# Potential of Micro-Hydropower Generation Systems in India

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## Abstract

Large-scale hydro-electric power has been used worldwide for a long time to generate huge amounts of power from water stored behind massive dams. Small-scale hydro power has been used for hundreds of years for manufacturing, including milling grain, sawing logs and manufacturing cloth. However, it can also be used without a dam to generate electricity for home scale remote power systems. These so-called micro-hydro installations can be a very good power source, as they produce electricity round the clock. Over the last few decades, there has been a growing realization in developing countries that micro hydro has an important role to play in the economic development of remote rural areas. Micro hydro can provide power for industrial, agricultural and domestic uses through direct mechanical power or by the coupling of the turbine to a generator to produce electricity. This paper deals with the potential of micro hydropower in India and the possibility of generating power in decentralized mode.

## Introduction

The lack of energy supplies in rural areas is a chronic problem. In many developing countries less than 10 percent of the rural population has access to electricity. There are still 1.6 billion people in the world with no access to electricity, almost all of them living in developing countries (Anon., 2006). Rural electrification through conventional means such as grid connection or diesel generators is very costly. Water is a traditional source of power in many countries. The decentralized small-scale water power or micro-hydro schemes are a particularly attractive option in many rural areas.

For some years, interest in small hydropower went down drastically due to a number of factors: fast growth in electricity demand globally; progress of other technologies; success of large generation schemes and large grids in bringing down costs; mass production of small diesel sets that are both portable and easily installed; and easy access to affordable diesel fuel. In the more recent past, the energy crisis, climate change and energy poverty in developing countries has led to a rethink. Planners and policy makers are being urged to review all available energy options, especially those decentralized sources that could play a role supplying poor and isolated communities with energy for development.

### History of Hydropower

The basic principle of hydropower is that if water can be piped from a certain level to a lower level, then the resulting water pressure can be used to do work. If the water pressure is allowed to move a mechanical component then that movement involves the conversion of the potential energy of the water into mechanical energy. Hydro turbines convert water pressure into mechanical shaft power, which can be used to drive an electricity generator, a grinding mill or some other useful device. The use of falling water as a source of energy has been known for a long time. Water wheels were used in ancient times, but the use of hydropower got a new impulse at the beginning of the nineteenth century with the invention of the hydro turbine.

Water wheels have been used since ancient times to supply power for grinding grain and other laborious tasks. The first modern hydraulic turbines were developed in the first part of the nineteenth century by Fourneyron in France. These were further developed by a number of researchers during the middle of the century, so that by 1890 most of the types of turbines now in use had been invented. Thomas Edison's invention of the electric light and ways to distribute electricity occurred at about the same time leading to a great boom in hydroelectric development in Europe and North America. Until about the 1920s, most hydroelectric developments were quite small in the size range, which is now called mini hydro or even micro hydro. This was for two reasons: people didn't know how to build really large dams and turbines, and the small electric transmission systems of the time made it difficult to sell large amounts of electricity. Generally, mini-hydro systems would be used to power a town and its surrounding area, while micro-hydro systems were used on isolated farms and ranches to provide power.

During the era of the 1950s and 1960s, advancing technology and cheap oil, combined with improved long-distance electric transmission made it possible to sell electricity cheaper than the earlier small hydro plants could make it. Small hydro is also well suited for developing countries, and is being actively encouraged by many governments and development organizations in order to reduce oil imports and encourage development. Micro hydro has a special role to play in developing countries, since it makes it possible to provide lighting, power, and communications (such as television and radio) even in areas far from the main electric power systems. Micro hydro can, thus, play an important role in promoting rural development in remote areas.

**Features of Micro Hydro**

The micro hydropower is one of the earliest known renewable energy sources, in existence in the country since the beginning of the 20th century. In fact, much before that, the technology was used in Himalayan villages in the form of waterwheels to provide motive power to run devices like grinders. References to mechanical energy extraction have been found from as early as twelfth century.

