AFREPREN/FWD

Energy, Environment and Development Network for Africa

BACKGROUND MATERIAL

Fundamentals of Small Hydro Power Technologies

Financing Cogeneration and Small-Hydro projects in the Sugar and tea Industry in East and Southern Africa Training

Small Hydro[1]

Module Overview:

This module presents the general overview of small hydropower development and how it can contribute to meet the electricity needs of the national grid as well as the isolated rural areas. Small hydro power provides reliable energy supply. It also has low operating costs and is independent of energy price volatility. It is a renewal source of energy and has minimum adverse environmental impacts. The hydropower potential of Africa, particularly in the small hydro power range (less than 10MW), is yet to be harnessed. Small hydro projects including micro hydro plants (less than 100 kW) and mini hydro (less than 0.5 MW) can be quickly implemented with reasonable financial requirements. Thus development of small hydro plants can help change the present low access of electricity in many countries in the continent. Its contribution to the national economy as well as to improvement in health, education and other social sectors of the benefited population will be very high.

The case study from Nepal shows how a country that relied on external assistance for its hydropower development has now developed its local capability and utilized the internal resources available to develop it hydropower resources, especially the small hydro projects.

Two spread sheet based packages, one for small hydro (developed by RETScreen International) and other for micro hydro (developed by Small Hydro Promotion Center/GTZ), will be introduced in a separate session as part of the training course. The participants will be able to carry out a hands-on preliminary assessment and design of a small hydro project using the RETScreen International Small Hydro Model during this session.

Key Aims

This module aims to introduce the participant to small hydro options, explain the fundamentals and principles of operation, provide the status of small hydro utilisation in Africa, present a case study of a country that has successful implemented small hydro.

Module Learning Outcomes

- Broad appreciation of small hydro, its application and its status in Africa
- Enhanced understanding of small hydro for electricity generation and mechanical power

[1] Prepared by Dr. Divas B. Basnyat for the ADB FINESSE Training Course on Renewable Energy & Energy Efficiency for Poverty Reduction, 19th-23rd June 2006, Nairobi, Kenya.

Financing Cogeneration and Small-Hydro projects in the Sugar and tea Industry in East and Southern Africa Training

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1.0 Introduction

Hydropower harnesses the power of falling water to generate electricity. The higher the flow of water and steeper the gradient of the rivers, more suitable are they for hydropower generation. It is a non-consumptive use of water which means that the flow used for power generation is discharged back to the river after power generation. It is a renewable source of energy as the river flows are sustained and renewed though the hydrological cycle. It is also considered a cheap, environmentally friendly source of energy.

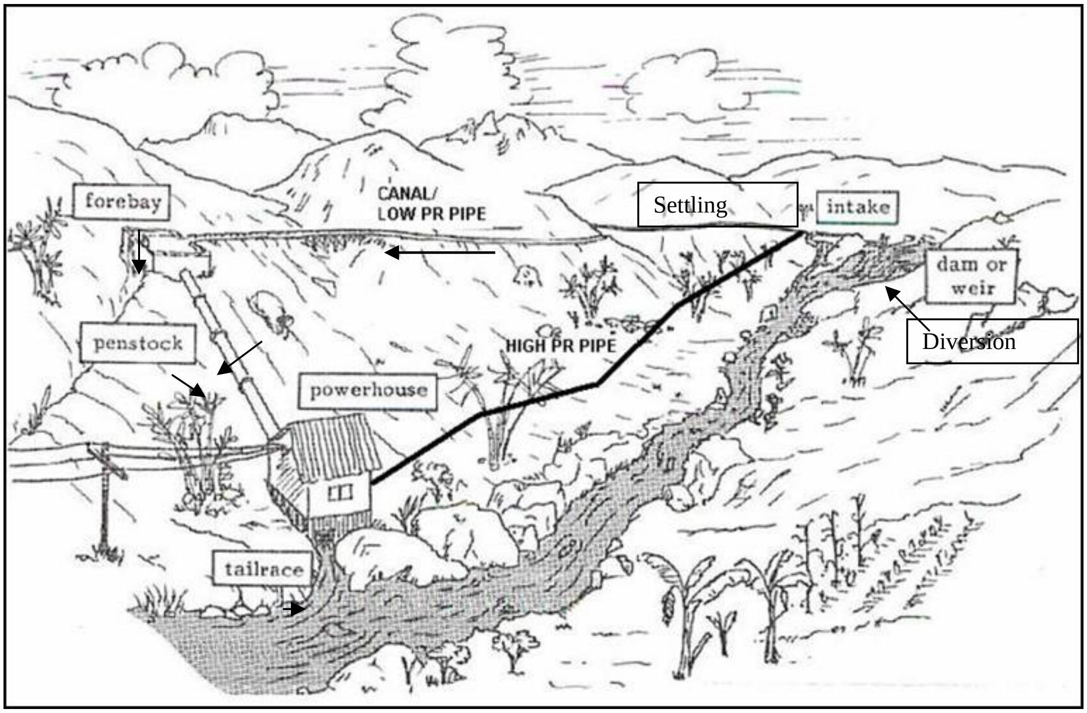
Small hydropower can be used to supply power to isolated and central grids. A grid is an interconnected network of power generating plants and transmission lines that supply power to a number of distributed consumers. Central grids cover a vast geographical area with a large number of generating plants and millions of consumers. Isolated grids cover a smaller area which are not connected to a central grid and supply electricity to small towns and villages which are normally remote and far from larger load centres. In some cases, small hydropower plants supply power to small and medium scale industries directly such as cement or fertilizer factories. Small hydropower is widely used for rural residential lighting, TV, radio and telephone services in the rural areas. It also supplies the power necessary for small industries, agriculture and other productive uses.

Small hydropower plants also have minimum environmental impacts as they are mostly harnessed through run-of-the-river (ROR) schemes. These schemes do not change the natural flow much and also does not have the environmental problems such as resettlement and land inundation associated with large dams.

Small hydropower is thus considered a reliable, low cost source of energy and is independent of the energy price volatility associated with plants using fossil fuels.

Figure 1 depicts a typical layout of a small hydropower scheme. A diversion dam or a weir is used to divert the water through a headrace canal or a pipe to the power house where turbines and generators are housed. Water is conveyed either through a canal or low pressure pipe to the forebay and then through a high pressure penstock to the powerhouse. Alternatively, it can be conveyed through a high pressure pipe to the powerhouse. A settling basin is used to settle and eject sediments that create problems to the turbine runners.

Figure 1: A Typical Layout of a Small Hydro Scheme



2.0 Definition

Small hydro is referred to harnessing of power from water in a small scale, usually with a capacity less than 10 MW. Based on the size (capacity) of the hydropower plant, they are further categorized into pico (usually below 5kW), micro (less than 100 kW), mini (between 100 kW and 1000 kW) and small (between 1000 kW and 10,000 kW). The definition of the small hydro based on the capacity however varies from country to country which are reflected on the local capability and demand/load of remote areas in that country. **Error! Reference source not found.** shows the variation of definition of small hydro in different parts of the world.

Table 1: Definition of Small Hydro (based on size)

Country	micro (kW)	Mini (kW)	small (MW)
United States	< 100	100 – 1000	1 - 30
China	-	< 500	0.5 - 25
USSR	< 100	-	0.1 - 30
France	5-5000	-	-
India	< 100	101 – 1000	1 - 15
Brazil	< 100	100 – 1000	1 - 30
Norway	< 100	100 – 1000	1 - 10
Nepal*	< 100	100 – 1000	1 - 10
Various	< 100	< 1000	< 10

Source: http://www.microhydropower.net/size

The design flow and the runner diameter are other parameters also used to define/categorize small hydro. Error! Reference source not found. shows the definitions for micro, mini and small hydropower used by RETScreen International.

