF(HLP.LT.0.02)THEN
      PRINT 5,'REDUCE DIAMETER BY ONE SIZE'
```

```
      READ*,B
      GOTO 10
   END IF
   PRINT*,'THE WATER FLOW VELOCITY = ',VP,'M/S'
   PRINT 5,'IS THIS WITHIN THE LIMITS? (Y/N)'
   READ 15,ANSVP
   IF(ANSVP.EQ.'N')THEN
      PRINT 5,'INCREASE PIPE DIAMETER'
      READ*,B
      GOTO 10
   END IF
      EFP = 1.0 - HLP

   PRINT 5,'ESTIMATE THE PENSTOCK PIPE THICKNESS,T(M)'
   READ*,T
   PRINT 5,'ENTER THE YOUNGS MODULUS OF ELASTICITY,YME, & ULTIMATE TE
  $NSILE STRENGTH FOR THE PIPE MATERIAL,UTS'
   READ*,YME,UTS
      X = 2.1E+9
30    A = 1/SQRT(D*((1/X)+(B/(YME*T))))
      HS=A*VP/G
      HMAX=HGROSS+HS
      TMIN=D*G*HMAX*B*SAFE/(2*UTS)
   IF(T.LT.TMIN)THEN
      PRINT 5,'INCREASE THE PIPE THICKNESS,T'
      READ*,T
      GOTO 30
   ELSE
      PRINT*,'MINIMUM PIPE THICKNESS IS ', TMIN
      PRINT 5,'CAN T BE CLOSER TO TMIN?(Y/N)'
      READ 15,ANST
      IF(ANST.EQ.'Y')THEN
         PRINT 5,'REDUCE T TO THE AVAILABLE THICKNESS CLOSEST
  $TO TMIN'
         READ*,T
```

```
          GOTO 30
        END IF
      END IF
      RETURN
      END


************************************************************************************

      SUBROUTINE CIVIL(HWEIR.HWALL.IH,IW,H,T,B.V,S)

************************************************************************************
*     THIS SUBROUTINE DESIGNS THE WEIR, INTAKE AND THE POWER CANAL AND *
*     GIVES THE WEIR AND WALL HEIGHT, INTAKE DIMENSIONS, SLOPE OF THE  *
*     CANAL AND ITS DIMENSIONS.                                        *
************************************************************************************

      REAL QRF,CW,LWEIR.HWALL,HWEIR,HTOPF,IH,VI,CD,HR,HH,QDES,QSPILL.HLC
      REAL R.N.S,AWET.HHF.QFM,QFD,HRF,X,VMIN,SFIX,IW.SLOPE,H.T.B.D.L,EFC
      INTEGER ANSO.CP.CHOICE
      CHARACTER*1 ANSV.ANSS,ANSSLO.ANSCAN

      COMMON G,D,PI,EFP.EFC
      COMMON / HYDRO / HGROSS.QDES.QSPILL,QRF,ANSCAN,VC

5     FORMAT(' ', A,E12.4)
15    FORMAT(' ', A /)
25    FORMAT(' ',A,F8.4/)
35    FORMAT(' ',A,F6.4,A /)
45    FORMAT( A1 )
      PRINT 15,'WHAT IS THE DESIRED LENGTH OF WEIR?,M'
      READ*,LWEIR
      PRINT 15,'DEDUCE THE VALUE OF COEFFICIENT OF DISCHARGE, CW, FOR TH
     $E CHOSEN WEIR PROFILE'
```

```
      READ*,CW
         HTOPF=(QRF/(CW*LWEIR))**0.667
      PRINT 15,'IS THE INTAKE ORIFICE, 1=SHARP EDGED AND ROUGH OR, 2=CAR
     $EFULLY FINISHED?'
      READ*,ANSO

