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Review of small hydropower system

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Abstract

Renewable energy resources play an important part in the world's future. Renewable energy sources have the following components: biomass, geothermal, solar thermal, directs solar, wind, tidal and hydropower. Hydropower is still the most efficient way to generate electricity worldwide. Hydropower projects can contribute as a cheap energy source, as well to encourage the development of small industries across a wide range of new technology; furthermore hydropower systems use the energy in flowing and falling water to produce electricity or mechanical energy. Hydropower systems are classified as large, medium, small, mini and micro according to their installed power generation capacity, as do the following components: water turbines, control mechanisms and electrical transmissions. In this article a review of small hydropower systems has been done on the principles surrounding the fundamentals of hydraulic engineering, the fundamentals of hydrology, identification of sites and economic analysis.

Keywords*: small hydropower, turbine, renewable energy resources*

1. INTRODUCTION

Renewable energy sources (RES) supply 14% of the total global energy demand [1]. The energy resources have been dividing into three categories: fossil fuels, nuclear resources and renewable resources [2]. The use of renewable sources is the most valuable solutions to reduce the environmental problems associated with fossil fuels based energy generation and achieve sustainable and clean energy development. Hydro, wind, biomass, solar and geothermal are considerable renewable sources for energy generation [3].

Hydroelectric power is currently the largest of the perpetual or so-called renewable energy resources (RESs). Hydropower con- tributes to electricity generation in 160 countries, but five of them (Brazil, Canada, China, Russia and the USA) account for more than half of the world's hydropower production [4]. Furthermore, it accounts for about 20% of all electricity generated in the globe and is utilized in more than 150 countries [5]. Hydropower is the world largest clean and renewable energy source with almost negligible

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levels of greenhouse gas emissions. Total global hydropower potential is approximately 970 GW with the addition of 25 GW of new capacity in the year 2011 [6].

Hydropower has an extensive list of positive characteristics. In addition to power generation and efficiency, it has benefits such as: flood protection, flow regulation, multiple use, fossil fuel avoidance, a long depreciation period, revenue by an adequate electricity rate, and low operating–maintenance–replacement costs. In addition, hydro plants are often superior to other power plants from the standpoint of socio-economic and environmental considerations. The environmental impacts of hydropower plants are at the lowest level compared with the other alternative resources [7]. Hydropower is available in a broad range of project scales and types. Projects can be designed to suit particular needs and specific site conditions. As hydropower does not consume or pollute the water it uses to generate power, it leaves this vital resource available for other uses. At the same time, the revenues generated through electricity sales can finance other infrastructure essential for human welfare. This can include drinking water supply systems, irrigation schemes for food production, infrastructures enhancing navigation, recreational facilities and ecotourism [8]. **Table 1** shows small hydropower benefits [9].

Table 1. Small hydropower benefits.

Small hydropower benefits
• Clean, sustainable and emissions-free source of renewable energy • Highly efficient (from 70% to 90%) • Proven and reliable technology • Predictable and easy to manage • Long lifespan of up to 100 years • Attractive energy pay-back ratio • Improves grid stability • Is an indigenous resource • Improves the diversity of energy supply • Technology suitable for rural electrification notably in developing countries

Small hydropower is in most cases 'run-of-river'; in other words any dam or barrage is quite small, usually just a weir, and generally little or no water is stored. The civil works purely serve the function of regulating the level of the water at the intake to the hydro-plant. Therefore run-of-river installations do not have the same kinds of adverse effect on the local environment as large hydro [8].

