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Micro Hydro-Electric Energy Generation- An Overview

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ABSTRACT: *Energy is required now more than ever due to population growth, industrialization and modernization. Challenges such as carbon dioxide (CO_2) emissions and depletion of conventional source of energy necessitate for renewable sources, of which hydro energy seems to be the most predictable. Micro-hydro which is hydro energy in a "small" scale provides electricity to small communities by converting hydro energy into electrical energy. This paper is an overview of micro-hydro system by reviewing some of its basic components such as turbine and generator that make this conversion process possible. Estimating micro-hydro energy potential which is a function of Head and Flow rate, planning, advantages and its limitation will also be reviewed to provide the basic knowledge of micro-hydro system.*

Keywords: *Renewable energy, Micro-hydro, Turbine, Generator, Head, Flow rate*

I. INTRODUCTION

Energy is the most fundamental sector for the progress of a nation [1]. It is inevitable for survival and indispensable for developmental activities to promote education, health, transportation and infrastructure for attaining a reasonable standard of living and is also a critical factor for economic development and employment [2]. Urbanization, economic development, industrialization and rapid increase in population growth have raised the demand for power generation manifolds [3]. As the human population and activities are progressively developing, it is most certain that the demand for energy worldwide is increasing as well, and this trend is most likely to continue in the future [4]. For meeting the expected energy demand as the population will rise and to sustain economic growth, alternative form of energy such as renewable energy needs to be expanded [5].

Hydro power energy is one of the most clean renewable sources of energy [3]. Water power can be harnessed in many ways; tidal flows can be utilized to produce power by building a barrage across an estuary and releasing water in a controlled manner through a turbine; large dams hold water which can be used to provide large quantities of electricity; wave power is also harnessed in various ways [6]. Hydropower on a small scale, or micro-hydro, is one of the most cost-effective energy technologies to be considered for rural electrification in less developed countries [7].

Micro Hydropower (from hydro meaning water and micro meaning small scale) refers to electrical energy that comes from the force of moving water used to power a household or small village [6, 8]. Micro hydro systems can be regarded as a renewable energy source resulting from the natural hydrological cycle, it is by some considered sustainable due to the lack of impoundment of water and assumed negligible environmental impact [9]. The technology was initially used in Himalayan villages in the form of water wheels to provide motive power to run devices like grinders [10]. Hydropower has various degrees of 'smallness'. To date there is still no internationally agreed definition of 'small' hydro [6, 10-12]. Table 1 shows the classification of hydropower system base on the generated power output.

Table 1: Classification of hydropower by size [6, 13].

S/N	Classification	Rated Power	Consumer
1.	Large- hydro	>100 MW	usually feeding into a large electricity grid
2.	Medium-hydro	15 - 100 MW	usually feeding a grid
3.	Small-hydro	1 - 15 MW	usually feeding into a grid
4.	Mini-hydro	100 kW - 1MW	either stand alone schemes or more often feeding into the grid
5.	Micro-hydro	5kW -100 kW	usually provided power for a small community or rural industry in remote areas away from the grid
6.	Pico-hydro	< 5kW	

The best geographical areas for micro-hydropower systems are those where there are steep rivers, streams, creeks or springs flowing year-round, such as in hilly areas with high year-round rainfall [14]. A hydro system is a series of interconnected component: water flow in one end and electricity comes out of the other [15]. The basic components of a typical micro-hydro system are: turbines, generators, headwork, intake, gravel trap with spillway, headrace canal, forebay and desilting basin, penstock pipe, powerhouse, tailrace, drive systems, controllers and transmission /distribution network [14].

This paper will contain a review of some of these basic component including, micro-hydro project planning, merits / demerits of micro-hydro power and the estimation of output energy of a micro-hydro project system.

II. HYDRO-TURBINES

The turbine is the heart of hydro power system, where water power is converted into rotational force that drives the generator [15]. They are generally classified as impulse turbine and reaction turbine [15-19]. Based on flow direction, they are further classified as: Tangential flow, radial flow, axial flow and mixed flow [16]. The water strikes the turbine blades and turns the turbine, which is attached to a generator by a shaft [20]. Turbine is connected either directly to the generator or is connected by means of gears or belts and pulleys, depending on the speed required for the generator [13].