C     CHOOSE THE COEFFICIENT OF DISCHARGE OF THE INTAKE ORIFICE

      IF(ANSO.EQ.2)THEN
         CD = 0.8
      ELSE
         CD = 0.6
      END IF
      PRINT 15,'WHAT IS THE MINIMUM ALLOWED WATER VELOCITY? (M/S)'
      READ*,VMIN
10    PRINT 15,'ESTIMATE THE WEIR HEIGHT, HWEIR (M).FIRST ESTIMATE BEING
     $ SLIGHTLY LOWER THAN THE ANNUAL AVERAGE DEPTH OF WATER AT THE POIN
     $T WHERE WEIR IS TO BE CONST UCTED.'
      READ*,HWEIR
         HR = HWEIR
50    PRINT 15,'ESTIMATE THE INTAKE ORIFICE HEIGHT,D METRES'
      READ*,IH
         HH = IH
         VI = CD*SQRT(2*G*(HR-HH))
      IF(VI.LE.VMIN)THEN
         PRINT 5,'THIS VELOCITY IS LESS THAN THE MINIMUM ALLOWED VE
     $LOCITY :-',VI
         PRINT 15,'1=INCREASE THE WEIR HEIGHT OR 2=REDUCE THE DEPTH
     $ OF WATER IN THE HEADRACE HH OR 3=INCREASE HR BY LOWERING THE INTA
     $KE POSITION'
         READ*,CHOICE
         IF((CHOICE.EQ.1).OR.(CHOICE.EQ.3))THEN
            GOTO 10
         ELSE
            GOTO 50
```

```
      END IF
  ELSE
      PRINT 35,'THE VELOCITY OF WATER IS ',VI,'M/S'
      PRINT 15,'IS THIS VELOCITY WITHIN THE LIMITS? (Y/N)'
      READ 45,ANSV
      IF(ANSV.EQ.'N')THEN
          PRINT 15,'1=REDUCE THE WEIR HEIGHT OR 2=INCREASE THE
 $DEPTH OF WATER IN THE HEADRACE HH OR 3= REDUCE HR BY RAISING THE I
 $NTAKE POSITION'
          READ*,CHOICE
          IF(CHOICE.EQ.1.OR.CHOICE.EQ.3)THEN
              GOTO 10
          ELSE
              GOTO 50
          END IF
      END IF
  END IF
      HWALL = HWEIR+HTOPF+0.5

C   THE INTAKE WIDTH IS GIVEN BY

      IW = QDES/(IH*VI)
  PRINT 15,'IS A POWER CANAL NECESSARY? (Y/N)'
  READ 45,ANSCAN
  IF(ANSCAN.EQ.'Y')THEN
      PRINT 15,'WHAT IS THE LENGTH OF THE POWER CANAL? (M)'
      READ*,L
      PRINT 15,'ENTER THE VALUE OF ROUGHNESS COEFFICIENT FOR THE CANA
 $L'
      READ*,N
      PRINT 15,'CHOOSE A SUITABLE VALUE OF VELOCITY OF FLOW IN THE CA
 $NAL'
      READ*,VC
      PRINT 15,'A TRAPEZOIDAL CANAL PROFILE IS RECOMMENDED.'
      PRINT 15,'ENTER THE APPROPRIATE SIDE SLOPE ANGLE (DEG)'
```

```
      READ*,X
          X = X*PI/180
40        AWET = QDES/VC
          R = 0.5*SQRT(AWET*SIN(X)/(2-COS(X)))
          S = (N*VC/(R**0.667))**2
      PRINT 5,'THE CALCULATED CANAL SLOPE IS ',S
      PRINT 15,'CAN THIS SLOPE BE ACHIEVED PRACTICALLY?(Y/N)'
      READ 45,ANSS
      IF(ANSS.EQ.'N')THEN
          PRINT 15,'WHAT IS THE MAXIMUM SLOPE THAT CAN BE ATTAI
     $NED?'
          READ*,SFIX
              R = 0.46*QDES**0.38/SFIX**0.19
              S = SFIX
              HLC = L*S/HGROSS
      ELSE
          HLC = L*S/HGROSS
          IF((HLC.GT.0.10).AND.(VC.LT.VI))THEN
              PRINT 15,'REDUCE THE CANAL WATER FLOW VELOCITY'
              READ*,VC
              GOTO 40
          END IF
      END IF

C   CALCULATE THE EFFICIENCY OF THE CANAL

      EFC = (1-HLC)
      H = 1.2*2*R
      T = 1.2*4*R/SIN(X)
      B = T-2*H/TAN(X)
C   DETERMINE THE FLOW IN THE HEADRACE DURING FLOODS