Hydropower has various degrees of 'smallness' and definition of 'small' hydro; the upper limit varies between 2.5 and 25 MW. A maximum of 10 MW is the most widely accepted value worldwide, although the definition in China stands officially at 25 MW. In the jargon of the industry, 'mini' hydro typically refers to schemes below 2 MW, micro hydro below 500 kW and pico hydro below 10 kW. These are arbitrary divisions and many of the principals involved apply to both smaller and larger schemes [10]. There is no internationally accepted formal definition of small hydro in place as yet, though small hydro is generally taken as a power station/plant having output up to 25MW. Different agencies use different upper limits for micro and mini hydro projects ranging from 0.1MW to 2MW for the former and >0.1MW to 50MW for the latter, but a ceiling value of 10MWis becoming more generally accepted [11], especially in Europe.

Small hydropower systems allow achieving self-sufficiency by using the best possible scarce natural resource that is the water, as a decentralized and low-cost of energy production [12]. And the upper limit of power generation capacity set by different countries to define smallness of hydropower projects is given in **Table 2**. Small hydropower projects in India are classified as follows [11]:

(a) Depending on capacity

Micro Hydropower:	up to	100	kW
Mini Hydropower:		101 - 1000	kW (i.e. 1MW)
Small Hydropower:	above	1MWup to 25MW	

(b) Depending on head (H)

Ultra low head:	below	3	m
Low head:	above	3	m
Medium/high head:	above	40	m

Table 2. Upper limits of power generation capacities of small hydropower units set by various countries.

Country	Limit (MW)
Sweden	<15
Colombia	<20
Australia	<20
India	▯ 25
China	<25
Philippines	<50
New Zealand	<50

2. FUNDAMENTAL OF HYDRAULIC ENGINEERING

2.1 The Principles of small hydropower

A hydro scheme requires both water flow and a drop in height (referred to as 'Head' (**Figure 1)**) to produce useful power. The power conversion absorbs power in the form of head and flow, and delivering power in the form of electricity or mechanical shaft power. No power conversion system can deliver as much useful power as it absorbs - some power is lost by the system itself in the form of friction, heating, noise, etc [13].

The power conversion equation is:

$$\text{Power input} = \text{Power output} + \text{Loss}$$

or

$$\text{Power output} = \text{Power input} \times \text{Conversion Efficiency}$$

The power input, or total power absorbed by the hydro scheme, is the gross power, (P_{gross}). The power output is the net power (P_{net}). The overall efficiency of the scheme (**Figure 2**) is termed E_o.

$$P_{net} = P_{gross} \times E_o \qquad \text{in kW}$$

The gross power is the product of the gross head (H_{gross}), the design flow (Q) and a coefficient factor (g = 9.8), so the fundamental hydropower equation is:

$$P_{net} = g \times H_{gross} \times Q \times E_o \qquad \text{in kW (g=9.8)}$$

where the gross head is in meters and the design flow is in cubic meter per second. E_o is derived as follows:

$$E_o = E_{civil\ work} \times E_{penstock} \times E_{turbine} \times E_{generator} \times E_{drive\ system} \times E_{line} \times E_{transformer}$$

Usually

$E_{civil\ work}$: 1.0 - (Channel length × 0.002 ~ 0.005) / H_{gross}
$E_{penstock}$: 0.90 ~ 0.95 (it's depends on length)
$E_{turbine}$: 0.70 ~ 0.85 (it's depends on the type of turbine)
$E_{generator}$: 0.80 ~ 0.95 (it's depends on the capacity of generator)
$E_{drive\ system}$: 0.97
E_{line} : 0.90 ~ 0.98 (it's depends on the transmission length)
$E_{transformer}$: 0.98

$E_{civil\ work}$ and $E_{penstock}$ are usually computed as 'Head Loss (H_{loss})'. In this case, the hydropower equation becomes:

$$P_{net} = g \times (H_{gross} - H_{loss}) \times Q \times (E_o - E_{civil\ work} - E_{penstock}) \qquad \text{in kW}$$

This simple equation should be memorized: it is the heart and soul of hydro power design work.

