A PRACTICAL GUIDE TO CONSTRUCTION OF HYDROPOWER FACILITIES

Suchintya Kumar Sur

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This book is dedicated to

my little grandson Shivansh Bhardwaj

and to my wife Ms. Bulbul Sur.

Contents

Preface

The global environmental change is a matter of great concern. The impact of these changes create an imbalance between basic elements of the universe and living creatures. The basic elements of the universe are earth, air, water, light, and ether. The constituents of the environment get disturbed if the percentage of any constituent goes beyond its limit, resulting in a disturbance in the natural balance. Any change in the natural balance causes huge problems to the living creatures of the universe.

Development is the order of the hour in this universe. Development indulges the utilization or overutilization of energy that transforms the environment. If energy required for development is produced through carbon-based technology like oil, gas, or coal, which create havoc in the environment, it will accelerate global warming beyond acceptable limits, and, who knows, one day temperatures may touch the temperature of Death Valley. Effective management of environmental change has become imperative in the last decade. Harnessing alternate energy sources to create a safe and balanced environment and to formulate other diverse plans of survival have gained top priority in high-level discussions on the international level. It has become a concern of all national governments, international organizations, PSUs, MNCs, private sectors, and individuals. Sustainable engineering is an emerging theme in the modern world, and there is need for environmentally friendly power generation systems in the present scenario for a better tomorrow. Renewable energy systems become the forerunner in this new race. Hydroenergy is the most effective tool in this scenario because it connects people, power, and prosperity and it is a cooler solution to a hotter earth.

There is a huge demand for electricity in developing countries. Approximately 12% of their population do not have access to electricity, and policymakers are ensuring their investment in hydropower. They have realized how the investment in hydropower is supporting national development priorities and the clean energy transition. Hydropower is a clean source of electricity as per the latest report from the IHA, which indicated that the world prevented approximately 4 billion tons of greenhouse gases by generating electricity from hydropower last year and avoided about a 10% rise in global emissions from fossil fuels while also successfully avoiding 150 million tons of air polluting particulates, 62 million tons of sulpher dioxide, and 8 million tons of nitrogen oxide from emission. Under the present trend, it is felt that a new category of book with improved course materials is essential to produce engineers suited to the newly metamorphosed power sector.

This book has been penned primarily as a reference book on conception of hydropower engineering with students and professionals in mind, and it is quite self-sufficient. It includes some unusual project activities generally not covered in other textbooks such as the theme and philosophy of hydropower, kick-off meetings and site mobilizations, philosophy of blasting operations per the Explosive Act, QA/QC, health, safety, and environment, environment impact assessments, contract management, and other topics related to the subject. The theoretical and practical aspects of engineering have been seamlessly integrated to ensure that the reader has a combination of engineering and managerial acumen to handle any contingency pertaining to a hydropower project.

This book provides readers with background information and guidance to help them to understand and deal more confidently with issues related to planning, construction, supervision, and analysis of hydropower projects. The author has attempted to address all issues both traditional and innovative in nature.

What motivated and rejuvenated my desire to write this book is my experience and knowledge acquired during construction of the hydropower project in Limestone Valley. This book has been written primarily as a reference book based on facts and figures obtained from that unique project. Design, planning, and construction of the project was a great challenge due to the existence of immense adverse geotechnical problems such as karst/sinkholes, fault/shear zones, and clay seams in the reservoir as well as in the dam foundation area, all of which made the project challenging and fascinating. This book will provide enriching technical and managerial insights to its readers, and will be a unique learning process. In addition to the aforementioned topics, prevalent issues such as corporate social responsibility measures, management of community risks, limiting the risks posed to the environment, and local/state level negotiations encompassing governments and local populations have also been covered. These aspects provide the reader a fundamental perspective on how a technical project can be engulfed in other issues that require astute management skills.