Table 2: RETScreen International's Definitions

	Typical Power	RETScreen® Flow	RETScreen® Runner Diameter
Micro	< 100 kW	< 0.4 m3/s	< 0.3 m
Mini	100 to 1,000 kW	0.4 to 12.8 m3/s	0.3 to 0.8 m
Small	1 to 50 MW	> 12.8 m3/s	> 0.8 m

3.0 Fundamentals and Principles

3.1 Hydropower Generation Process

Potential energy of flowing water is converted to kinetic energy as it travels through the penstock. Kinetic energy of the flowing water is converted to mechanical energy as it turns the turbines. Mechanical energy of the rotating turbine is then converted to electrical energy as the turbine shaft rotates the generator

Hence, the power generated from a hydropower plant is basically a function of head and discharge. The power generation is calculated using the following formula:

$$P = \eta * \rho * g * Q * H$$

<u>Where,</u>
P = power in Watts
η = efficiency (micro – 50-60%, small > 80%)
ρ = density of water (1000 kg/m3)
g = acceleration due to gravity (9.81 m/s2)
Q = flow passing thru the turbine (m3/s)
H = head or drop of water (m) (difference between forebay level and turbine level or tail water level)

If we consider η to be 80%, power generation can be approximately estimated as being equal to P = 8*Q*H kW.

3.2 Types of Small Hydro

Small hydropower plants are generally categorized on the basis of the type of grid it is connected to and the regulation of flow, if any, by the plant. Small hydro can be connected to a central grid, to an isolated grid or can be connected to a dedicated power load such as a cement factory, lodges, mines etc.

Flow available in the river varies over time, from one season to another and from one year to the other. In run-of-river schemes, there is no water storage and the natural flow available in the river is diverted to generate power. Hence, the power generation from a run-of-river scheme also varies with time and the firm capacity can be quite low. They are normally not suited for isolated grids or off-grids unless the minimum power generated in the lowest flow season is sufficient to meet the peak demand. When they are used to supply a grid, they can be used in conjunction with other power generators to meet the power demand at all times. During high flow season, small hydros generate more and other reservoir type or thermal generators generate less and vice versa. In some cases, a small pondage is used to store water so that the available flow even in the lowest season can be regulated over a daily period and more power can be generated during some peak demand hours of the day such as the morning and evening. At other times of the day when the demand is low, less power is generated and water is stored. These types of hydro plants are used for daily peaking plants.

When there is a reservoir used to store water, the power generation can be varied according to the load. Hence, the firm capacity is higher and more power can be generated when there is more demand. Creating a reservoir to store water however requires damming the river. Dams create environmental problems as they can displace people living there, inundate fertile land or forests, and also change the flow regime impacting the aquatic life downstream. Therefore, unless there is a pre-existing lake or dam that can be used, reservoir type small hydro plants are less likely. Hydropower plants can also use what is known as pumped storage, where energy in off-peak periods can be used to pump water back to the reservoir and the pumped water can later be used to generate power during peak load hours. Again, given the requirements for a reservoir and pumping facilities, they are less likely for a small hydro.

3.3 Main Components

The main components of small hydro are civil works, turbines and electrical and other equipments.

3.3.1 Civil Works

The cost of civil works for small hydro accounts for about 50-60% of the total cost. Large dams to store water will normally be costly for small hydro. Hence, a low dam or simple diversion weir made of concrete, wood or masonry is mostly used in small hydro. They divert water through the conveyance system (usually a headrace canal or pipe and sometime even tunnels) to the power house. Intake with the trash racks and gates are provided. Any excess water is discharged downstream the weir. Fish ladders may also be provided for the fish to travel upstream as per its requirements. Sometimes the power house is located just below the intake and no water conveyance system is this necessary. Valves and gates at the entrance and exit of turbines are used to shut off flow during maintenance.

Other civil structures are the settling basins for settling and excluding the sediment from entering the turbines. A forebay is also used upstream of the penstock to balance the fluctuations in the water levels during sudden operation and shutdown of the turbines. When a tunnel is used for water conveyance, a surge tank or shaft is used to avoid the impacts of sudden opening and shutting down of power generation. Water from the power house is discharged back to the river through the tail race canal or tunnel.

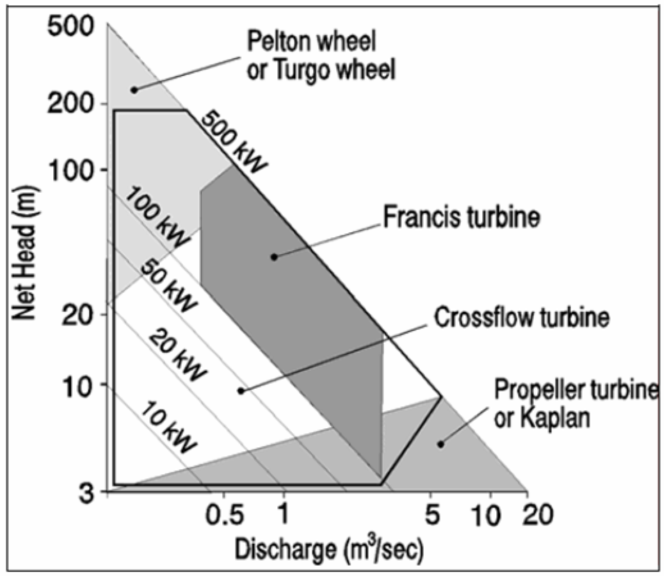
The power house, housing the turbines, generators and other electrical and mechanical equipment, is also part of the civil works.

3.3.2 Turbines

Turbines in small hydro plants need to perform well over a highly variable range of flow available. Multiple turbines are therefore used so that they can optimally operate in a small range of flow. Turbines used in small hydro plants operate at an efficiency level of about 90%.

Turbines can be categorized into two types: reaction and impulse. In a reaction turbine, the runner or spinning wheel is completely immersed in the flow and they use water pressure and kinetic energy of the flow. They are appropriate for low to medium head applications. On the other hand, in impulse turbines the high pressure flow passes through the nozzle that converts it into a jet of water at atmospheric pressure but high velocity and high kinetic energy. Thus it uses the kinetic energy of a high speed jet of water which exerts an impulsive force on the runner and causing it to spin. Examples of reaction turbines are Francis, fixed pitched propeller turbines and Kaplan and examples of impulse turbines are Pelton, Turgo and cross flow turbines.
Source: BHA, *2005*
presents the range of head and flow different type of turbines.

Figure 2: Head-flow Range of Small Hydro Turbines



Source: BHA, 2005

3.3.3 Electrical and other Equipment

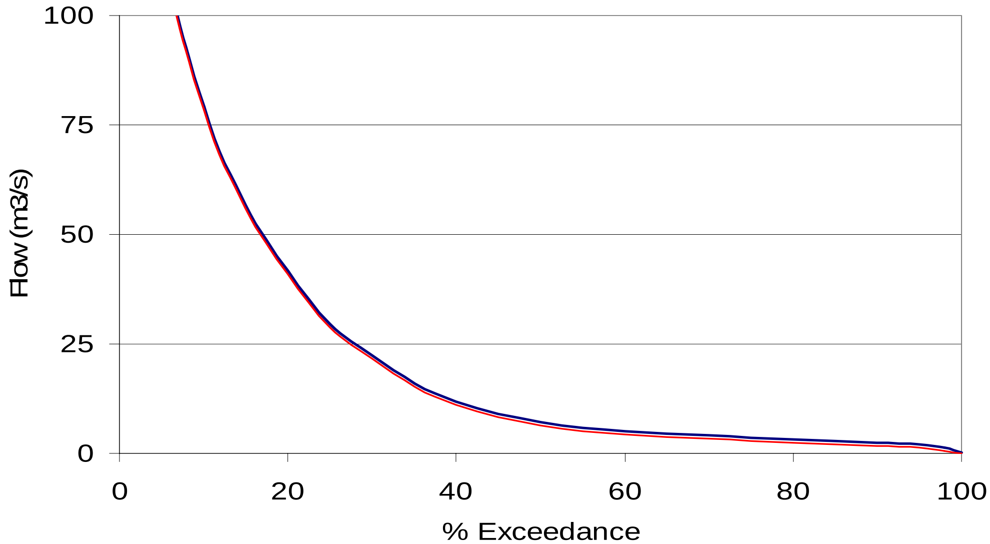
The main electrical component in a small hydro is the generator. There are two types of generators: induction and synchronous generators. Induction generators are used to supply to large power grids whereas synchronous generators are used for stand-alone and isolated-grid applications.