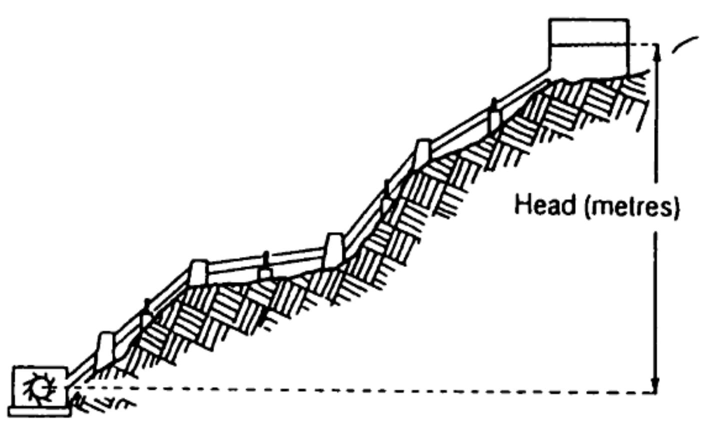

Figure 1. Head is the vertical height through which the water drop

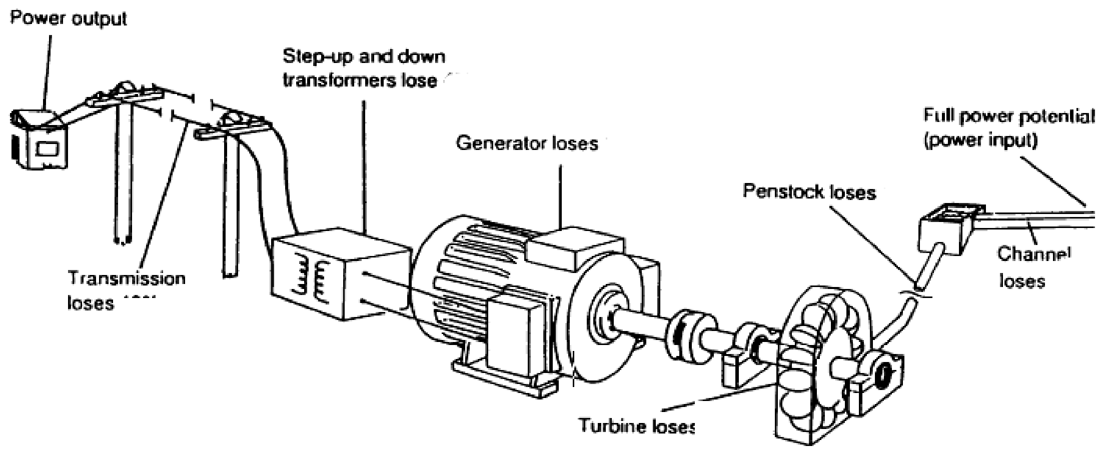

Figure 2. Typical system efficiencies for a scheme running at full design flow

2.2 Types of hydropower turbines

Turbines used in hydroelectric systems have runners of different shapes and sizes [14]. There are two main kind of hydro turbines in use: impulse and reaction turbines. The selection of any type of hydropower turbine for a project is based on the head and the water flow or volume of water at the site. However, other deciding factors include how deep the turbine must be set efficiency and cost [15].

Some Author expounds Hydropower turbines are classified as follows:

- Impulse turbines
  - Pelton turbines
- Reaction turbines
  - Radial flow: Francis turbines
  - Axial flow: propeller (fixed blades) or Kaplan (variable pitch blades) turbines
- Reversible pump-turbines

Turbines can be crudely classified as high-head, medium-head, or low-head machines, as shown in **Table 3**. But this is relative to the size of machine: what is low head for a large turbine can be high head for a small turbine; for example a Pelton Turbine might be used at 50 m head with a 10 kW system but would need a minimum head of 150 m to be considered for a 1 MW system.

Table 3. Impulse and reaction turbines [10].