It is a pleasure to acknowledge the considerable help I received from my seniors and colleagues during my acquaintances with them. I convey my thanks to Mr. Sanjay Kumar Sharma and Mr. Kamal Kumar Sharma for their kind help during the process. I wish to express my thanks to the professionals of my publisher for their cooperation throughout the formative period of the book and particularly to Dr. Gagandeep Singh and his colleague Ms. Mouli Sharma for their editorial advice and guidance. I convey my thanks to Bipasha Bhardwaj, my daughter, for her necessary support during the process.

Author

Suchintya Kumar Sur was Visiting Professor at Jaipur National University and former Head of the Department of Civil Engineering at Jaipur Engineering College and Research Centre. He had also served as Vice President (Construction) at M/s Reliance Industries Ltd, Mumbai, and Construction Manager at Engineers India Limited, New Delhi, and SDO in North Eastern Electric Power Corporation Ltd, Shillong. He has expertise in the construction of a major hydel project in Limestone Valley and was instrumental in completion of the world's largest grassroots oil refinery and oil refining hub in Jamnagar, India in record time, which became a landmark of Indian success in the global market. He is equally adept in the handling of mechanical underground and aboveground piping networks with high temperature and pressure, along with erection and commissioning of dynamic, static, and rotary equipment. He has flair in earthquake engineering and design of RCC structures.

1

Concepts of a Hydropower Project

1.1 Introduction to Objectives, Scope, and Outcomes

Hydro is a word of Greek origin that means water. Water is the mother of all necessities and is a vital component of life. Without water, nothing is possible in our planet. It is synonymous with life. Water enabled evolution of life. It is a crucial factor for Earth's evolution and the survival of human grace. Without it, no life is possible on Earth and the ecological balance will be disturbed. Our Mother Earth would become barren and it would also have influence over the universe.

Water is going to be a critical and scarce commodity in the near future, which will be detrimental to development of mankind. Time has come to take serious steps to preserve rain water by creating ponds, lakes, reservoirs, dams, weirs, check dams, barrages and other surface water and subsequently recharge the ground water table so as to keep the Hydrologic Cycle alive in this planet. The Hydrologic Cycle (HC) is a phenomenon by which water moves from place to place above and below the earth and it changes states between liquid, vapor and ice. Water and air, both mediums essential to life, are the most critical source for potential energy. Hydropower engineering taps this huge quantity of energy available in the flowing water on the surface of Earth, which convert this potential energy to mechanical energy and subsequently to electrical energy for the generation of power.

Based on the forecast of scientists, it is indicated that our planet will be warmed up by between 1.0°C and 6.0°C in next 90–100 years, and 25% of World GDP would be spent to deal with it as suggested by economists of world repute. Emission models of the future predict about the amount of carbon emission which will be influenced by population growth, third world development, usage of fossil fuels and the rate at which we switch over to alternative energy, the rate of deforestation, and effectiveness of international agreement to cut down emission. Under the cloud of this global threat, it is essential to understand the history of the theory of global warming and evidence that supports it so as to welcome renewable energies for sustainable development of the universe.

Sustainable development is accepted and defined as "The development that meets the need of present without compromising the ability of future generations to meet their own needs," and it has three basic arms of a magic triangle such as Environment, Economy and Social aspects.

Renewable Energy (RE) is a golden thread which is a nucleus of development of the society. Renewable or Cleaner Energy (CE) is derived from water to meet the basic need of human being.

It retards global warming and carbon emissions which can be treated as a cool solution to a hotter earth.

A consensus concern all over the world is that of the increasing trend for utilization of renewable energy. This clean energy will retard the global warming process. Renewal or clean energy is derived from water, wind, solar and biogas to meet the basic need of human beings. Renewal energy in the present scenario is the nucleus of development of the country. India, a vast country, is having paramount potentiality of 1,45,000 MW of Hydropower that is still unexplored and only 27% of it remained explored. Hydropower came down from 45% to 18% as per reports, and growth has been reduced due to remoteness and inaccessibility to site, lack of infrastructure and land acquisition, environmental and deforestation, acute geotechnical constraint, etc.