Other electrical and mechanical equipment used in a small hydro are speed increasers, water flow valves, electronic controls and protection devices, and transformers. Speed increasers are used to match the rotational speed of the turbine to the speed of the generator, as dictated by the grid frequency. Valves, electronic controls and protection devices are used to protect the equipment from unexpected situations. Transformers are used to increase the voltage of electricity produced to reduce transmission losses.

4.0 Power/Energy Calculation

The power or energy generated by a small hydro is dependent on the flow and head. Head in a small hydro is normally constant as run-of-river plants have a fixed head water level. Flow available can however be quite variable. The variability of the flow in the river is represented by what is called the flow duration curves (FDCs). FDC is a curve with the probability of exceedance in the x-axis and the flow (in m^3/s) in the y-axis. The minimum flow is considered to be exceeded 100% of the time whereas the maximum flow is exceeded 0% of the time. Hence, a 90% dependable flow means that the flow is exceeded 90% percent of the time or that the flow is more than this value in 9 out of 10 years. The design discharge of a run-of-river type small hydro can be selected anywhere between 90% to 50% or 60% dependable flow values. **Error! Reference source not found.** presents a typical FDC.

Figure 3: Flow Duration Curve



While calculating the power or energy generation of a small hydro, one also has to take in consideration the compensation flow which cannot be diverted but has to be discharged downstream. These compensation flows are environmental flow requirements, irrigation requirement downstream and any leakages that may occur at the point of diversion. The available flow for power generation is thus the natural flow available in the river minus the compensation flow requirement.

Net head available is the gross head minus the head losses at the headworks, headrace, penstock and other hydraulic structures. Hence, power/energy generation calculations is made using the flow, net head and efficiency values on the power equation given in the Section 3.1 above. Error! Reference source not found. and Error! Reference source not found. present a typical power duration curve and month energy pattern for a small hydro.

Figure 4: Power Duration Curve

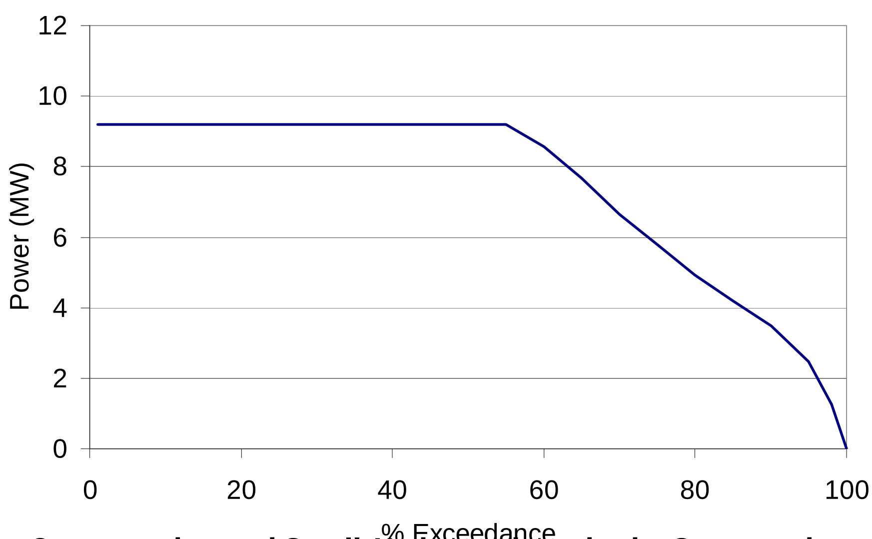


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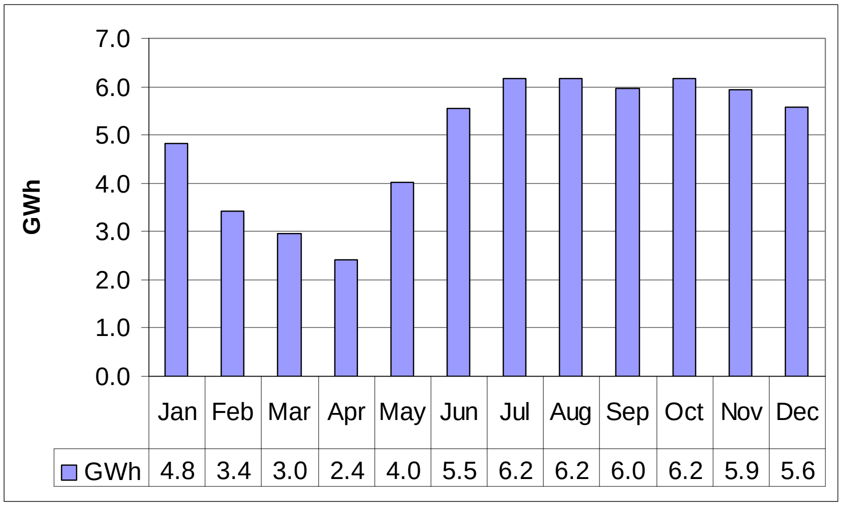
Figure 5: Monthly Energy Generation



5.0 Small Hydro in Africa[2]

Eastern and Southern Africa has many permanent rives and streams providing excellent hydropower development potential. However, as shown in **Error! Reference source not found.**, small hydropower utilisation in the region is still very low. Hydropower contributes about 18% of the total power generation in Africa. Error! Reference source not found. and Error! Reference source not found. present the potential of small hydro in Africa.

Table 3: Small Hydropower Utilisation in Africa

Country	Harnessed (MW)	Country	Harnessed (MW)
Botswana	1.00	Rwanda	1.00
Burundi	2.93	Somalia	4.60
Ghana	1.20	South Africa	0.40
Kenya	13.64	Swaziland	0.30
Lesotho	8.74	Tanzania	4.00
Malawi	4.50	Uganda	8.00
Mauritius	6.70	Zambia	4.50
Mozambique	0.10		

Source: Karekezi and Kithyoma, 2005

Table 4: Small Hydropower Developed and Potential in Selected African countries

Country	Small hydro potential (MW)	Harnessed (MW)
Uganda	46	8 .00
Mauritius		6.70
Kenya	600	14.00
Burundi	42	18.00
Zambia	4	1.05
Tanzania	70	9.00
Lesotho	?	5.10
Malawi	20	4.50
Botswana		1.00

[2] Adapted from the Background Material prepare by AFREPREN

Rwanda		3
South Africa	?	0.40
Swaziland		0.1
Mozambique		

Source: Karekezi and Kithyoma, 2005, UNIDO and REEEP, 2006

Table 5: Small Hydro Power Sites in Selected Countries in Africa

Country	Number of Sites
Madagascar	Over 100
Burundi	Over 100
Kenya	Over 100
Uganda	22
Lesotho	22
Zambia	20
Rwanda	8

Source: AFREPREN, 1998

Burundi has a large hydro potential estimated at 1,300 MW and 6,000 GWh, from which 300 MW could be economically exploited. Today, 27 micro hydro power plants have been installed in Burundi with a total capacity of 32 MW

Hydropower is **Mozambique's** most important commercial energy resource, with the potential estimated at about 14,000 MW, of which about 2,300 MW has so far been developed, 2,075 MW at Cahora Bassa Dam over the Zambezi River and the remaining is distributed among a number of sites throughout the country. Mapping of hydro resources for medium and high size hydro plants has been made in around 60 rivers throughout the country, during the seventies [1]. No specific study has been undertaken for small hydro power plants, but the Ministry of Energy has plans to start such a study soon (Cuamba, 2006).