Micro hydro is usually defined as having a generating capacity of up to about 100 kW (Curtis, 1999). This is about enough power for 6 or 8 houses in a developed country, or it can provide basic lighting and other services to a village of 50 to 80 houses. Micro-hydro generation is best suited to providing small amounts of power to individual houses, farms, or small villages in isolated areas. Mini-hydro systems are larger, which is enough electric power for a medium-sized town. In general, micro-hydro plants use much simpler and lower cost technology than mini-hydro plants. For this reason, micro-hydro plants are usually well suited to village level development and local self-help projects. With their simpler technologies, they can usually be built by people with little special training, using mostly local materials and skills. They are usually lower in cost than mini-hydro and conventional hydro plants, but they are also less efficient, and the quality of the electricity is not as good. Mini-hydro plants, on the other hand, cost more, but they produce the same constant-frequency alternating current (AC) electricity as large electric power systems, so that they can even be interconnected with a larger system.

Micro-hydro plants generally produce low-voltage direct current (DC) electricity, or else low-voltage variable-frequency alternating current (AC). These kinds of electricity are suited for lights, small motors, and electric cookers, but not to run large motors, many appliances, or most industrial machinery. Perhaps, most importantly, micro-hydro plants cannot be interconnected with other generating plants in an electric system the way mini-hydro and large hydro plants can. Special machines called inverters can convert DC power to the AC power used in large electric systems, but these are expensive and have limited capacity.

The biggest advantage of micro hydropower is that it is the only 'clean' and renewable source of energy available round the clock. It is free from many issues and controversies that continue to 'hound' large hydro, like the submergence of forests, siltation of reservoirs, rehabilitation and relocation, and seismological threats. Other benefits of small hydro are user friendliness, low cost, and short gestation period. In addition to these obvious benefits, micro hydro contributes numerous economic benefits as well. It has served to enhance economic

**Table 1** Definitions of small, mini, and micro hydro plants

| Country | Micro hydro, kW | Mini hydro, kW | Small hydro, MW |
|---|---|---|---|
| India | < 100 | 101-1000 | 1-15 |
| United States | < 100 | 100-1,000 | 1-30 |
| China | - | < 500 | 0.5-25 |
| Brazil | < 100 | 100-1,000 | 1-30 |
| Norway | < 100 | 100-1,000 | 1-10 |
| USSR | < 100 | - | 0.1-30 |
| France | 5-5,000 | - | - |
| Various | < 100 | < 1,000 | < 10 |

Source: Moreire and Poole (1993)

development and living standards especially in remote areas with limited or no electricity. In some cases, rural dwellers have been able to manage the switch from firewood for cooking to electricity, thus, limiting deforestation and also cutting down on carbon emissions. On the macro level, rural communities have been able to attract new industries - mostly related to agriculture - owing to their ability to draw power from micro hydropower stations.

Hydropower is a very clean source of energy. It does not consume but only uses the water; after use it is available for other purposes. The conversion of the potential energy of water into mechanical energy is a technology with a high efficiency (in most cases double that of conventional thermal power stations). The use of hydropower can make a contribution to savings on exhaustible energy sources. Each 500 kWh of electricity generated with a hydro plant is equivalent to 100 litre of oil (assuming an efficiency of 38 percent).

**World Potential**

Hydropower technology has been extensively deployed throughout the world at both large and small scale for electricity generation, and at small scale for mechanical power. This generally places hydropower at an advantage over other renewable technologies for new deployment, since operational or abandoned schemes are often available within the target country. Operation, design and construction experience may also be available there. The technology is technically and commercially mature. Small scale hydro schemes can make a useful contribution to rural electrification strategies, presenting a suitable alternative to decentralized diesel generation, particularly where fuel supply is a problem. Some countries are encouraging deployment through subsidies and incentives.

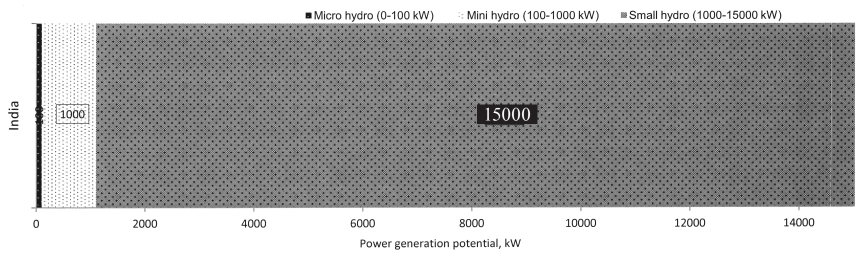
About 737 GW of hydropower with production 2,767 GWh/year has been developed globally, 47 GW/site of which is small hydropower. A total of about 118 GW of hydro capacity is under construction. The remaining non utilized global hydropower potential is estimated at 300 GW (Anon., 2004). About 82 percent of total technically feasible hydropower potential is exploited in USA, 73 percent in Germany, 65 percent in Canada, 23 percent in China, but only 5 percent in Africa and 13 percent in Asia as a whole (Anon., 2006).