Hydropower is synonymous with energy of water and the hydroelectric (hydel) project is a golden avenue to harness this energy for the benefit for mankind. River water is not subjected to market fluctuation. It is the only energy whose efficiency, flexibility and reliability are a matter of great consideration. Hydroelectricity means clean energy today and for tomorrow: an instrument for sustainable development. It is economically viable, environmentally sensible and socially responsible.

Obviously, access to Hydropower is one of the main factors for sustainability, but it has limitations due to geographic situation and geotechnical constraint. It is encouraging that the focus of India is on Hydropower in their 12th 5-year plan for 12.8 GIGA WATT for optimization, which is a morale booster and beneficial to every citizen.

Dam site geology has endless varieties of fascinating problems. It is treacherous as well as mysterious. Dam site geology has a tremendous influence on design and construction of dams.

The civil engineers who work in dam sites should be inquisitive and curious, careful and cautious, alert and astute. They should possess a high curiosity quotient. Their observations should be keen and investigative like detectives, and they should attempt to be more vigilant to formulate the problems in accurate terms to solve them under the light of relevant facts that can be collected by observations and experiments. Their insatiable minds should echo, now and then, some questions such as what and why? And these questions will challenge them to find a clue which may give them possible answers to the unforeseen problems on variable unpredictable sub surface ground conditions; otherwise, it might pose severe constraints in design and construction of safe hydel projects. Any indifference and lack of concern may cause havoc that may lead to a huge national disaster.

Dam and reservoir sites need extensive investigation before design and construction begin. Geological studies are most vital and essential in this process, especially for larger hydel projects. Site investigation involves exploration on and below the surface of the Earth. It is a mandatory and vital requirement for successful and economic design of dam structures. Questionnaires arise in the mind of sensible civil engineers before investigation regarding the perfect location of a dam and its geological features such as foundation condition, type of soil and rock with over burden, and weathering profile available at selected site. Minds of civil engineers suggest to assess carefully whether the type of rocks encountered will be able to support or sustain the weight of the dam. Are there any fault zones or shear zones, buried channels, sink holes or karsts, or clay seams? Are the bed rocks fractured and weathered, vulnerable and susceptible to hazardous seepage that may lead to instability of dam? The geologist sometimes needs to answer very difficult questions, whether a fault exists at site can become active or whether it can be deactivated by impounded water. All these data are to be obtained by investigative methods so as to supply adequate information to the designer in order to design a stable and safe hydraulic structure.

During construction, experienced geologists should be posted in areas like the dam site, low and high pressure tunnel, powerhouse, etc. Geologists work hand in hand with engineers who make geological logs of each working area to give overall ideas of geological features of the particular working site. The subject mapping comprises of the existence of fault, fold, clay seam, dip and strike, etc., along with detailed foundation treatment which will guide site engineers to formulate the methodology of construction and often seek approval/advice of the Resident Geologist for going ahead with the work.

Civil engineering is the oldest engineering in the world. Civil engineering is the mother of all Engineering. The civil engineer, in pursuing his field of endeavor, has two responsibilities: toward the society and toward hydropower … a golden thread that connects people, power and prosperity by designing and constructing stable hydro structures along with safe guarding the life of people using and passing by the structure.

The aim of this book is to present how an opportunity was explored and clean energy was extracted from a difficult natural scenario by accepting the challenge where in renewable energy was derived from the critical base of water through an integrated approach to economy, society and the environment. Opportunity meets preparedness which delivers services to meet the basic needs of human beings that would sustain for long.

This book is a complete package on Concept of Hydropower Engineering and offers unique insight, domain specific knowledge and problem solving domain to the readers (Students, Engineers and Researchers) and enable them to become hydropower engineers in the true sense.

1.2 Outcomes

Readers of this guide will acquire a comprehensive concept of hydropower and its formation through various stages starting from investigation, design, planning, estimation and budgeting, construction and up to generation of power. They will come to know how this book offers guidance on key issues pertaining to development of renewable energy, be aware of its unique characteristics compared to other energy sources, and learn about various hydropower schemes like run off river, storage, pumped storage and from small hydro to mini to micro to pico hydro plant, including their benefits and future in the world market of power generation. The readers will envisage how the hydropower reservoir renders services to mankind in different aspects like local livelihood, economic growth, water quantity management inclusive of drought control, ground water stabilization and ecosystem services inclusive of guaranteed downstream flows both for environment and human—water quality management and reduction of carbon emission.