The history of mini/small hydropower development in **Tanzania** dates back to the colonial period where small hydro plants were developed to supply power to specific communities like religious centres (schools and hospitals). Error! Reference source not found. shows existing mini/small scale hydro power stations (Kassana, 2006).

Table 6: Existing Mini/Small Scale Hydropower Stations in Tanzania

Location	Turbine/Manufacturer	Installed Capacity (kW)	Remarks/Owner
Tosamaganga - Iringa	Gilkes & Gordon/Francis	1,220.0	TANESCO
Kikuletwa - Moshi	Boving & Voith Reaction	1,160.0	TANESCO
Mbalizi - Mbeya		340.0	TANESCO
Uwemba - Njombe		840.0	TANESCO
Kitai - Songea	Cross-flow/ Ossberger	45.0	PRIVATE
Lupilo (Chipole) - Songea	Francis	400.0	PRIVATE
Maguu - Mbinga		50.0	PRIVATE
Nyagao - Lindi	Cross Flow/Ossberger	15.8	PRIVATE
Isoko - Tukuyu	Cross Flow/Ossberger	15.5	PRIVATE
Uwemba Mission - Njombe		100.0	PRIVATE
Bulongwa – Makete	Cross Flow/Ossberger	180.0	PRIVATE
Kaengesa - Sumbawanga	Cross Flow/Ossberger	44.0	PRIVATE
Rungwe - Tukuyu	Cross Flow/Ossberger	21.2	PRIVATE
Ngaresero - Arusha	Gilbsk	15.0	PRIVATE
Sakare – Soni _Tanga	Geiselbrecht	6.3	PRIVATE
Ndanda - Lindi	Gilbsk	14.4	PRIVATE
Peramiho - Songea	Cross Flow/Ossberger	34.6	PRIVATE
Ndorage – Bukoba	B. Maler	55.0	PRIVATE
Mbarari – Mbeya	Chinese	700.0	PRIVATE
Mngeta Kilombero	Xxxxxxx/North Korea	400.0	PRIVATE

Location	Turbine/Manufacturer	Installed Capacity (kW)	Remarks/Owner
Ikonda – Njombe	CMTIP	40.0	PRIVATE
Total		***5.3 MW***	

Source: TANESCO/MEM in Kassana, 2006

The government policy on small hydropower is to develop small sites in areas, which are not supplied with power from the National grid, or to replace diesel generation in isolated areas. Based on this policy, several small-scale hydropower development activities have been initiated by the government in cooperation with local and foreign agencies. On-going development activities in small hydro development range from site identification, pre-feasibility/feasibility studies (Kassana, 2006).

Both large and small hydropower business fall under the same energy structure as other sources of energy. At this time in point, they are still controlled and regulated under mainly, the ministry of energy and minerals (Kassana, 2006).

The general status of the small-hydro power sites (Non-Nile sites) in **Uganda** is shown in Error! Reference source not found.. The table shows the installed capacities of the sites, the general status of the power site whether operational or non-operational and the districts in which they are located (Opio, 2006).

Table 7: Small Hydro Sites (Non-Nile) in Uganda

Site	District	Installed Capacity (MW)	Potential (Estimated) (MW)	STATUS
Maziba	Kabale	1.0	-	Out of operation- needs rehabilitation
Kuluva	Moyo	0.12	-	In operation feeding Kuluva Hospital
Kagando	Kasese	0.06	-	In operation feeding Kagando Hospital
Kisiizi	Rukungiri	0.06	-	In operation at 60 kW Expansion program to 365 kW is in progress. Project exemption was approved in 2002.
Mobuku 1	Kasese	5.4	-	In operation by Kilembe Mines. Supplies Kilembe and feeds into the Main Grid
Mobuku 3	Kasese	10	-	Operated by Kasese Cobalt Co and feeds into the Main Grid
Muzizi	Kibale/ Kabalore	-	10-20	Developer SN Power Invest AS Permit granted Nov/Dec 2004 for 12 months Feasibility study still going on
Paidha/Nyagak	Nebbi	-	3.5MW	Feasibility study completed and ready for development WENRECO was awarded concession in March 2003 Conducting a Resettlement Action Plan (RAP). Construction expected to begin Jan 2007
Rwizi	Mbarara	-	0.5	Pre-investment studies carried out
Kakaka	Kabarole	-	7.2	Feasibility studies carried out by SWECO Eco Power has applied for a permit and is carrying out pre-investment studies
Nshungyezi	Mbarara	-	20	EDM has a permit to develop the site.
Nyamabuye	Kisoro	-	2.2	Developer USEC (Uganda Sustainable Energy Company Limited. Permit granted Feb 2005 Feasibility study was conducted by Norplan. USEC yet to start on pre-investment study
Siti	Kapchorwa	-	3.3	Developer Mt. Elgon Power Company Permit issued July 2002 and extended until expiry in September 2004
Sipi-Chebonet	Kapchorwa	-	2.5	Developer Mt. Elgon Power Company Permit issued July 2002 and extended until expiry in September 2004
Anyau/ Olewa	Arua	-	1.5	WENRECO has exclusive rights to the site through the West Nile License
Haisesero	Kabale	-	1.0	Estimate
Kitumba	Kabale	-	0.2	Estimate
Mpanga	Kabarole	-	0.4	Estimate
Nyakibale	Rukungiri	-	0.1	Estimate
Leya	Moyo	-	0.12	Estimate
Amua	Moyo	-	0.18	Estimate

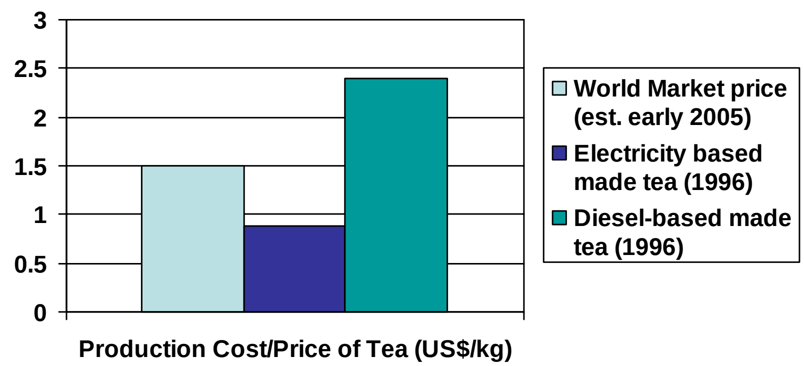
Site	District	Installed Capacity (MW)	Potential (Estimated) (MW)	STATUS
Narwodo	Nebbi	-	0.4	Estimate
Mvepi	Arua	-	2.4	Estimate
Adjumani Rural Electrification Project (River Esia)	Moyo	-	1	Permit granted 29th July 2005 for 12 months Developer Adjumani Rural Electrification Company Limited (ARECO)
Ela	Arua	-	1.5	Estimate
Agoi	Arua	-	0.35	Estimate
Nkussi	Kibale	-	0.9	Estimate
Kikagati	Mbarara	-	20	Old Power plant used to operate at 1MW. China Shang Sheng Industrial Intl Ltd to rebuild and expand the plant to 20MW. Permit granted 29th July 2005 for 12 months
Sezibwa	Mukono	-	0.5	Estimate
Tokwe	Bundibugyo	-	0.1	Developer Uganda Energy for Rural Development (UERD)
Mgiita	Bundibugyo	-	0.15	Estimate
Miria Adua	Arua	-	0.1	Estimate
Sogahi	Kabalore	-	2.0	Estimate
Ishasha	Rukungiri	-	5.0	Feasibility studies carried out by Tele Consult Eco Power has applied for a permit and is carrying out pre-investment studies
Buseruka	Hoima	-	10	Feasibility studies completed by Hydromax 12 months extension of the permit granted effective 1st August 2005
Nengo Bridge	Rukungiri/Kanungu	-	7.5	Developer SN Power Invest AS Permit granted Nov/Dec 2004 for 12 months
Waki	Masindi/Hoima	-	5	Feasibility study by Norplan Developer SN Power Invest AS Permit granted Nov/Dec 2004 for 12 months
Bugoye	Kasese	-	11	Developer SN Power Invest AS Permit granted Nov/Dec 2004 for 12 months
Kyambura	Bushenyi	-	10	Pre-feasibility studies being carried out by Eco Power
Muyembe-Sirinutyo	Sironko	-	2.6	Developer Mt. Elgon Power Company Permit issued July 2002 and extended until expiry in September 2004
Ririma	Kapchorwa	-	1.2	Developer Mt. Elgon Power Company Permit issued July 2002 and extended until expiry in September 2004
Mahoma	Rutete Sub-County		3	Developer Uganda Energy for Rural Development Permit granted Nov/Dec 2004 for 12months
Rwebijooka	Buheesi Sub-County		1	Developer Uganda Energy for Rural Development Permit granted Nov/Dec 2004 for 12months