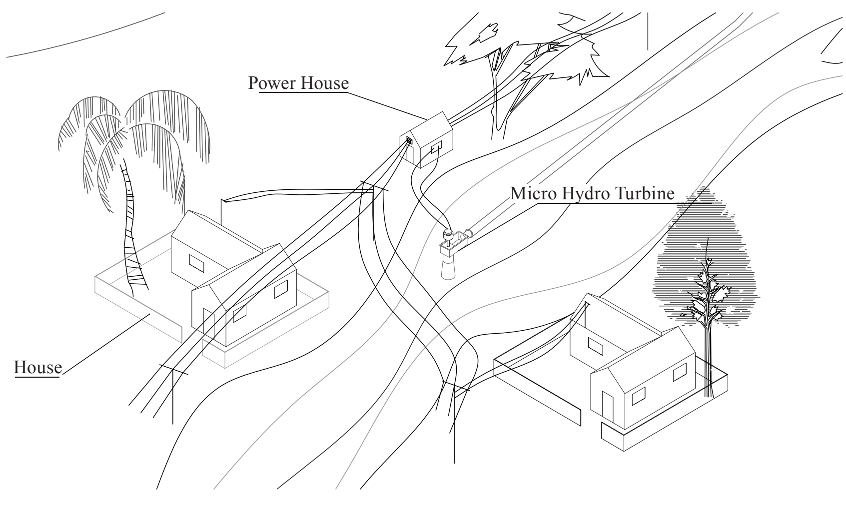
**Indian Scenario**

The Ministry of Power, Government of India is responsible for the development of large hydropower projects in the country, whereas Ministry of New and Renewable Energy (MNRE) has been responsible for small and mini hydro projects up to 3 MW station capacity since 1989. The subject of small hydro between 3-25 MW has been assigned to MNES from 1999. While there has been a continuous increase in the installed capacity of hydropower stations in India, which presently is 29,500 MW, the share of hydropower has been reduced to only 25 percent in the total installed for power generation from 50.62 percent in 1963 (Anon., 2005).

An estimated potential of about 15,000 MW of small hydropower projects exists in India (Anon., 2004). Ministry of New and Renewable Energy has created a database of potential sites of small hydro based on information from various states and on studies conducted by

**Fig. 1** Hydropower categorization in India



the Central Electricity Authority. For projects up to 25 MW capacity, 4,096 potential sites with an aggregate capacity of 10,071 MW have been identified. Himachal Pradesh, Jammu Kashmir, Uttar Pradesh, Gujarat, Maharashtra, Andhra Pradesh, Karnataka, Kerala, Tamil Nadu, Bihar, West Bengal and Arunachal Pradesh have been identified as key states with potential for small hydro.

Small hydropower technology was introduced in India shortly after the commissioning of the world's first hydroelectric installation at Appleton, USA in 1882. The 130 kW plant at Darjeeling in the year 1897 was the first small hydropower installation in the country. A few other power houses belonging to that period such as Shivasundaram in Mysore (2 MW, 1902), Galgoi in Mussoorie (3 MW, 1907), and Chaba (1.75 MW, 1914) and Jubbal (50 kW, 1930) near Shimla, are reported to be still functioning properly.

**Performance of Micro Hydro**

To determine the power potential of the water flowing in a river or stream it is necessary to determine both the flow rate of the water and the head through which the water can be made to fall. The flow rate is the quantity of water flowing past a point in a given time. Typical flow rate units are litres per second or cubic metres per second. The head is the vertical height, in metres, from the turbine up to the point where the water enters the intake pipe or penstock. The potential power can be calculated as follows:

$P = 9.81 \times Q \times H$

where, P is theoretical power in kW, Q is flow rate in $m^3/s$, H is head in m, and g is acceleration of gravity (9.81 $m/s^2$).

However, energy is always lost when it is converted from one form to another. Small water turbines rarely have efficiencies better than 80 percent. Power will also be lost in the pipe carrying the water to the turbine, due to frictional losses. By careful design, this loss can be reduced to only a small percentage. A rough guide used for small systems of a few kW rating is to take the overall efficiency as approximately 50 percent. Thus, the theoretical power must be multiplied by 0.5 for a more realistic Fig.