1.3 Theme and Philosophy

Green power energy is the need of the hour to reduce impact on the environment. Hydropower is favored as renewable and alternative energy which is generated by extracting energy from moving water and depends on rain fall; with more rain fall more power will be generated. Hydropower is a golden thread of high ductility where long development and sustainable growth connects with people, power and progress.

1.4 Concept of Hydropower Project

The eternal Hydrologic Cycle has become vulnerable and susceptible to global warming and the emission of carbon phenomena. Whatever was given by Mother Earth has been stolen by Father Time due to our ignorance, carelessness and indifferent attitude towards life. Under the cloud of this global threat, renewable energy is one of the possible cool solutions to a hotter earth which is the universal need of the hour.

Hydro is a word of Greek origin which means water, and hydropower is the energy contained in water. It is generated by the water in motion and a combination of head and flow. The river water flows from the source at higher elevations to lower elevations by gravitational force, and it loses its potential energy to gain kinetic energy. The difference in water level is called hydrostatic head, which is capable of helping water to flow downstream, and in many projects; the requisite head created by building an impervious barrier across the river is called a dam, which enables the creation of a water reservoir in the upstream side of the river. Hydropower engineering taps this energy of water (potential), which is converted into kinetic energy due to gravity, for subsequently onward transmission to mechanical energy and finally into electrical energy.

This transformation of energy is done through a system known as a Water Conducting System. Stored water is released from the reservoir and flows through an intake and subsequently through a low pressure tunnel to the surge shaft and onward flow through the high pressure tunnel/penstock to rush down below to the power house (underground or surface) to rush through the turbine, which spins the shaft, and a generator is coupled with the turbine through the shaft which generates power. The water continues to flow through the tailrace channel to the river. The generation of electricity is nothing but the conversion of one kind of power to another. The turbine converts water power to rotational power at its shaft which is then converted to electrical power by the generator. It is a fact that some power will be lost through friction during conversion and efficiency is measured by the amount of power that is actually converted.

$$\text{Approximate power developed} = W \cdot Q \cdot H \cdot \eta$$

where

W = Specific weight of water, N/m^3
Q = Rate of flow of water, m^3/sec
H = Hydro-static head, m
η = Efficiency of conversion of potential energy to kinetic energy

1.4.1 Role of Hydropower in Energy Mix

Our planet contains many sources of energy like oil, natural gas, coal, water, solar, geo thermal, biogas, nuclear, and wind. The combination of these sources of energy is called energy mix. It varies in accordance with the available energy in a country.

Energy mix is of two types:

a. *Primary energy*: When energy is converted directly from the fuel in a single stage of process, it is known as primary energy. Water is utilized as fuel in hydropower which directly produces electricity, so it falls under primary energy.
b. *Secondary energy*: When energy is produced in a multi-stage conversion process from fuel, it is known as secondary energy. Fuel like gas, oil or coal is burnt in power plants to heat water to produce steam for generation of thermal power.

Global energy mix was controlled by fossil fuel and it has been a major contributor for global warming and carbon emission. Renewable energy is found to be one of the alternatives to have a cooler earth where hydro—a clean energy, is a possible solution which can dominate the world's energy mix as a cooler solution to hotter earth so as to change the power generation mix in the world. Hydropower is the leading renewable source for generation of electricity in the world. Global Hydropower generation has increased by more than 30% in last few years.

Hydropower is a reliable generation system in energy mix due to its constant and steady flow of water through turbines.

Hydropower plants have the ability to release water at the shortest possible notice so as to meet the immediate high demand of electricity.

Hydropower plants with reservoirs with storage provide, with a high degree of flexibility, the ability to store potential energy for usage to meet demand at any point of time.

1.4.2 Energy Storage and Its Function

Energy storage is the capture of energy during off demand to utilize this energy at the time of peak demand in the future in order to avoid the waste of energy and create a positive effect on the economy.