Turbine type	Head classification		
	High (>50 m)	**Medium (10–50 m)**	**Low (<10 m)**
Impulse	Pelton	Crossflow	Crossflow
	Turgo	Turgo	
	Multi-jet Pelton	Multi-jet Pelton	
Reaction		Francis (spiral case)	Francis (open flume)
			Propeller
			Kaplan

Table 4. Turbines Type Selection.

Turbines Style	Head (H) Range in Meters (m)
Kaplan and Propeller	2<H<40
Francis	10<H<350
Pelton	50<H<1300
Banki-Michell	3<H<250
Turgo	50<H<250

The approximate ranges of head, flow and power applicable to the different turbine types are summarised in the chart of **Figure 3** (up to 500 kW power). These are approximate and dependent on the precise design of each manufacturer.

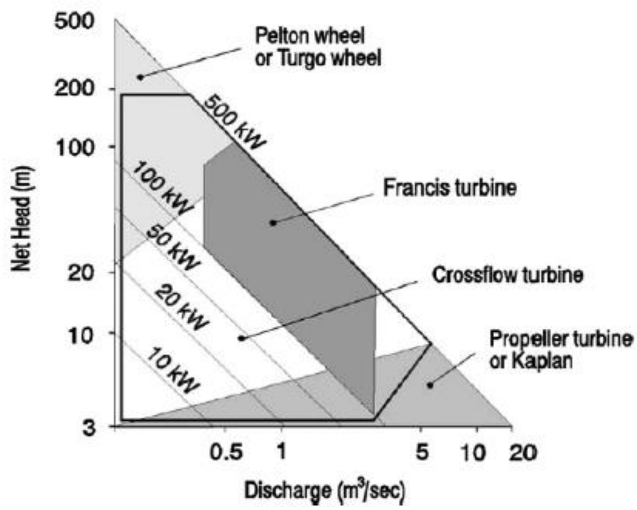

Figure 3. Head-flow ranges of small hydro turbines

2.2.1 Impulse turbines

There are three types of impulse turbine in use: the Pelton turbine **(Figure 4)**, the Turgo, turbine **(Figure 5)** and the Crossflow turbine **(Figure 6)** (the latter is also known as the Banki turbine) [10].

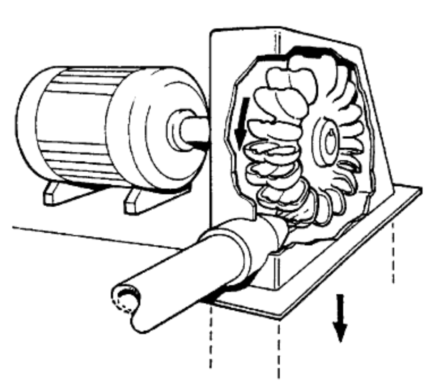

Figure 4. Pelton turbine

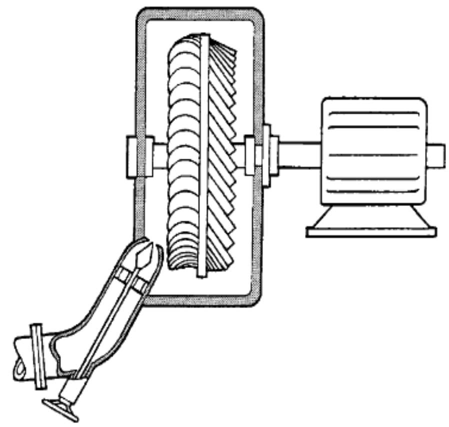

Figure 5. Turgo turbine

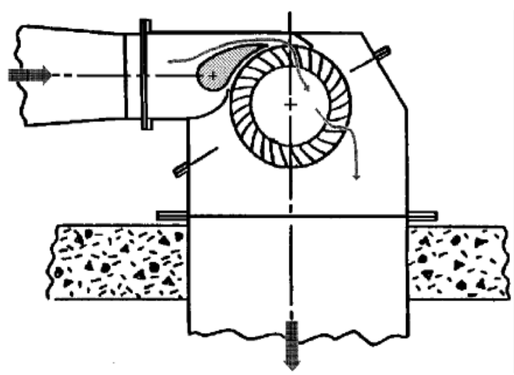

Figure 6. Crossflow turbine

2.2.2 Reaction turbines

The two main types of reaction turbine are the propeller turbines **(Figure 7)** (with Kaplan variant) and Francis turbines **(Figure 8)** [10].