If a machine is operated under conditions other than full load or full flow then other significant inefficiencies must be considered. Part flow and part load characteristics of the equipment need to be known to assess the performance under these conditions. It is always preferable to run all equipment at the rated design flow and load conditions, but it is not always practical or possible where river flow fluctuates throughout the year or where daily load patterns vary considerably.

Depending on the end use requirements of the generated power, the output from the turbine shaft can be used directly as mechanical power or the turbine can be connected to an electrical generator to produce electricity. For many rural industrial applications shaft power is suitable (for food processing such as milling or oil extraction, sawmill, carpentry workshop, small scale mining equipment, etc.), but many applications require conversion to electrical power. For domestic applications electricity is preferred.

**Components of Micro Hydro**

There are many variations of micro-hydro systems. Some of the factors that will affect the kind of system to be built are: the amount of power needed; the quantity of flowing water available; the available head; the source of the water (from an irrigation canal, a pipeline, behind a dam, or from a free-flowing river or stream); affordable investment; and the manual skills and local materials available. All micro-hydro systems, whatever their other differences, have a number of features in common. Each must have a source of water, and a place to put the water afterwards (the discharge). The source must be higher than the discharge; the greater the difference in height, the greater the available head will be. In addition, there must be some means of getting the water from the source to the power plant, and then from the power plant to the discharge. Finally, there must be the power plant itself, which will contain one or more turbines driven by the flowing water, and one or more generators driven by the turbines. Alternatively, the turbines can supply mechanical power to drive some other machinery, such as a mill or saw, directly, without converting the mechanical power into electrical power and back. Sometimes, systems are arranged to supply mechanical power during the day, and then supply electricity for lighting at night.

***a) Site and construction***

The best geographical areas for exploiting small-scale hydropower are those where there are steep rivers flowing all year round, for example, the hill areas of countries with high year-round rainfall, or the great mountain ranges and their foothills, like the Himalayas. Islands with moist marine climates are also suitable. Low-head turbines have been developed for small-scale exploitation of rivers where there is a small head but sufficient flow to provide adequate power. To assess the suitability of a potential site, the hydrology of the site needs to be known and a site survey carried out, to determine actual flow and head data. This data gives a good overall picture of annual rain patterns and likely fluctuations in precipitation and, therefore, flow patterns. The site survey gives more detailed information of the site conditions to allow power calculation to be done and design work to begin. Flow data should be gathered over a period of at least one full year where possible, so as to ascertain the fluctuation in river flow over the various seasons.

The extent and the cost of the civil

works needed for a micro hydro plant vary a great deal, depending on the nature of the site where the plant is located. Generally, the more water-hydropower plants must handle, and the further they must carry it, the more expensive the civil works will be. For this reason, micro hydro plants with a lot of head are usually cheaper than low-head plants, since the lower head means a greater amount of water is required. However, many low-head plants can be built to take advantage of existing irrigation and water-supply works, such as dams and canals. Combining micro hydro with a water supply or irrigation project can also help to make that project more practical, since the power from the hydro plant can help to pay for some of the cost of the total project. The civil works can usually be built from local materials, using local construction techniques and labor, along with a few imported materials such as cement. The exception to this may be the penstock, which must be able to withstand the pressure of the water. If the head is more than 5 m, this will require metal pipe. This can be expensive, since a fairly large diameter pipe is required in order to reduce the amount of head lost from friction. If a dam should break, it can release water with great violence, and even a seemingly small amount of water can cause enormous destruction and loss of life.

Most hydro systems require a pipeline to feed water to the turbine. The exception is a propeller machine with an open intake. The water should pass first through a simple filter to block debris that may clog or damage the machine. The intake should be placed off to the side of the main water flow to protect it from the direct force of the water and debris during high flows. It is important to use a pipeline of sufficiently large diameter to minimize friction losses from the moving water. When possible, the pipeline should be buried. This stabilizes the pipe and prevents critters from chewing it. Pipelines are usually made from PVC or polyethylene although metal or concrete pipes can also be used.

***b) Hydraulic turbine***

Although traditional waterwheels of various types have been used for centuries, they are not usually suitable for generating electricity: They are heavy, large and turn at low speeds. They require complex gearing to reach speeds to run an electric generator. They also have icing problems in cold climates. Water turbines rotate at higher speeds, are lighter and more compact. Turbines are more appropriate for electricity generation and are usually more efficient.