Source: Ministry of Energy and Mineral Development in Opio, 2006

The mini hydro potential in **Zambia** is estimated at more than 60 MW; however, no countrywide studies have been done to verify this figure. Exploitation of this resource continues to be very low. With the setting up of the Rural Electrification Authority, it is anticipated that more small hydro power stations will be developed. Currently almost all the small hydro stations are in the north and North West of the country and operate as isolated systems. ZESCO, Zambia's power utility, owns and operates small hydropower plants in the northern half of the country. These are the 12 MW Lusiwasi hydropower station, the 6MW Chishimba Falls power plant on the outskirts of Kasama, 5MW Musonda Falls power station in Mansa and the 0.75MW Lunzua Power station near Mpulungu (Phiri, 2006).

A study on feasibility of electricity based tea processing in East Africa shows that use of small hydro in the tea processing industries make the tea prices very competitive to the world market price compared to the diesel based tea Error! Reference source not found..

Figure 6: Tea and Small Hydro in East Africa



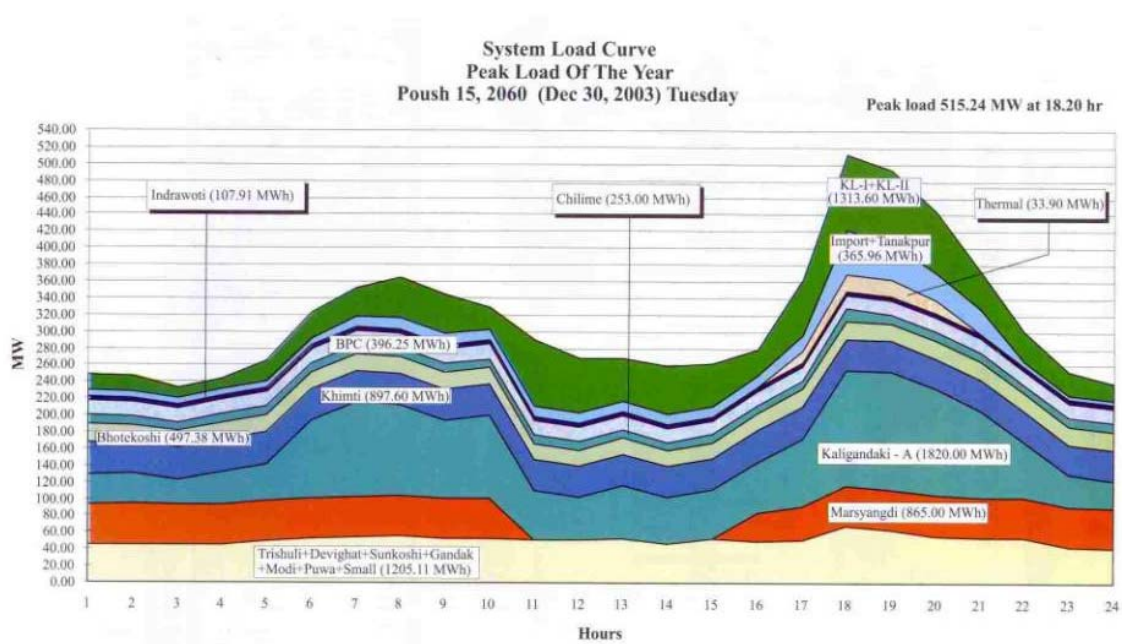
Source: *http://greeningtea.unep.org*

6.0 Applications of Small Hydro

6.1 Electricity Generation

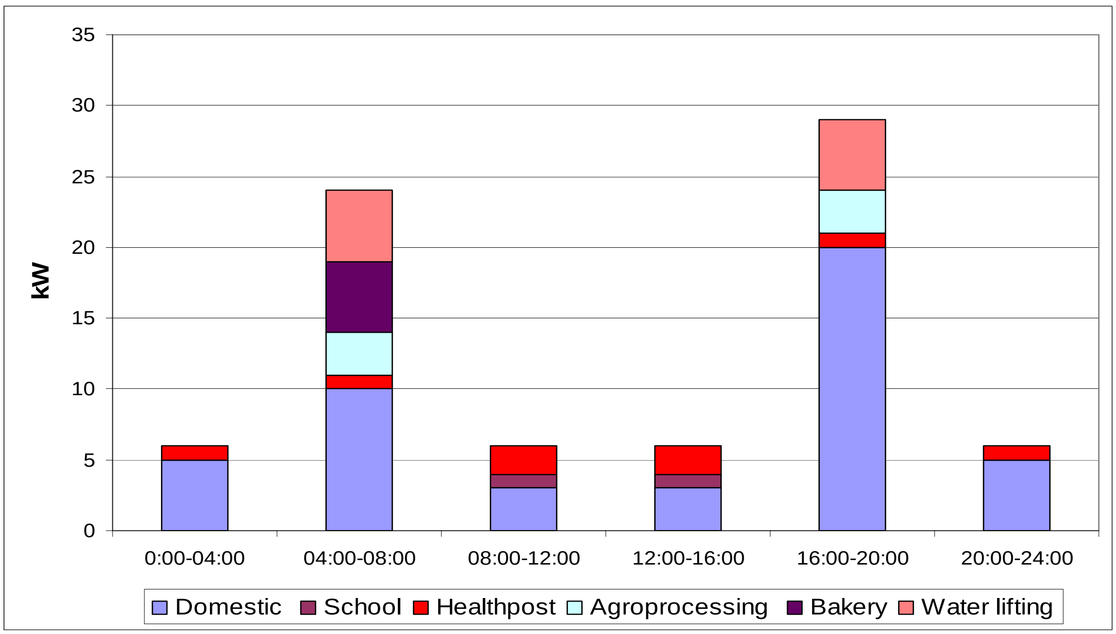
As explained earlier, small hydro is used to supply electricity to central grid, isolated grid or even to dedicated supply to a factory, mill, mine, hotel etc. In the case of a central grid, electricity generated from a small hydro is used in conjunction with other generating plants in the system. And example of the type of daily load of a national grid in Nepal is presented in Error! Reference source not found..