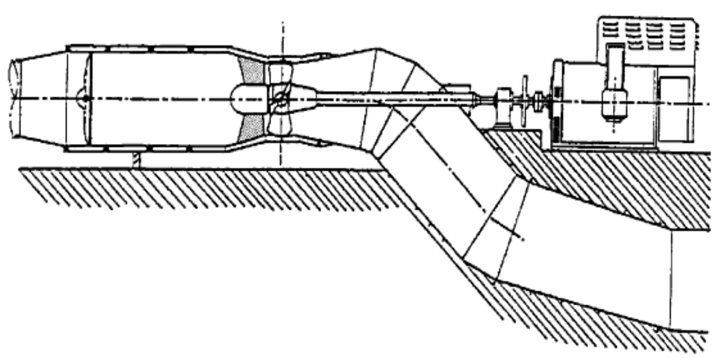

Figure 7. Propeller-type turbines

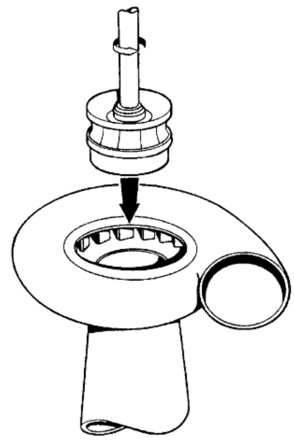

Figure 8. Francis turbine

3. FUNDAMENTAL OF HYDROLOGY

The volume of the river flow or discharge (Q) depends on the catchment area and the volume of rainfall. **Figure 9** shows how the rainfall is divided on both sides (A and B) of the watershed. For example, there is an existing Hydropower Plant at A-side, the rainfall at B-side cannot be used for power generation at this Hydropower Plant. Therefore, the catchment area of a proposed hydropower plant should be known at the first step of the study of hydro scheme [13].

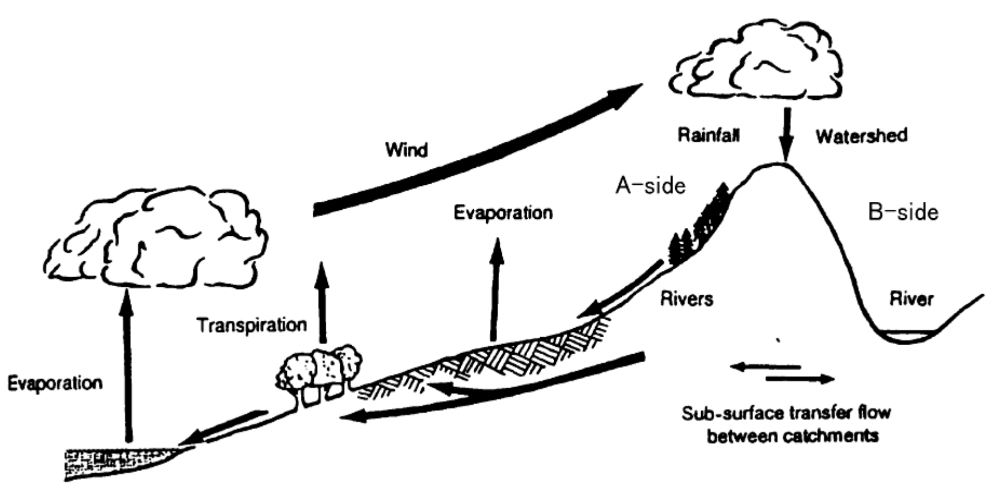

Figure 9. The hydrological cycle

The broken lines in **Figure 10** indicate the watershed of Point-A and Point-B. The catchment area is the area enclosed by broken lines.