There are two basic kinds of turbines: impulse and reaction. Impulse machines use a nozzle at the end of the pipeline that converts the water under pressure into a fast moving jet. This jet is then directed at the turbine wheel (also called the runner), which is designed to convert as much of the jet's kinetic energy as possible into shaft power. Common impulse turbines are pelton, turgo and cross-flow (Smith, 1994). In reaction turbines the energy of the water is converted from pressure to velocity within the guide vanes and the turbine wheel itself. Some lawn sprinklers are reaction turbines. They spin themselves around as a reaction to the action of the water squirting from the nozzles in the arms of the rotor. Examples of reaction turbines are propeller and Francis turbines.

In the family of impulse machines, the pelton is used for the lowest flows and highest heads. The cross-flow is used where flows are highest and heads are lowest. The turgo is used for intermediate conditions. Propeller (reaction) turbines can operate on as little as two feet of head. A turgo requires at least four feet and a pelton needs at least ten feet. These are only rough guidelines with overlap in applications. The cross-flow (impulse) turbine is the only machine that readily lends itself to user construction. They can be made in modular widths and variable nozzles can be used. Most developed sites now use impulse turbines. These turbines are very simple and relatively cheap. As the stream flow varies, water flow to the turbine can be easily controlled by changing nozzle sizes or by using adjustable nozzles. In contrast, most small reaction turbines cannot be adjusted to accommodate variable water flow. Those that are adjustable are very expensive because of the movable guide vanes and blades they require. If sufficient water is not available for full operation of a reaction machine, performance suffers greatly.

An advantage of reaction machines is that they can use the full head available at a site. An impulse turbine must be mounted above the tail-water level and the effective head is measured down to the nozzle level. For the reaction turbine, the full available head is measured between the two water levels while the turbine can be mounted well above the level of the exiting water. This is possible because the draft tube used with the machine recovers some of the pressure head after the water exits the turbine. This cone-shaped tube converts the velocity of the flowing water into pressure as it is decelerated by the draft tube's increasing cross section. This creates suction on the underside of the runner. Centrifugal pumps are sometimes used as practical substitutes for reaction turbines with good results. They can have high efficiency and are readily available (both new and used) at prices much lower than actual reaction turbines. However, it may be difficult to select the correct pump because data on its performance as a turbine are usually not available or are not straightforward. One reason more reaction turbines are not in use is the lack of available machines in small sizes.

***c) Generator and electric gear***

Most battery-based systems use an automotive alternator. If selected carefully, and rewound when appropriate, the alternator can achieve very good performance. A rheostat can be installed in the field circuit to maximize the output. Rewound alternators can be used even in the 100-200 V range. An induction motor with appropriate capacitance for excitation can be used as a generator, for higher voltages (100-400 V). This will operate in a small battery charging system as well as in larger AC direct systems of several kilowatts. Another type of generator used with micro hydro systems is the DC motor. Usually permanent magnet types are preferable. However, these have serious maintenance problems because the entire output passes through their carbon commutators and brushes.

The electrical gear or electrical system for a micro hydro system consists of the electric generator, other electrical devices in the powerhouse, and electric wires that take the electricity from the powerhouse to the place where it is to be used. There are a number of different possible arrangements for this. One of the most common arrangements for micro-hydro systems is a low-voltage DC system, similar to an automobile's electrical system. This arrangement can also be used to produce moderate-voltage AC power (like that which is available from an electric utility) by means of an inverter. Another arrangement, which is commonly used in mini hydro, is to generate moderate-voltage or high-voltage AC directly, using a synchronous generator.

***d) Load control governors***

The load factor is the amount of power used divided by the amount of power that is available if the turbine were to be used continuously. Unlike technologies relying on costly fuel sources the 'fuel' for hydropower generation is free and, therefore, the plant becomes more cost effective if run for a high percentage of the time. If the turbine is only used for domestic lighting in the evenings then the plant factor will be very low. If the turbine provides power for rural industry during the day, meets domestic demand during the evening, and maybe pumps water for irrigation in the evening, then the plant factor will be high. It is very important to ensure a high plant factor if the scheme is to be cost effective and this should be taken into account during the planning stage. Many schemes use a 'dump' load (in conjunction with an electronic load controller - see below), which is effectively a low priority energy demand that can accept surplus energy when excess is produced, e.g. water heating, storage heaters or storage cookers.