60    PRINT 15,'ESTIMATE THE DEPTH OF WATER IN THE HEADRACE DURING FL
     $OODS'
      READ*,HHF
```

```
          HRF = HTOPF+HWEIR
          QFM = HHF*T*(SQRT(S)/N)*(T*HHF/(T + 2*HHF))**0.667
          QFD = IH*IW*CD*SQRT(2*G*(HRF - HHF))
          ACC = ABS(QFM - QFD)
        PRINT*,'QFM =',QFM,'AND QFD =',QFD
        IF(ACC.GT.1E-2)THEN
          GOTO 60
        END IF

C   THE DISCHARGE THAT THE SPILLWAY MUST GET RID OFF IS

        QSPILL = QFM - QDES
      ELSE
        EFC = 1
      END IF

      RETURN
      END

**********************************************************************************

        SUBROUTINE TURGEN(NS,TYPE,VRATED,TXRATE,IGEN,ITXHV)

**************************************************************************************
*   THIS SUBROUTINE GIVES THE TYPE OF TURBINE THAT IS MOST APPROPRIATE *
*   FOR A GIVEN SITE AND ALSO GIVES THE BEST GENERATOR TYPE AND RATING*
**************************************************************************************

      REAL NS,NT,PTURO,EFT,PGENVA,CMIN,INL,IFL,IM,PGENKW,TXRATE,ITXHV
      REAL PFFL,XC,VPEAK,VRATED,PMOTOR,HGROSS,QDES,PSITE,TOL,IGEN,TRATIO
      CHARACTER*1 IMDATA
      CHARACTER*30 TYPE

      COMMON G,D,PI,EFP,EFC
```

```
      COMMON / HYDRO / HGROSS,QDES,QSPILL,QRF,ANSCAN,VC
      COMMON / EPARAM / F,PSITE,PGENVA


25    FORMAT(' ',A /)
35    FORMAT(' ',A,F6.2,A/)
45    FORMAT(' ',A,F6.2)

      PRINT 25,'CHOOSE THE TURBINE SPEED (RPM)'
      READ*,NT
      PRINT 25,'ENTER THE APPROXIMATE TURBINE EFFICIENCY AT RATED FLOW (
     $%)'
      READ*,EFT
         EFT=EFT/100
         PTURO = PSITE*EFC*EFP*EFT
         NS=NT*SQRT(1.4*PTURO)/(HGROSS**1.25)
      PRINT 45,'THE SPECIFIC SPEED OF THE TURBINE REQUIRED IS ',NS
      PRINT 25,'CHOOSE A MATCHING RUNNER(S) FOR THIS VALUE OF SPECIFIC S
     $PEED.'
      PRINT 25,'IF THERE IS MORE THAN ONE CHOICE, USE THE EFFICIECY CURV
     $ES FOR THE ELLIGIBLE TYPES TO CHOOSE THE ONE WITH THE BEST PART LO
     $AD EFFICIENCY.'

C     DETERMINE THE SIZE AND TYPE OF GENERATOR REQUIRED

         PGENKW = PTURO*0.85
      IF(PGENKW.LT.10.0)THEN
         PRINT 25,'CHOOSE A SINGLE PHASE 240V, 50HZ SYNCHRONOUS GENERATO
     $R'
         PRINT 25,'WHAT IS THE MACHINE''S RATED VOLTAGE? (V)'
         READ*, VRATED
         TYPE ='1-PHASE SYNCHRONOUS'
            PGENVA = PTURO*1.6/0.8
      ELSE IF((PGENKW.LT.25.0).AND.(PGENKW.GT.10.0))THEN
         PRINT 25,'USE A 3-PHASE 415V,50HZ INDUCTION GENERATOR'
```

```
      TYPE = '3-PHASE INDUCTION MOTOR'
         PMOTOR = PTURO/0.8
      PRINT 35,'RATING OF MOTOR TO BE USED AS GENERATOR IS',PMOT
     $OR,'KW'
      PRINT 25,'FROM THE MANUFACTURER''S LIST WHICH IS THE STAND
     $ARD SIZE CLOSEST TO THIS RATING?'
      READ*,PMOTOR