2.1 Impulse turbine

Impulse turbines, which have the least complex design, are most commonly used for high head micro-hydro systems [21]. They generally use the velocity of the water to move the runner and discharges to atmospheric pressure [22]. These turbines are more efficient for site with high head and low flow. High head hydro generally provides the most cost effective projects, since the higher the head, the lesser the water required for a given amount of power, so smaller and hence less costly equipment is needed [7]. Water is driven into the pipeline at forebay. This pipeline leads the water to a nozzle, where the kinetic energy of the water is used to push or impulse the blades coupled to the alternator. The most common types of impulse turbines include the Pelton turbine (figure 1) and the Turgo turbine [21].

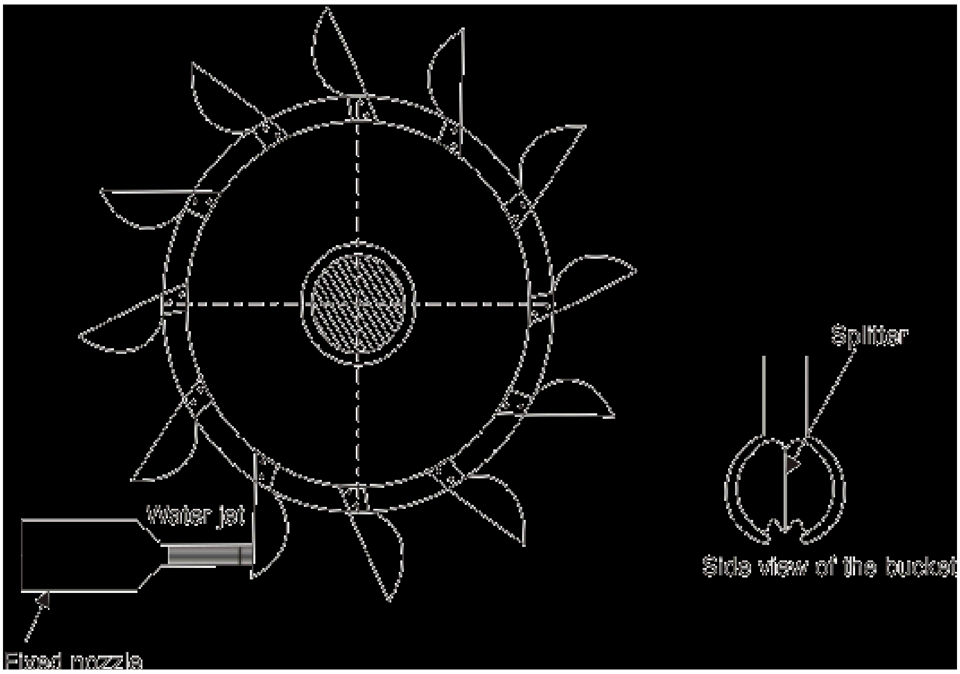

Fig. 1: Pelton Wheel, example of an impulse turbine [23]

2.2 Reaction turbine

Reaction turbines, which are highly efficient, depend on pressure rather than velocity to produce energy [21]. They have better performance in sites with low head and high flow [15]. Reaction turbines exploit the oncoming flow of water to generate hydrodynamic lift forces to propel the runner blades [7], and run fully immersed in water [15]. They can operate on heads as low as 2 feet, but require much higher flow rates than an impulse turbine [8]. Typical examples are Francis (figure 2) and Kaplan/propeller turbine [15, 24].

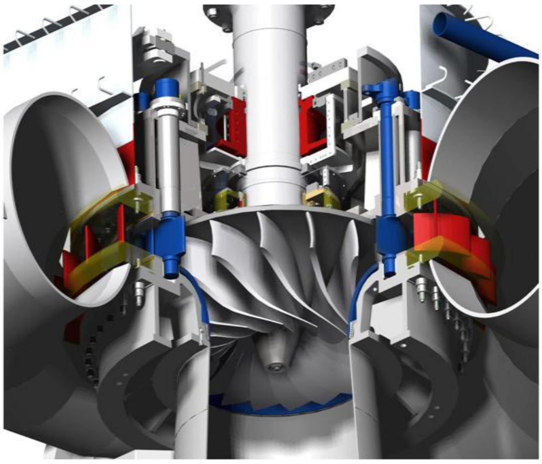

Fig. 2: Francis turbine, example of reaction turbine [17]