Figure 7: A Typical Daily System Load



When the small hydro is used to meet the load of an isolated grid of small town or village, different types of loads need to be considered. Domestic Load which is dependent on the number of households and the electrical items used on the households such as lighting, TV, radio etc. Industrial and commercial load of small town or village constitute the loads required by the small enterprises, agro-processing units, shops etc. Social loads are the electricity demands of schools, health posts etc. Hence, the load curve of the isolated load centres depends on the share of these various loads. A typical example of a load curve of an isolated system is in presented in Error! Reference source not found.. The morning and evening peak demand is considerably higher than other times. If the capacity of small hydro is designed to meet the peak demand, there would be surplus/spill energy at other times. This type of load is a problem for isolated systems.

Figure 8: A Typical Load Curve of an Isolated Grid



6.2 Mechanical Power

Hydropower can also be used as a means of mechanical power, where the mechanical energy from the turbines are directly used for some useful purpose instead of connecting it to a generator to generate electricity. Example of such uses are for lift irrigation, water supply, agro-processing (gain milling), saw milling, lathe machine operation etc. Water mills are extensively used world wide to grind grains and paddy hauling. Each mill use or produce an equivalent of 0.5kW of power. Traditional water mills are quite inefficient and improve water mills (IWM) which are more efficient are being promoted worldwide. IWMs are used both for grinding grains during day time and for electricity generation in the evenings.

7.0 Barriers to Development and Implementation

Small hydro are known to requite high initial investments although the operation and maintenance cost is negligible later on. And with competition on investment from other sectors, investment is not always available for small hydro. As most good sites are also located in remote areas, infrastructure constraints such as access roads and transmission lines make these good sites difficult to develop. There are also a number of technical and non-technical risks associated with small hydro. Developers and lending agencies are sensitive to these risks. Technical risks are the hydrological and geological uncertainties associated with the project locations. Non-technical risks are the market risks, political risks associated with a high investment required for small hydro. Due to the complex nature of implementation of small hydro, there are very often time and cost over-run in the construction of small hydro. These impact the financial viability of the project. Most countries in the developing world also lack local capability of the design and construction of small hydro. The local manufacturing and construction industry in these countries are also not developed to implement even small hydro projects. In such cases, foreign companies and manpower come and develop the projects making them very expensive and non-affordable by the local population. Foreign companies are also mostly interested in large projects making it difficult to develop small hydro. Institutional shortcoming such as lack of coherent policy framework and monopolistic role of national power utilities are other known barriers to small hydro.

8.0 Design Aids

There are a number of design aids available to assist in the planning and design of small hydros. Most of the popular ones are based on a spreadsheet. Two popular ones available as a free ware are the one developed by RETScreen International and another developed by the Small Hydro Promotion Project/GTZ, Nepal. The former one is more of a planning tool with basic calculations of energy generation and cost including financial and economic analysis. The latter is more of a design tool where templates are used to design and compute the basic parameters of a small hydro project.

9.0 Case Study – Nepal

9.1 Potential and Status

Nepal is a country known for its hydropower potential. It is estimated that a theoretical potential of 83,000 MW and an economical potential of 42,000 MW exist in the country. This relates to about 727,000 GWh/year of energy using average flow and 145,900 GWh/year of energy based on 95% exceedance flow. Currently, the country is generating more than 600MW of hydropower, out of which about 15% is from small hydro. In addition, more than 2200 schemes (2003 data) of micro hydro (1-100 kW) are generating more than 15MW of electricity and meeting the needs of remote communities all over the country. Similarly, more than 25,000 traditional water mills are used for agro-processing, each mill is estimated to be of 0.5kW equivalent capacity.

Small hydropower promotion has now been the stated policy of the government since a new hydropower policy was formulated in 1992. Private sector is now actively involved in the small hydro sector. Licenses are not required for projects under 1 MW. And there are a number of INGOs and NGOs actively promoting micro and small hydro in the country. There is also a government subsidy provided for micro hydro supplying power to rural communities that are very unlikely to be connected to the central grid soon. The 1992 and the revised hydropower policy of 2001 also provide tax and other incentives for private sector participation. This has led to a paradigm shift in the way hydropower (especially small hydro) is taken in Nepal. In a country where most hydropower projects were undertaken by the public sector with donor support, there have now been more than 150 MW of power generated by the private sector since 2000. Local financial institutions are now actively involved in small hydropower development with 7 projects of a total capacity of 55 MW being completed in recent years through commercial credit from local banks. This has led to the cost of generation being reduced drastically (almost by one third or more). It has also led to the expansion of the national hydropower industry and enhancement of the local capability to undertake even medium scale hydro projects.

9.2 Small Hydro Financing Modality

There are various modalities in place in Nepal for hydropower development. They differ in terms of the cost of capital and the technology used. These can be broadly classified as follows:

- Donor assisted concessional loans (presently used only for large hydros)
- International private companies with commercial loans (which have undertake medium sized projects of 36MW and 60MW capacity)
- National private companies with local commercial loan (which have undertaken a number of small hydros)
- National utility (Nepal Electricity Authority (NEA)) through local commercial loans (mainly between 5 – 20 MW)
- Government/donor supported agencies like Alternate Energy Promotion Center (AEPC) provide subsidy and technical support to micro hydro development in remote locations.

It can be seen from Error! Reference source not found., Error! Reference source not found. and Error! Reference source not found. that the cost composition is markedly different for the various modalities of development.

Figure 9: **Cost Composition of Typical Project Developed By the National Electric Utility**

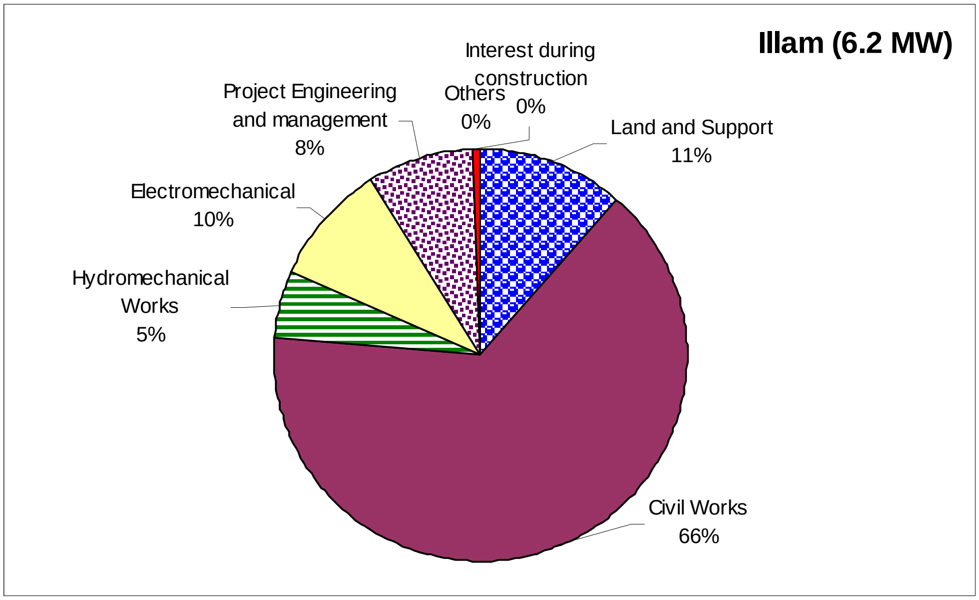


Figure 10: **Cost Composition of a Typical Project Developed By an International Private Developer**