C   DETERMINE THE MINIMUM VALUE OF CAPACITANCE REQUIRED FOR EXCITATION

      PRINT 25,'IS AN INDUCTION MACHINE MANUFACTURER''S DATA AVA
     $ILABLE?(Y/N)'
      READ*,IMDATA
      PRINT 25,'WHAT IS THE MACHINE''S RATED VOLTAGE? (V)'
      READ*,VRATED
         PGENVA = PMOTOR/0.8
      IF(IMDATA.EQ.'Y')THEN
         PRINT 25,'READ FULL LOAD CURRENT AND THE CORRESPONDIN
     $G POWER FACTOR'
         READ*,IFL,PFFL
            IM=IFL*SIN(ACOS(PFFL))
      ELSE
         PRINT 25,'CARRY OUT A NO-LOAD TEST ON THE MOTOR AND D
     $EDUCE THE NO-LOAD CURRENT AT RATED VOLTAGE AND ENTER THIS VALUE (A
     $)'
         READ*,INL
            IM=INL
      END IF
         XC=VRATED*1.732/IM
         CMIN=1/(2*PI*F*XC)
         VPEAK=VRATED*1.414
      PRINT 45,'THE MINIMUM CAPACITANCE REQUIRED IS',CMIN,'WITH
     $PEAK VOLTAGE OF ',VPEAK
      PRINT 25,'ALLOW MARGIN FOR PEAK VOLTAGE AND CHOOSE A STAND
     $ARD CAPACITOR THAT IS WITHIN 10% OF THE CALCULATED VALUE'
```

```
      ELSE
         PRINT 25,'USE A 3-PHASE 415V, 50HZ SYNCHRONOUS GENERATOR'
         PRINT 25,'WHAT IS THE MACHINE''S RATED VOLTAGE? (V)'
         READ*,VRATED
         TYPE = '3-PHASE SYNCHRONOUS'
         IF(PGENKW.LT.200)THEN
            PGENVA = PTURO*1.6/0.8
         ELSE
            PGENVA = PTURO*0.85/0.8
         END IF
      END IF

      PRINT 35,'THE GENERATOR SIZE REQUIRED IS ',PGENVA ,'KVA'
      PRINT 25,'WHICH IS THE STANDARD SIZE CLOSEST TO THIS?'
      READ*,PGENVA

C     DETERMINE THE SIZE OF TRANSFORMER REQUIRED

      IF(PGENVA.GT.50)THEN
         PRINT 25,'CHOOSE A STANDARD RATING OF TRANSFORMER OF VOLTAGE RA
     $TIO 0.415/11KV.'
         READ*,TXRATE
         PRINT 25,'WHAT IS THE TRANSFORMER''S TURNS RATIO, HV/LV'
         READ*,TRATIO

C     CALCULATE CT RATING REQUIRED FOR DIFFERENTIAL PROTECTION

         PRINT 25,'WHAT IS THE MACHINE''S PERCENTAGE TOLERANCE? (0 -100)'
         READ*,TOL
            TOL = (TOL+100)/100
            IGEN = PGENVA*TOL*1000/(1.7321*VRATED)
            ITXHV = IGEN/(1.7321*TRATIO)

C     CALCULATE THE MVA FAULT RATING OF THE CB JUST BEFORE THE BUSBAR
```

```
      END IF

      RETURN
      END

************************************************************************************

         SUBROUTINE ECON

************************************************************************************
*    THIS SUBROUTINE EVALUATES THE ECONOMIC ANALYSIS OF THE PROJECT     *
*    USING THE NET PRESENT WORTH METHOD AND COMPARES THE COST OF G-     *
*    ENERATING POWER USING MHP ON ONE HAND AND USING A DIESEL PLAN-     *
*    T ON THE OTHER. THIS IS EVALUATED FOR DIFFERENT INTEREST AND       *
*    DISCOUNT RATES AND FOR VARIOUS CAPACITY FACTORS.                    *
************************************************************************************

      REAL A(100),C,K,T,N,OM,UCE,CF(100),P,B(100),PWC(500),NPW(500),CD
      REAL SUMC(500),PWA(500),PWOM(500),PWB(500),SUMB(500),INTE(100)
      REAL AH(10),CCD,ULD(10),ICOM,AD(10),OMD,UCED(200),TFC(200)
      REAL UCEH(200),ULH(10),CCH,OMH,DIS(100)
      INTEGER J,L,I,G,R,Q,D,M,Z,E
      CHARACTER*1 ANS