The energy storage system has become an important tool for the management of energy and provides different technologies to manage the power supply. There are many technologies for storage such as storage in hydrogen, electrochemical storage, thermal storage, and fast energy storage systems which are not the matter of discussion. Our focus shall be on hydro pumped storage. A dam in a hydroelectric project acts as a barrier to create a reservoir for storing water in the upstream in the form of potential energy and can be utilized to generate electricity at the time of need.

Pumped storage is a unique phenomenon for the storage of energy like a battery system. The phenomenon explains that electrical energy, already produced, is converted into potential energy when water is pumped from the lower reservoir to the higher one and stored in the form of water at the time of less demand, and later this water can be released from the higher reservoir through a pipe or any suitable tunnel to flow through a turbine to convert into electrical energy.

This plant consists of two water reservoirs at different levels. Water is pumped from the lower reservoir to the higher one with a force of magnitude equivalent to $F = mg$ against gravity when demand of electricity is low, resulting to work done ($W = F \times h = m \times g \times h$) in the process. Ability to do the work is energy, so potential energy equivalent to $m \times g \times h$ is stored at a reservoir of a higher level. The stored water is released when the supply of water is less than the demand of electricity. The water travels from the higher reservoir through pipes to flow through the turbine in order to generate electricity and store the water in the lower reservoir instead of releasing this water back to the river to complete the cycle. The potential energy becomes zero when water touches the ground and kinetic energy is generated before converting into electrical energy. Refer to Section 2.7.3 for details of scheme and Figure 2.1.

1.5 Global Status of Hydropower

1.5.1 Hydropower Installed Capacity by Region

The world around us has changed and people now understand the effect of environmental change in daily life. All around efforts are being made from all sectors to protect the environment, which has led to a focus on the development of hydropower in the world.

There has been significant growth in the development of hydropower globally as per the report of the World Energy Council, 2016. Hydropower has become the leading renewable source for electricity generation in the world. It supplied 71% of all renewable electricity at the end of 2015. Undeveloped worldwide potential is approximately 10,000 TWh/y. The world hydropower installed capacity has increased by 39% from 2005 to 2015, with an average growth of 4% per year, accounting to a total of 1209 GW in 2015, of which 145 GW in pumped storage (Table 1.1).

1.5.2 Top 10 Hydropower Producing Countries, 2016

Hydropower is being generated in the most of the countries in the world. China, as per report, is the largest hydropower generating country in the world. The 10 top hydropower generating countries are indicated in Table 1.2.

1.5.3 Ten Largest Hydropower Project in the World

Ten largest hydropower projects of the world are tabulated in Table 1.3.

TABLE 1.1

Hydropower Installed Capacity by Region, 2017

Sl No.	Region	Installed Capacity Including Pumped Storage (GW)	Pumped Storage (GW)	Generation (TWh)
1	Africa	35.33	3.376	131
2	East Asia and Pacific	468.3	66.45	1501
3	Europe	248.56	51.76	599
4	North and Central America	203.05	22.966	783
5	South America	166.959	1.004	716
6	South and Central Asia	144.71	7.451	456
	Total	1266.95	153.04	4185

Source: Adopted from hydropower status report, IHA 2018.

TABLE 1.2

Top 10 Hydropower Producing Countries, 2016

Sl No.	Country	Installed Capacity including Pumped Storage (GW)	Installed Capacity Pumped Storage (GW)
1	China	319.37	23.00
2	United States of America	101.755	22.44
3	Brazil	91.65	0.003
4	Canada	79.202	0.177
5	India	47.05	4.78
6	Japan	49.05	27.63
7	Russia	50.62	1.38
8	Norway	30.56	1.35
9	Turkey	25.88	Nil
10	France	25.397	6.98

Source: Data collected from World Energy Council, 2016.