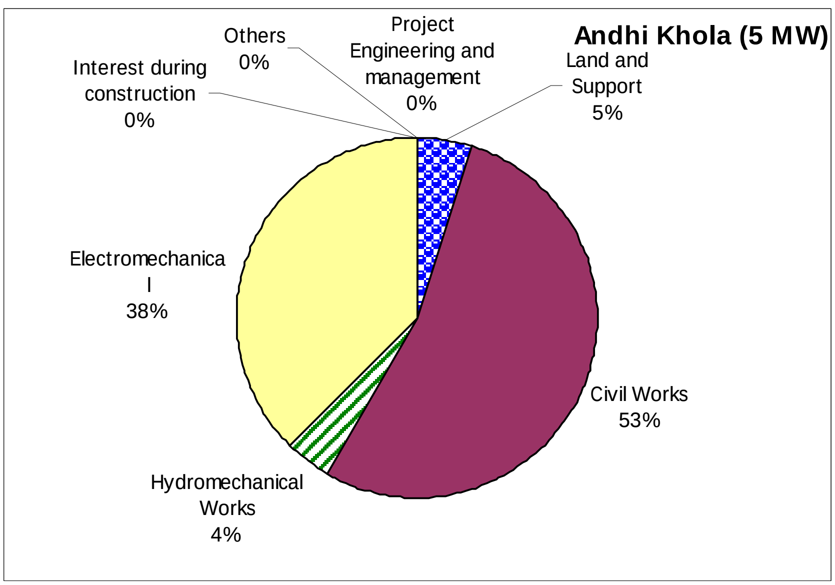
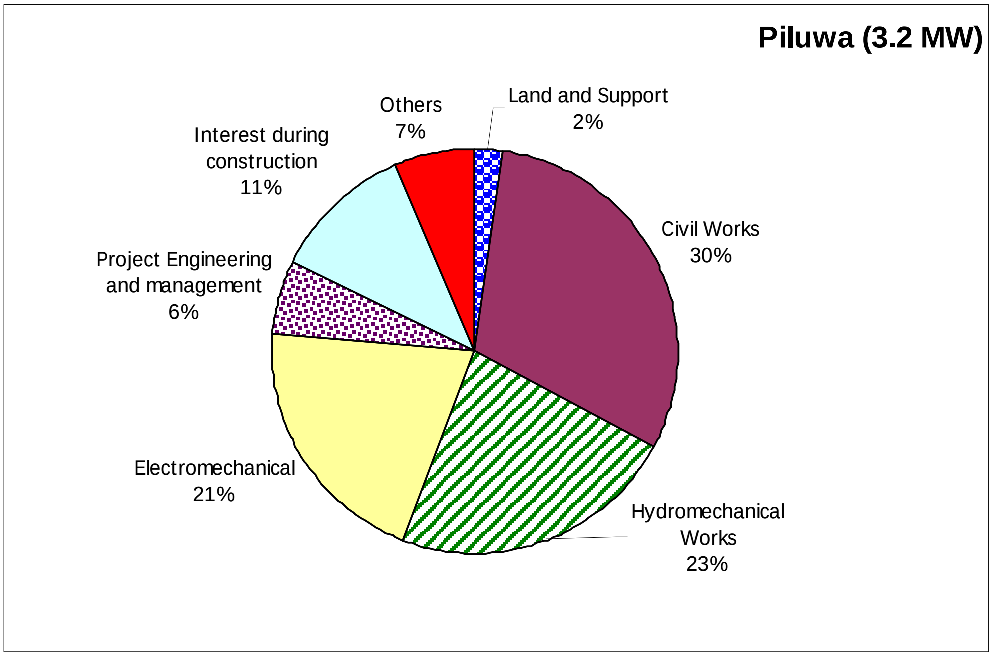


Figure 11: Cost Composition of a typical project developed by a National Private Sector



Similarly, if you compare the average cost per unit capacity of the past projects developed by the public sector, the international private sector and the local private sector, we can see a wide variation in the cost. The cost of development of the local private sector is markedly lower than the unit of cost of the others. The range of unit costs is as follows:

- Public sector, donor concessionary projects (60MW – 144 MW) - $3,100 – $5,600/kW
- Int'l private sector with int'l commercial financing (36 MW and 60 MW) - $2,400 - $2,800/kW
- Local Pvt. Sector with local currency funding (3MW project Piluwa) - $1,450/kW
- Micro Hydro (<100kW) - $1,982/kW

It can thus be said that the advent of national private sector in the hydropower sector in Nepal has shown the way to lower the energy prices in the country. The public sector projects, although financed by concessional loans, are attached with many conditionalities imposed by the donors which make the project cost very high.

9.3 Investment Scenarios

The Nepal hydropower investment scenario is considered to be very investor friendly with policies catered to attract private investment in the sector. A case in point is the financing of about 60m US$ by the local commercial banks to develop 7 small hydro projects totalling 55 MW capacity in the last several years. It is estimated that the local banks and financial institutions can finance up to 30m US$ every year to develop about 30 MW of capacity in the country. In addition, power bonds are being issued to mobilize capital for small hydro development in the country.

The World Bank and the Government of Nepal has recently created a Power Development Fund (PDF) with an initial capital of 35m US$. This fund will provide project finance "core funding" to supplement private sector. It will finance up to 60% of the cost of projects less than 10MW and up to 40% of the cost of projects bigger than 10MW. The PDF core funding envisages to help the private sector embark on 'project financing" of small hydros.

In the case of micro hydro, the government provides subsidies to local communities to develop projects in the range of 1-100 kW.

9.4 Barriers and Constraints

The major barriers and constraints faced by small hydro in Nepal can be listed as follows:

- Institutional Framework - unclear and overlapping roles and responsibilities of existing institutions
- Inadequate internal financial resources including mechanisms for its mobilizations on account of a capital market
- Inconsistencies and conflicts in various acts/policies/ regulations
- Shortcomings in the compliance of acts and regulations
- Political risk and the adverse situation for investment
- Market risk
- License holding by Independent Power Producers (IPPs)
- Shortage of a specialized human resource in financial institutions with professional expertise to appraise, implement and monitor hydropower projects
- Isolated rural communities/loads (low load factor)

9.5 Reform Process

The hydropower reform process in Nepal can be said to have started in 1992 with the introduction of the new hydropower policy. This policy was geared towards attracting the private sector for hydropower especially in small hydro. Various incentives and tax holidays were provided to private developers by this policy. This policy was later amended in 2001 to include the experience of the last 10 years of private sector participation in hydropower.

The main drivers of the Hydropower Policy of 2001 are to increase access to electricity & contribute towards energy security, stimulate economic growth, attract private investment and facilitate power trade. The policy has provided special incentives where no license is required and no royalty is imposed for SHP up to 1 MW. The royalty structure is $1.4/kW and 1.75% energy royalty for 15 years and $14/kW & 10% energy royalty thereafter. 1% royalty is allocated to village development committees affected by the hydropower projects.

Certain institutional reforms especially in unbundling of the electricity sector is proposed and a new act is in the offing that will un-bundle present utility into generation, transmission and distribution. A national grid authority will be established to operate the national grid, where as the generation and distribution will be open to multiple players and actors. Another important reform presently being undertaken is to hand over small hydro to communities and private sector by NEA. The Community Electricity Distribution Bye-law (2003) has made provisions for Rural Electric Entities (REEs) to be owned by CBOs/NGOs which will buy bulk power from NEA and then own and manage the distribution of electricity in rural communities. Such organizations will receive 80% grant from the government and 20% will have to be borne by the communities.

A Rural Energy Policy (2006) is currently being formulated which aims to supply about 12% of electricity from micro and small hydro systems and 3% from alternate sources of energy such as biomass, PV, wind etc.

To address some of identified barriers and constraints faced by the private sector in developing small hydro, various mechanisms and tools have been developed. For example, the market risks are now addressed by standardized power purchase agreements (PPAs) between the developers and the utility. There is also some support for pre-investment (cost sharing) from various agencies. Various agencies involved in promotion of small hydro are now engaged in providing due diligence training to financial institutions and the local financial institutions now have trained manpower to handle hydro financing.

The present national policy for hydropower development is geared towards utilizing the public-private complementaries. Local financial resources available from financial institutions (FIs), employee provident fund, army welfare funds are now being mobilized for financing of small hydro. On the other hand, public sector funding will be used for multi-purpose projects, large hydro and transmission line.