III. HYDRO GENERATOR

Generators convert the mechanical (rotational) energy produced by the turbine to electrical energy [11]. The principle of generator operation is quite simple: when a coil of wire is moved past a magnetic field, a voltage is induced in the wire [14]. As the turbine blades turn, the rotor inside the generator also turns and electric current is produced as magnets rotate inside the fixed-coil generator to produce current [20]. The basic parameters to be considered in the selection of a suitable type of electrical generator are; Type of desired output, Hydraulic turbine operation modes and Type of electrical load i.e Interconnection with the national grid, storage in batteries or an isolated system supplying variety of household or industrial loads [25]. There are basically two types of generator which are induction and synchronous generator [18]

3.1 Induction (Asynchronous generator)

Asynchronous generators are simple squirrel-cage induction motors with no possibility of voltage regulation and running at a speed directly related to system frequency. They draw their excitation current from the grid, absorbing reactive energy by their own magnetism. Adding a bank of capacitors can compensate for the absorbed reactive energy [11]. The asynchronous generators are generally suitable for the micro hydropower generation [26], due to advantages such as availability, low cost and robustness [27]. Induction generator (IG) offers many advantages over a conventional synchronous generator as a source of isolated power supply. Reduced unit cost, ruggedness, brushless (in squirrel cage construction), reduced size, absence of separate DC source and ease of maintenance, self-protection against severe overloads and short circuits, are the main advantages of IG [13]

3.2 Synchronous generator

Synchronous generator are equipped with a DC excitation system (rotating or static) associated with a voltage regulator, to provide voltage, frequency and phase angle control before the generator is connected to the grid and supply the reactive energy required by the power system when the generator is tied into the grid [11]. A synchronous generator usually has a built-in excitation system and automatic voltage regulation [28]. It can be used in stand-alone or grid-tied system; it has higher efficiency but higher cost [18].

IV. THE OUTPUT ENERGY

The generation of electrical energy is simply conversion of energy from one form to another. The turbine converts water energy into rotational energy at its shaft, which is further converted into electrical energy by the generator. Part of the energy will be used to overcome frictional force at every point of conversion. The energy generated per year (KWH) can be calculated as:

$$E = \rho * Q * H_n * \eta * n \quad (1)$$ [2, 5, 6, 13, 18], [29-33].

Where g is gravitational constant (9.8 m/s^2), ρ is water density (1000 kg/m3), Q is flow rate (m^3/s), H_n is net head (m) and *n* is number of hours in year for which the specified flow occurs.

η is efficiency which is a measure of how much energy is actually converted [15].

$$\eta = \eta_{tu} * \eta_{ge} * \eta_{gb} * \eta_{tr} \quad (2)$$ [2]

Where: η_{tu} is turbine efficiency, η_{ge} is generator efficiency, η_{gb} is gear box efficiency and η_{tr} is transformer efficiency. The head and flow determine everything that needs to be known about the hydro system such as pipeline size, turbine type, rotational speed, generator size and even to obtain the rough estimate [15].

4.1 Estimating the Flow Rate

The quantity of water falling is called flow. It is usually measured in cubic meters per second but in small scale schemes, it is often measured in liters per second (where 1000 liters/second equals 1 cubic meter/second) [34]. To measure the water flow rate (discharge), several methods are available [2], of which include Container/bucket method, Weir method and Float/velocity area method [14].

Flow rate can measured using the bucket method, which involves damming your stream with logs or boards to divert its flow into a bucket or container [21]. It works only for a very small system. [15] The rate that the container fills is the flow rate, which is calculated simply by dividing the volume of the container by the filling time [14].

If the watercourse being developed is reasonably small (say < 4 m^3/s) then it may be possible to build a temporary weir [11]. This is a low wall or dam across the stream to be gauged with a notch through which all the water may be channeled [35]. All the water is directed through an area that is exactly rectangular making it very easy to measure the height and the width of the water to compute the flow [15]. It involves installing a stake at the level of the crest, measuring the height (in cm) and the width (in cm) and checking the flow (l/sec) in the weir table [36]. Since the amount of water in a stream varies, then measurements should be taken over as long a period of time as possible, in all conditions [34].

For larger streams where the construction of a weir may not be practical, or for a quick estimate of the flow, the float method is useful. This float method is useful for large streams if it is possible to locate a section of about 10 feet long where the stream is fairly consistent in width and depth [11]. This is a conventional method for medium to large rivers, involving the measurement of the cross-sectional area of the river and the mean velocity of the water through it; it is a useful approach for determining the stream flow with a minimum effort. To compute the cross-sectional area(s) of a natural watercourse it should be divided into a series of trapezoids (figure 3). Measuring the trapezoid sides, the cross-section would be given by:-

$$s = b((h_1 + h_2 + \cdots \ldots\ldots h_n) \div n) \quad (3)$$[35]

Where b is the width of the river, n is number of series of the trapezoids and h_1, h_2……h_n are the corresponding height of each division.