TABLE 1.3

Largest Hydropower Project in the World

Sl No.	Name of Project	Country	River	Installed Capacity (MW)
1	Three Gorges Dam	China	Yangtze	22,500
2	Itaipu Dam	Brazil and Paraguay	Parana	14,000
3	Xiluodu	China	Jinsha	13,800
4	Guri	Venezuela	Caroni	10,235
5	Tucurui	Brazil	Tocantins	8370
6	Grand Coulees	USA	Columbia	6809
7	Xiangjiala	China	Jinsha	6448
8	Longlan	China	Hongshui	6426
9	Sayano	Russia	Yenisei	6400
10	Krasnoyarsk	Russia	Yenisei	6000

1.6 Definition of Hydropower

The hydropower project is a project where energy of water (potential) is used, controlled and converted into kinetic energy due to gravity for subsequent onward transmission to mechanical energy, and finally, into electrical energy by the help of a hydro turbine connected to a generator. This transformation of energy is done through a system known as a water conducing system, which is comprised of many structures such as a dam, dyke, reservoir, intake, low pressure tunnel, surge shaft/fore bay, high pressure tunnel/penstock, power house, and tailrace tunnel.

Hydropower is a versatile, mature and flexible energy source. A hydropower plant is unique and site-specific, which solely depends on the geotechnical, topo-graphical and hydrological features of each site and accordingly, the type of facility to be built is decided.

Hydropower plants are generally very diverse. Some plants are made with dams to create the reservoir and head, some plants are made with run off rivers, and sometimes on small rivers or on tail race channels, and even on small streams or springs.

Before going onto details of the hydropower project, let us focus on merits and demerits of the hydropower project.

1.6.1 Merits and Demerits

Hydropower is a renewable energy where potential and kinetic energy of water is utilized to generate electricity through turbines. Hydropower offers both merits and demerits as mentioned below.

1.6.1.1 Merits

- *No fuel cost*: Hydropower does not require any fuel, so there is no effect of enhancement of cost of fuel as it happens now and then in case of other energies
- Efficient, flexible and reliable because river water is not subjected to market fluctuation
- Sustainable development tool
- Economically viable as cost of production of electricity is low; payback time within 8–10 years, having long span of life of up to 100 years
- Environmentally sensible as hydropower is a clean energy and reduces emission of greenhouse gases
- Energy storage is a unique phenomena of pumped hydro storage, where energy is stored for the utilization at the time of need
- Any size hydropower project is possible such as pico, micro, mini, small, medium and large hydropower plants as per the need
- High load factor varies from 40% to 60% which is higher than other energies
- *Long life*: Varies from 50 to 100 years
- Socially responsible
- Controls flooding
- Facilitates irrigation systems
- Provides drinking water for human consumption as well as for industrial use

- Creates recreation facilities, fisheries and navigation
- Recharges ground water tables and makes the land suitable for cultivation
- Provides employment in rural areas

1.6.1.2 Demerits

- Long gestation time
- Displacement and loss of livelihood of locals and rehabilitation is required
- Wildlife is affected
- Heavy deforestation, especially in reservoir area
- Siltation
- Dam failures
- Earthquake vulnerability as construction of large dam increases the possibility of earthquake
- Geotechnical constraints in dam foundation and in reservoir area for water tightness

1.6.2 Type of Hydropower Projects

Hydropower plants are classified based on their installed capacity in MW and it is also related to the head. Hydropower facilities can be categorized in the following types of facility.

1.6.2.1 Large Hydro Project

Power is generated through either run-off-river or storage type in this category of hydro project, and is connected to the national grid of the country. The national grid is the high voltage electric power transmission network in the mainland which transmits power safely to the users through the main power station and sub stations. The installed capacity of this type of project is greater than 100 MW and feeds into a large electricity grid.

1.6.2.2 Medium Hydro Project

Power is also generated through either run-off-river or storage type in this category of hydro project and is connected to the national grid of the country. The national grid is the high voltage electric power transmission network in the mainland which transmits power safely to the users through the main power station and sub stations. The rated capacity of this type of project is between 20 and 100 MW and always feeds into a grid.