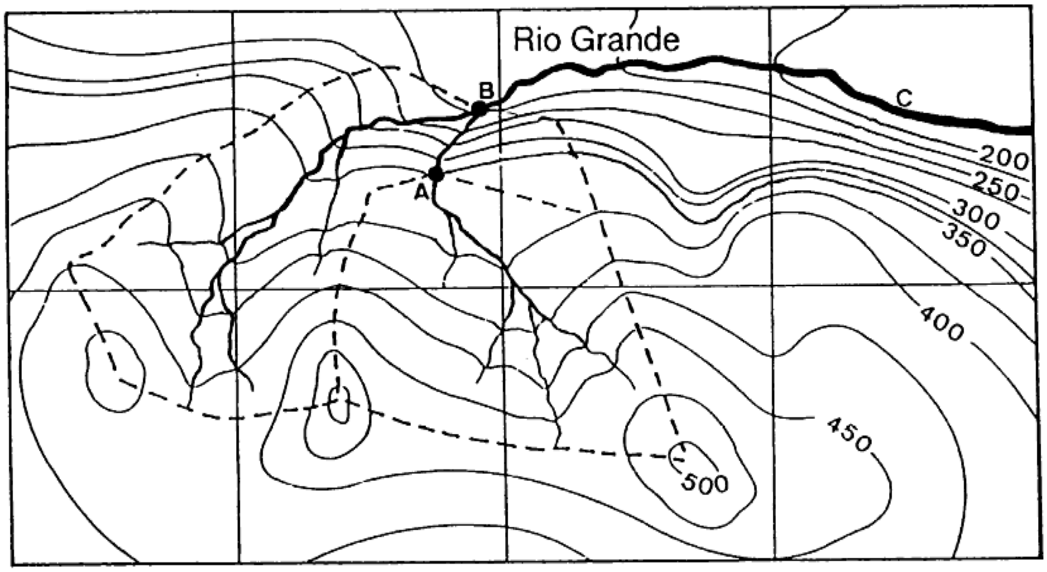

Figure 10. The catchment area and the watershed

4. IDENTIFICATION OF SITES

The best geographical areas for small hydropower plants are those where there are steep rivers, creeks, streams or springs flowing year-round, such as in hilly areas with high year-round rainfall. To assess the suitability of a site for a small hydropower plant, a pre-feasibility study should be made. This involves surveying the site to determine the water flow rate (Q) and the head (H) through which the water can fall.

The basic reference materials required are the following [13]:

1) Topographical map: scale: 1/50,000

Topographical map provides important information, such as landform, location of communities, slope of the river, catchment area of proposed sites, access road, etc.

2) Rainfall data: isohyetal map and others

Although it is unnecessary to gather detailed rainfall data at this stage, it is necessary to have a clear understanding of the rainfall characteristics of the project area using an isohyetal map for the region and existing rainfall data for the adjacent area. Isohyetal map provides the interpolation and averaging will give an approximate indication of rainfall.

Flow rate of the water and the head through which the water can fall, as defined in the following:

• The flow rate is the quantity of water flowing past a point at a given time. Typical units used or flow rate are cubic metres per second (m^3/s), litres per second (lps), gallons per minute (gpm) and cubic feet per minute (cfm).

• The head is the vertical height in metres (m) or feet (ft.) from the level where the water enters the intake pipe (penstock) to the level where the water leaves the turbine housing.