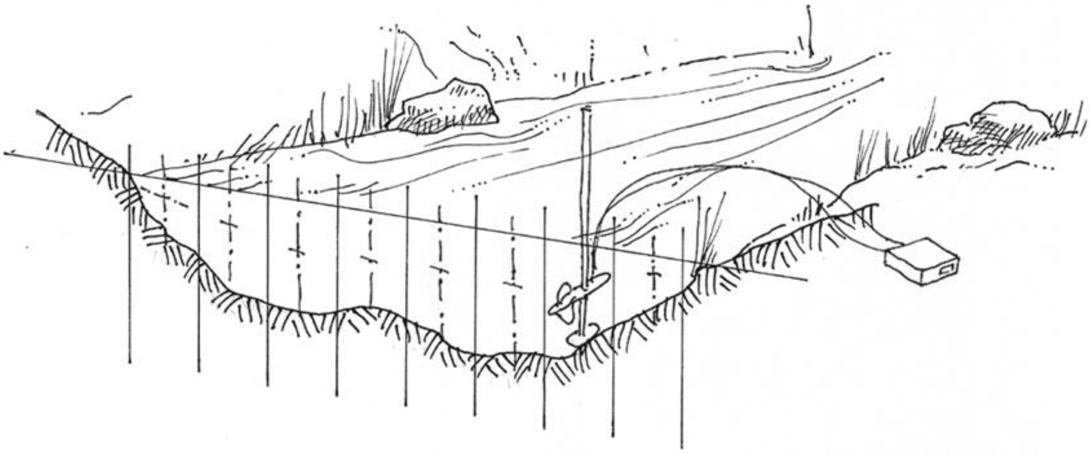

Figure 3: velocity-Area method [36]

A good way to measure speed is to mark off about ten foot length of the stream that includes the point where you take the cross section [15]. A floating materials is dropped before the marked length, the time t (seconds) elapsed to traverse the length L (m) is recorded. The surface speed (m/s) would be the quotient of the length L and the time t [11]. To estimate the mean velocity, the above value must be multiplied by a correction factor that may vary between 0.60 and 0.85 depending on the watercourse depth and their bottom and riverbank roughness (0.65 is a well accepted value) [35]. The flow rate is the product of the area and the velocity.

4.2 Measurement of Head

Head is a water pressure which is created by the difference in elevation between the water intake and the turbine [15]. Accuracy is critical when measuring head because it is necessary for determining hydrodynamic design of turbine blade or bucket, expected power and the type of turbine to be used. This head can be created by dams or by leading the water in parallel to the river in a waterway with low head losses compared to the natural stream, or very often, by a combination of both [34].

Field measurements of gross head are usually carried out using surveying techniques. The precision required in the measurement will impose the methods to be employed [35]. In the past, several method were used of which include, meridian clinometers, angular leveling, pocket sighting level and spirit level and plank (or string) method [36]. The modern electronic digital levels provides an automatic display of height and distance within about 4 seconds with a height measurement accuracy of 0.4 mm, and the internal memory makes it possible to store approximately 2,400 data points [11]. The value obtained from these measurements is the net head. Having established the gross head available, it is necessary to allow for the losses arising from trash racks, pipe friction, bends and valves, In addition to these losses, certain types of turbines must be set to discharge to the atmosphere above the flood level of the tail water (the lower surface level) [35]. A properly design pipeline will yield a net head of about 85%- 90% of the gross head measured [15].

V. DIVERSION SYSTEMS

Diversion System refers to the means to “divert” water from the source and transport it to turbine. A water diversion system serve two primary purposes: to provide deep enough pool of water to create smooth, air-free to the pipeline and to remove dirt and debris [15]. It consists of Intakes, spillways, forebay tank, penstock, tailrace etc [37]. There are various methods for diverting and transporting the water, but diversion systems can be grouped into two basic types: closed and open systems. Matching the correct type of diversion system to a particular style of micro-hydro turbine is critical to the optimal performance of the turbine [8].