      COMMON / EPARAM / F,PSITE,PGENVA

 5    FORMAT(' ',A / )
 15   FORMAT(' ',/ A,T6,A,T19,A,T32,A,T48,A )
 25   FORMAT(' ',T2,I2,T6,F15.2,T19,F15.2,T32,F15.2,T48,F15.2)
 35   FORMAT(' ', A,F15.2/ )
 45   FORMAT(' ',/A,F10.2  )
 55   FORMAT( A1 )
 65   FORMAT(' ',/ A,F6.4 / )
 75   FORMAT(' ',T5,F4.2,T20,F10.2  )
 85   FORMAT(' ',A,T30,A / )
```

```
95  FORMAT(' ',T30,A,T40,A /)
105 FORMAT(' ',T5,F4.2,T30,F5.3,T40,F5.3 )

    OPEN(20,FILE='A:CAPFAC.DAT',STATUS='OLD')
    REWIND(20)
    OPEN(10,FILE='ECONOM.RES')
    REWIND(10)

    PRINT 5,'HOW MANY VALUES OF INTEREST RATE DO YOU WANT TO TEST?'
    READ*,L
    PRINT 5,'HOW MANY VALUES OF DISCOUNT RATE DO YOU WANT TO TEST?'
    READ*,Q
    PRINT 5,'WHAT IS THE CAPITAL COST OF THE PROJECT INCLUDING THE DIS
   $TRIBUTION SYSTEM? ($)'
    READ*,C
    PRINT 5,'WHAT IS THE UNIT COST OF ENERGY FROM THE ALTERNATIVE SOUR
   $CE?(US$/KWH)'
    READ*,UCE
    PRINT 5,'ENTER THE CONSTRUCTION & FINANCING PERIODS AND THE USEFUL
   $ LIFE OF THE PROJECT'
    READ*,T,K,N
        P = PGENVA*0.8
    DO 40 R=1,Q
        PRINT 5,'ENTER THE DISCOUNT RATE (%)'
        READ*,DIS(R)
        WRITE(10,45)'DISCOUNT RATE = ',DIS(R),'%'
        DIS(R)=DIS(R)/100
        DO 50 I=1,L
            PRINT 5,'ENTER THE INTEREST RATE (%)'
            READ*,INTE(I)
            WRITE(10,45)'INTEREST RATE = ',INTE(I),'%'
                INTE(I)=INTE(I)/100
                A(I) = (C*INTE(I)*(1+INTE(I))**K)/((1+INTE(I))**K-1)
                OM = 0.03*C
            DO 60 M=1,10
```

```
          READ(20,*)CF(M)
          WRITE(10,45)'CAPACITY FACTOR =',CF(M)
             B(M) = UCE*CF(M)*P*8760
          WRITE(10,45)'ANNUITY FOR 6 YEARS REPAYMENT = ',A(I)
          WRITE(10,45)'ANNUAL O & M = ',OM
          WRITE(10,45)'ANNUAL BENEFITS = ',B(M)
          WRITE(10,15)'YEAR','PW ANNUITY','PW O&M','PW COSTS','PW
$ BEN.'
          SUMB(M) = 0
          SUMC(M) = 0

          DO 10 J=1,N
             IF(J.LE.K)THEN
                PWA(J) = A(I)/(1+DIS(R))**J
             END IF
             IF(J.GE.T+1)THEN
                PWOM(J) = OM/(1+DIS(R))**J
                PWB(J) = B(M)/(1 + DIS(R))**J
             END IF
             PWC(J) = PWA(J) + PWOM(J)
             SUMC(M) = SUMC(M) + PWC(J)
             SUMB(M) = SUMB(M) + PWB(J)
             NPW(M) = SUMB(M) - SUMC(M)
             WRITE(10,25)J,PWA(J),PWOM(J),PWC(J),PWB(J)
10        CONTINUE
          WRITE(10,35)'THE NET PRESENT WORTH IS =',NPW(M)
60     CONTINUE
       WRITE(10,95)'CAP. FACT.','NET PW'
       DO 20 E=1,10
          WRITE (10,75)CF(E),NPW(E)
          REWIND(20)
20     CONTINUE
50   CONTINUE
40 CONTINUE
```