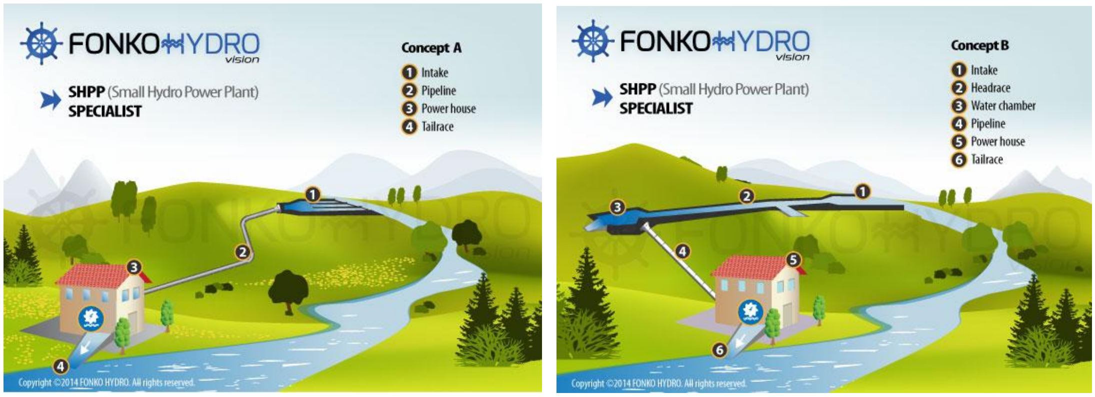

Figure 11. Small Hydro Power Plants [19].

If you are new to the area, local residents have the best source of information on the nature of the stream, flow variations during the year and any abnormal flows in the past. This will give an overall picture of annual river flow fluctuations over the seasons. If possible, flow data should be gathered over a period of at least one full year, although two to five years is ideal. Your local utility may also have an inventory listing of potential small hydropower sites in your area. A site survey is carried out for promising sites in order to gather data that is detailed enough to make power calculations and start design project [16].

5. ECONOMIC ANALYSIS

The “cost analysis” step, a detailed cost analysis is performed taking into account initial costs and annual costs (maintenance, staff and insurances) involved in the project. **Figure 12** presents the distribution of initial expenses [17].

The cost of civil works, electromechanical equipment, and other miscellaneous cost constitute the total cost of the project. Cost of establishment including designs, audit and account, indirect charges, tools and plants, communication expenses, preliminary expenses on report preparation, survey and investigations, and cost of land are considered as miscellaneous costs, which comes out to be 13% (CEA,1982) of the sum of the cost of civil works and electromechanical equipment [18].

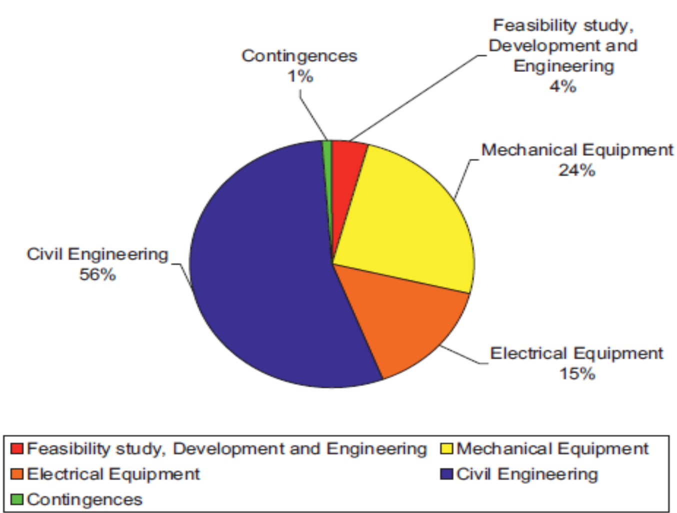

Figure 12. Summary of the initial costs of the facility

5. CONCLUSION

This paper presented small hydropower system is one of the most common systems used for electricity generation. Small hydropower systems have been done on the principles surrounding the fundamentals of hydraulic engineering, the fundamentals of hydrology, identification of sites and economic analysis for produce electricity. Small hydropower is the essential alternative way of future renewable energy system global development. It is available, clean energy and cheap.

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