Water turbines, like petrol or diesel engines, will vary in speed as load is applied or relieved. Although not such a great problem with machinery, which uses direct shaft power, this speed variation will seriously affect both frequency and voltage output from a generator. Traditionally, complex hydraulic or mechanical speed governors altered flow as the load varied, but more recently an electronic load controller (ELC) has been developed which has increased the simplicity and reliability of modern micro hydro sets. The ELC prevents speed variations by continuously adding or subtracting an artificial load, so that in effect, the turbine is working permanently under full load. A further benefit is that the ELC has no moving parts, is very reliable and virtually maintenance free. The advent of electronic load control has allowed the introduction of simple and efficient, multi-jet turbines, no longer burdened by expensive hydraulic governors.

***f) Power supply***

Power can be supplied by a micro hydro system in two ways. In a battery-based system, power is generated at a level equal to the average demand and stored in batteries. Batteries can supply power as needed at levels much higher than that generated and during times of low demand, the excess can be stored. If enough energy is available from the water, an AC-direct system can generate power as alternating current (AC). This system typically requires a much higher power level than the battery-based system.

*i) Battery based systems:* Most home power systems are battery based. They require far less water than AC systems and are usually less expensive. Because the energy is stored in batteries, the generator can be shut down for servicing without interrupting the power delivered to the loads. Since only the average load needs to be generated in this type of system, the pipeline, turbine, generator and other components can be much smaller than those in an AC system. Very reliable inverters are available to convert DC battery power into AC output (120 volt, 60 Hz). These are used to power most or all home appliances. This makes it possible to have a system that is nearly indistinguishable from a house using utility power. The input voltage to the batteries in a battery-based system commonly ranges from 12 to 48 Volts DC. If the transmission distance is not great then 12 Volts is often high enough. A 24 Volt system is used if the power level or transmission distance is greater. If all of the loads are inverter powered, the battery voltage is independent of the inverter output voltage and voltages of 48 or 120 may be used to overcome long transmission distances. Although batteries and inverters can be specified for these voltages, it is common to convert the high voltage back down to 12 or 24 Volts (battery voltage) using transformers or solid state converters. Wind or solar power sources can assist in power production because batteries are used. Also, DC loads (appliances or lights designed for DC) can be operated directly from the batteries. DC versions of many appliances are available, although they often cost more and are harder to find, and in some cases, quality and performance vary.

*ii) AC-direct systems:* This is the system type used by utilities. It can also be used on a home power scale under the right conditions. In an AC system, there is no battery storage. This means that the generator must be capable of supplying the instantaneous demand, including the peak load. The most difficult load is the short-duration power surge drawn by an induction motor found in refrigerators, freezers, washing machines, some power tools and other appliances. Even though the running load of an induction motor may be only a few hundred watts, the starting load may be 3 to 7 times this level or several kilowatts. Since other appliances may also be operating at the same time, a minimum power level of 2 to 3 kW may be required for an AC system, depending on the nature of the loads. In a typical AC system, an electronic controller keeps voltage and frequency within certain limits. The hydro's output is monitored and any unused power is transferred to a shunt load, such as a hot water heater. The controller acts like an automatic dimmer switch that monitors the generator output frequency cycle by cycle and diverts power to the shunt load(s) in order to maintain a constant speed or load balance on the generator. There is almost always enough excess power from this type of system to heat domestic hot water and provide some, if not all, of a home's space heating.

## Conclusion

Even though micro hydro has had an early start, the pace of growth in this sector has been very slow; vis--vis large hydro. This can be attributed to the rapid pace of industrialization after independence, which requires huge amounts of power and necessitates the installation of large multi-purpose power projects. However, with growing consciousness and concern about the environment, the focus has shifted towards the development of small, user friendly, and decentralized power projects with low gestation periods. Multi-faceted impetus is being provided by various agencies in the sector; for instance World Bank credit through the Indian Renewable Energy Development Agency and the Hilly Hydro Project funded by United Nations Development Programme-Global Environment Facility. The Ministry of New and Renewable Energy is offering, through its normal budget, a host of incentives for surveys, investigations, preparation of detailed project reports, and execution of projects. With these new and exciting developments, micro hydropower in India is poised to make a big splash.

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