With regards to specific Small Hydro Project (SHP) Policy, a fixed buyback rates are announced by the utility for up to 5 MW projects. The per kWh rates are $0.04 for wet seasons (mid Apr. – mid Nov.) and $0.057 for dry seasons (mid Nov. – mid Apr.). An annual 6% escalation for the first 5 years is then provided. The design flow criteria which was based on the Q90% flow has now been changed to Q65%. This criterion has positive implications to the financial viability of the projects. In the case of projects between 5-10 MW, the prices are fixed on a competitive basis.

9.6 Example of Small Hydro Implementation

9.6.1 Micro Hydro

Efforts by the government to promote micro hydro projects have shown a positive trend in the expansion of the micro hydro projects.

Figure 13: Trend of Traditional Water Mills (left) and Improved Water Mills (right) in Nepal

shows the trend of micro hydro projects developed over the years (Data Source: AEPC). It is seen that 63% of the micro hydro projects are owned by communities and 37% are owned by the private sector. Statistics show that the about 9.2 HH are served by 1 kW of micro hydro capacity.

Another important source of micro hydro is the water mills. AEPC and other organizations are now actively involved in promoting improved water mills in place of the traditional water mills. Figure 13: shows the trend of traditional water mills and improved water mills installation in the country (data source: AEPC).

Figure 12: Trend of Expansion of Micro Hydro Projects in Nepal

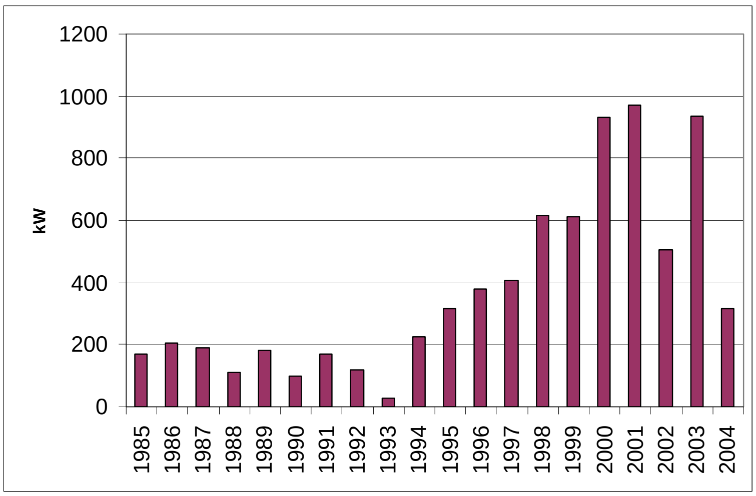
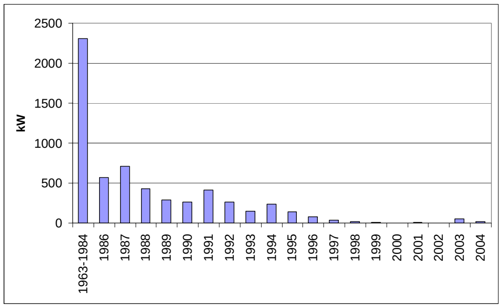
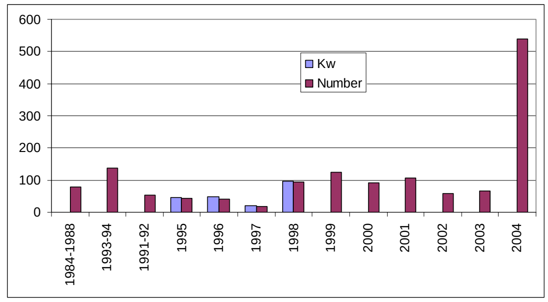


Figure 13: Trend of Traditional Water Mills (left) and Improved Water Mills (right) in Nepal





9.6.2 Piluwa Khola[3]

There are many success stories of small hydro projects implemented in Nepal. Piluwa Khola (3MW) is the case of a successful implementation of a 3 MW project by a local private investors with a consortium financing of about 56% of the total project cost (4.6m US$) by the local commercial banks in Nepal. The equity component was 35% and a bridge gap loan was 9% of the total cost. The unit cost (1462 US$/ KW) of the project was comparatively lower that the projects developed by the public sector or by the international private investor in Nepal.

In order to guarantee the repayment of the loans from the local banks, a certain procedure for the payment of the energy supplied to NEA is made in the PPA. NEA pays the bill of purchased energy every month with a time lag of 35 days. The payment comes directly to the lead bank account. The bank deducts the principal and interest of the loan from the payment. And the company gets remaining balance if there is something left over.

The salient features of the project are as follows:

- Installed Capacity : 3 MW
- Plant Load Factor : 74.4 %
- PPA Signed on : 2000 Jan.
- Contract energy : 19.54 GWh
- Dry months : 4.89 GWh (25%)
- Wet months : 14.65 GWh (75%)
- Production Started : 2003 Sep.
- Commercial Operation : 2003 Oct
- Company Established : March 1997
- Financial Plan (Consortium Financing)
  - ⇒ Total cost : 4.6 m$
  - ⇒ Cost/kW : 1462 $/kW
  - ⇒ Loan from local banks : 56%
  - ⇒ Equity : 35%
  - ⇒ Bridge gap loan : 9%

[3] Adapted from Pandey (2005)

9.6.3 Jhankre Mini Hydro[4]

Jhankre Mini Hydro Project (500kW) is a typical project where the potential water used conflict between hydropower generation and irrigation is amicably managed for the greater good of the community. It is also an example of a modality of providing rural electrification in an area where a larger sized project was constructed. Jhankre project was constructed to initially provide electricity during the construction of a 60MW Khimti Hydro Project. The power generation from Jhankre was used to replace diesel generation during the construction of the Khimti project. The benefit derived from this was used to construct the mini project which was later handed over to the local community to meet the rural electricity needs of the area. One potential problem seen in the implementation of this project was that a farmer managed irrigation project was using water from the intake location for irrigation about 13 ha of land. Hence, there was a need for a water sharing agreement between hydropower and irrigation.

The salient features of the project are as follows:

- 500 kW plant with H= 180m Design Q=450l/s
- Intake shared with Farmer Managed Irrigation Project – 13 ha (conflict in operation)
- Owner Khimti Power developer
- Now being handed over to community
- Plant built to replace diesel generators during construction of Khimti Project (60MW)
- After Completion of Khimti- for rural electrification (~5000 HH supplied)

The main features of the water sharing agreement between hydropower and irrigation were as follows:

- Temporary irrigation supply during construction
- Hydro developer to refurbish irrigation canal
- Employment priority to local
- Existing irrigation water requirements for wheat, rice seedlings and rice prioritized

This project can be considered a success story in management of water between two conflicting uses and also for cost sharing by the developer of a larger hydro project in providing rural electrification. The benefits of replacing diesel generation during construction of the larger hydro (infrastructure) power project could off-set some of the cost of development of this mini hydro. This was indeed a win-win situation for the local community as well as the developer of the larger hydro project.

10.0 Conclusion

This module provides the basic overview of small hydropower development process, including a brief technical overview, constraints and barriers and ways to address

[4] Adapted from Karki, 2004

them. The following conclusions can be drawn on the role of small hydropower in Africa:

- Small hydropower has a huge potential to meet the energy needs of Africa.
- Since small hydro projects require relatively lower investment and reasonable technical and management capability, they can be quickly implemented to meet the growing energy needs.
- Private sector participation is now considered a key partner in the development of hydropower.
- Hence, adequate policy and other enabling environment need to be in place for its successful implementation.
- One key factor for the development of small hydro power projects is the availability of required human resources in the country.
- Similarly, national banks and financial institutions need to be convinced of the scope of investment in this sector.

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