In a closed diversion system (such as pipe), the system is sealed and water is isolated from direct gravitational forces while in the pipe (figure 4). The energy in the water flowing in a closed conduit of circular cross section, under a certain pressure, is given by Bernoulli.s equation:

$$H_1 = h_1 + \frac{P_1}{\gamma} + \frac{V_1^{\,2}}{2g} \qquad (4)$$

Where H_1 is the total energy, h_1 is the elevation head, P_1 the pressure, γ the specific weight of water, V_1 the velocity of the water and g the gravitational acceleration. The total energy at point 1 is then the algebraic sum of the potential energy h_1, the pressure energy P_1/γ, and the kinetic energy $V_1^2/2g$ [11]. Closed diversion system work well for developing high pressure head with relatively low water flow volume (impulse turbines). [8, 38].

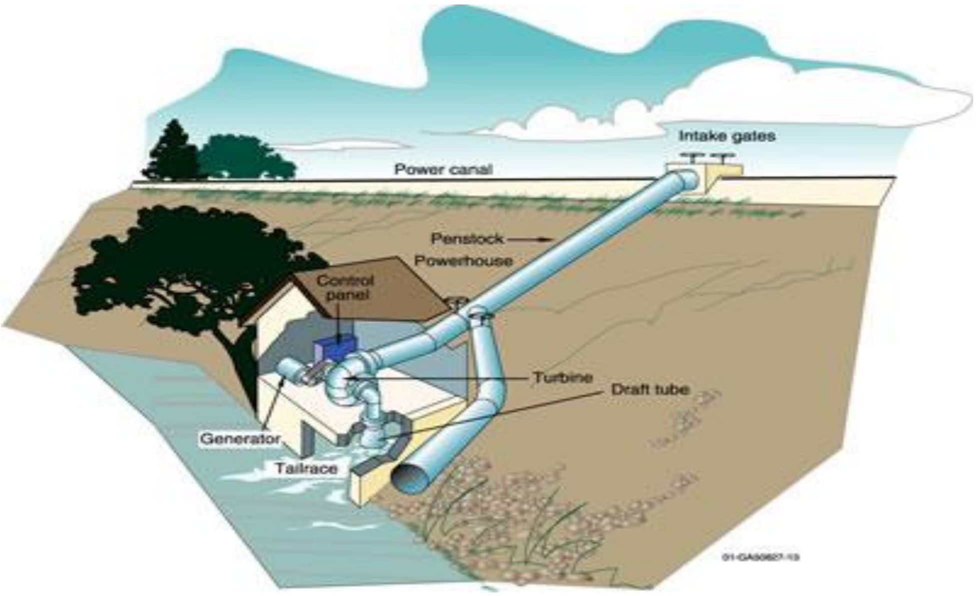

Figure 4: Closed Diversion System [25].

Contrary to what happen in closed pipes, where the water fills the entire pipe, in an open canal there is always a free surface (figure 5). Normally, the free water surface is subject to the atmospheric pressure, commonly referred to as the zero pressure reference, and usually considered as constant along the full length of the canal [11]. At the point where the water is diverted, solid matter, such as sand or gravel floating in the river, has to be abstracted to protect the turbine, avoid accumulation in the channel and protect the basins [36]. Open diversion systems work well for supplying large volumes of water to the turbine (Reaction turbines) with low friction loss [38]. Some reaction turbines (such as the Nautilus) may utilize a combination of open and closed diversion systems, with the open system leading to a closed system (such as a pipe). The open segment diverts a large volume of water close to the turbine site, while the closed portion allows development of the necessary pressure head for the turbine without the expense of long lengths of piping. In these combination systems, the starting elevation for the pressure head is the water surface at the point where the water enters the closed system [8].

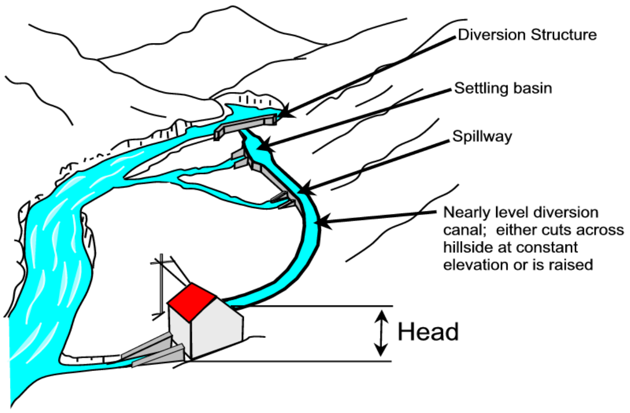

Figure 5: Open diversion system [8].