```
C   COMPARATIVE STUDY OF MHP AND DIESEL ENGINE

      PRINT 5,'DO YOU WANT TO CARRY OUT A COMPARATIVE STUDY OF THE MHP A
     $ND THE EQUIVALENT DIESEL PLANT? (Y/N)'
      READ 55,ANS
         CCH = C
      IF(ANS.EQ.'Y')THEN
         PRINT 5,'ENTER THE TOTAL CAPITAL COST OF THE DIESEL PLANT'
         READ*,CCD
         PRINT 5,'HOW MANY VALUES OF USEFUL LIFE DO YOU WANT TO USE?'
         READ*,M
         PRINT 5,'ENTER THE COST OF FUEL PER KWH - ASSUME 0.30 LIT/KWH'
         READ*,FC
         PRINT 5,'WHAT INTEREST RATE DO YOU WANT TO USE (%)'
         READ*,ICOM
            ICOM = ICOM/100
         WRITE(10,5)'CAPACITY FACTOR AND AVERAGE GENERATION COST'
         WRITE(10,5)'FOR HYDRO AND DIESEL POWER STATIONS'
         WRITE(10,85)'AV. ANNUAL CF','AV. COST ($/KWH)'
         WRITE(10,95)'HYDRO','DIESEL'
         DO 80 J=1,M
            PRINT 5,'ENTER THE USEFUL LIFES OF THE HYDRO AND DIESEL PLANT R
     $ESPECTIVELY'
            READ*,ULH(J),ULD(J)
            DO 70 I=1,10
               READ(20,*)CF(I)

C   CALCULATE THE FIXED AND VARIABLE COST OF EACH UNIT

               AD(J) = (CCD*ICOM*(1+ICOM)**ULD(J))/((1+ICOM)**ULD(J)-1)
               OMD = 0.035*CCD
               TFC(I) = (AD(J)+OMD)/(CF(I)*P*8760)
               UCED(I) = FC+TFC(I)
               AH(J) = (CCH*ICOM*(1+ICOM)**ULH(J))/((1+ICOM)**ULH(J)-1)
               OMH = 0.02*CCH
```

```
          UCEH(I) = (OMH + AH(J))/(CF(I)*P*8760)
          WRITE(10,105)CF(I),UCEH(I),UCED(I)
70      CONTINUE
        REWIND(20)
80    CONTINUE
    END IF

    CLOSE(20)
    CLOSE(10)
    RETURN
    END
```

APPENDIX B

Gumbel Distribution (Extreme-Value Type I Distribution)

This method has two approaches. In both cases, streamflow data taken over a number of years must be available. For the determination of flood flow rate for a given recurrence frequency, the peak river flow rate for each recorded year must be known.

The first approach calculates the recurrence period T_r as

$$T_r = \frac{n+1}{m}$$

where n = number of years of record

m = rank of event in order of magnitude, the highest annual peak discharge being m=1 down to the lowest being m = n.

The probability, P, that a flood recurs is the reciprocal of the return period

$$P = \frac{1}{T_r}$$

The graph of annual peak discharge against return period on a special extreme-value probability graph paper yields a straight line. Other values are extrapolated from the graph.

The second method involves the calculation of the mean and standard deviation of the annual peak discharge rate values. The flood discharge rate, X, with a specified recurrence period is given by

$$X = \bar{X} + K\sigma_x$$
$$K = 0.7797y - 0.45$$

where

$\bar{X}$ - is the mean of the annual peak discharge rates

σ_x - is the standard deviation

y - is the reduced variate given by

$$y = -\ln[-\ln(1-p)]$$

Values of K are given in the table below.

Table B-1 : Values of K for the extreme-value (type I) distribution.

Return period, years	Probability	Reduced variate, y	K
1.58	0.63	0.000	-0.450
2.00	0.50	0.367	-0.164
2.33	0.43	0.579	0.001
5	0.2	1.500	0.719
10	0.1	2.250	1.30
20	0.05	2.970	1.87
50	0.02	3.902	2.59
100	0.01	4.600	3.14
200	0.005	5.296	3.68
400	0.0025	6.000	4.23

For example, the flood discharge rate with a return period of 50 years (probability of 0.02) will be equal to

$$X(50) = \bar{X} + 2.59\sigma_x$$