VI. MICRO HYDRO PROJECT PLANNING

The basic concepts considered in micro hydro planning are: topography and geomorphology of the site, evaluation of the water resource and its generating potential, site selection and basic layout, hydraulic turbines and generators and their control, environmental impact assessment and mitigation measures, economic evaluation of the project and financing potential, Institutional framework and administrative procedures to obtain the necessary consents [35].

For any micro-hydro project to be successful, the following three steps must not be missed: (1) Project formulation and layout i.e. hydrological study (flow duration, flood conditions, dry/wet year conditions), basic topographical overview (possible head, access conditions, and existing roads), preliminary assessment of slope stability/sediment loads and basic project layout with first approximation of electricity generation. (2) Engineering design and layout optimization i.e. pre-design of hydraulic structures with cost estimations, optimization of sizing and evaluation of layout alternatives. (3) Definition of project layout i.e. Detailed field investigations, detailed engineering design and bill of quantities and budgetary quotations for Equipment [39].

Planning micro-hydro project involves brainstorming, taking critical decision and following a chronological step as shown in fig 6.

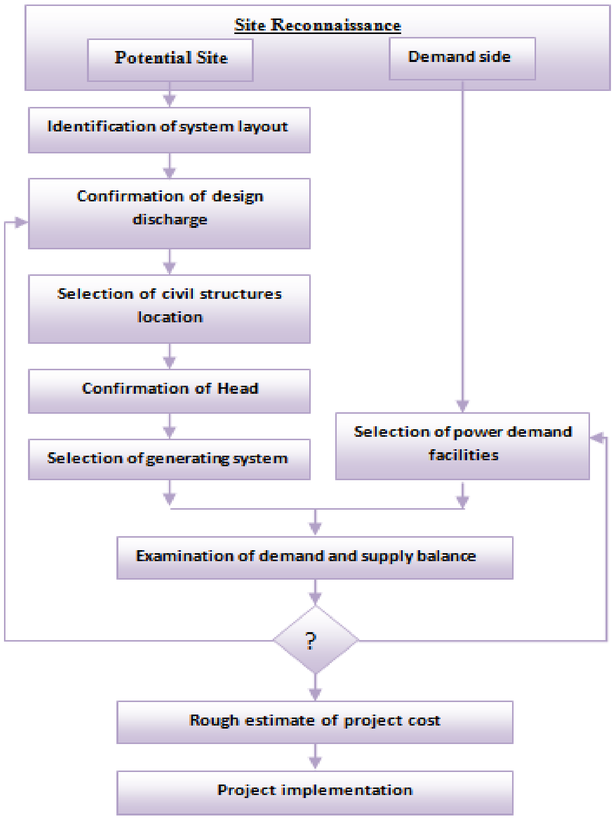

Fig 6: Micro-Hydro Project Planning [40]

If the demand and supply is not balance, findings of the survey should be presented to the benefitting community at an open meeting in which local government staff, local development organizations and all the stake holders should also be encouraged to attend to take necessary decision.

VII. ADVANTAGES AND LIMITATIONS OF HYDRO-ELECTRIC ENERGY

In particular, the advantages that micro-hydro-electric power plant has over the same size wind, wave and solar power plants are: High efficiency (70-90%), by far the best of all energy technologies, High capacity factors (> 50%) compared with 10% for solar and 30% for wind power plant and Slow rate of change; the output power varies only gradually from day to day not from minute to minute [2]. In general, hydro energy are predictable, small start up time and output time can easily be adjusted, more reliable, low operating cost, long-lasting technology and no environmental impact.

Despite the aforementioned advantages, hydro technology is site-specific with limited level of expansion unlike wind and solar i.e. Sites that are both well suited to the harnessing of water power and close to a location where the power can be exploited are not that common and maximum available power (which depend on head and flow rate) cannot be expanded by addition of turbine [7]. The fact that micro-hydropower requires high initial capital cost and water is not readily available all season round contributes to the low level of investment in the technology.

VIII. CONCLUSION

In this paper the basic component of micro-hydro system such as turbine, generator, and the diversion system has been discussed with emphasis on the technology involve, application and the necessary condition under which such components will be applied. The methods involved in estimating the flow rate and the head in order to have an idea of the available power were also discussed. Micro hydro benefits the rural folks in many as well as other advantages. The limitation, these advantages as well as planning involve in micro-hydro project were discussed. Though micro hydro itself will not solve all the energy problems around the globe, through proper and careful planning and implementation involving the recipient communities, it can serve as an excellent decentralized electricity generation grid or as a secondary power generating unit, making the grid more robust [4].

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