1.6.2.3 Small Hydro Project

A small hydro project is mainly based on run-off-river where the size of the dam is very small, and even in some cases, where a weir serves the purpose. It does not need any storage of water, resulting in no adverse environmental effect on locals. It is very effective to have access to rural area of developing countries. The rated capacity of small hydro projects is between 1 and 20 MW and usually feeds into a grid.

1.6.2.4 Mini Hydro Project

The rated capacity of this type of hydro project varies between 100 KW and 1 MW. The construction of this type of project is very convenient as it requires a small area and less time than other projects. It is constructed on a small flowing river, on a canal drop or on a tailrace channel. It is a standalone system but sometimes it is connected to an available mini grid or national grid, if any.

1.6.2.5 Micro Hydro Project

The rated capacity of micro hydro varies between 5 and 100 KW. It is generally constructed on a small stream or a small stream with some difference in elevation to have a sufficient flow of water. It is not connected to the national grid and it is only used in rural electrification or a small community.

1.6.2.6 Pico Hydro Project

The output of electricity of this type of hydro project is up to 5 KW. It is most suitable for a hilly area and also at rural areas. This system can use water from a source a few meters above ground level to facilitate the flow of water to pass through a small scale turbine generator for generation of power for domestic use.

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2

Planning, Project Cost Estimation, and the Future of Small Hydropower (SHP): Large Hydro and Its Various Schemes and Components

2.1 Global Definition and Various Rated Capacity of SHP

There is no global consensus on a definition of Small Hydropower. The definition differs from country to country and continent to continent. As per the European Small Hydro Association, the UK favors 5 KW, France likes 8 MW, and Italy settles for 3 MW. ESHA, the European Commission and UNIPEDE agree upon 10 MW or less.

Hydropower with installed capacity not more than 50 MW is considered as SHP category in China, whereas India favors up to 25 KW.

Here is the under rated power of SHP as tabulated below for different countries in the world (Table 2.1).

2.2 Type of Facilities and Its Applicability

The type of hydropower facility is classified as tabulated in Table 2.2.

2.2.1 Classification of Small Hydro by Head

Hydraulic head and specific speed are the key factors for the selection of turbine for hydro projects of any magnitude so some reference model shall be fixed for an easy solution but other parameters shall be considered as per site prevailing condition/site specific (Table 2.3).

TABLE 2.1

Rated Power of SHP of Different Countries

Sl No.	Country	Installed Capacity in MW
1	Italy	≤3 MW
2	Domenian Republic, Guatemela, Macidonia	≤5 KW
3	Mauritius	≤0.05 MW
4	Morocco	≤MW
5	Afghanistan, Burundi, Iran, Malaysia, Mali, Nepal, Norway, Sri Lanka, Tunisia, Kenya, Uganda, Zambia, Madagascar, Armenia, Austria, Croatia, Montenegro, Nigeria, Turkey, Serbia, Slovenia, Switzerland, Senegal, Azerbaijan, Cambodia, Philippines, Indonesia	≤10 MW
6	Georgia	≤13 KW
7	Bangladesh, Laos, Lesotho, Thailand	≤15 MW
8	El Salvador, Peru	≤20 MW
9	Bhutan, India, Mozambique	≤25 MW
10	Argentina, Brazil, Mexico, Benin, United States	≤30 MW
	Canada, China, Pakistan, New Zealand	≤50 MW

Source: Adopted from AHEC-IITR, "1.1-General: Small Hydropower Definitions…Ministry of New and Renewable Energy," Roorkee, September 2013.

TABLE 2.2

Type of Hydropower Facility

Sl No.	Type of Facility	Rated Power	System of Distribution	Applicability
1	Large hydro	>100 MW	National grid	Large population centre
2	Medium hydro	25–100 MW	National grid	Medium population centre
3	Small hydro	2–25 MW	National grid/ Regional grid or Stand alone	Small community and expected to connect regional or local grid
4	Mini hydro	100 KW to 2 MW	Do	Isolated communities or small factories
5	Micro hydro	5–100 KW	Rural electrification	Small isolated locals
6	Pico hydro	<5 KW	Do	3–4 houses

Source: Adopted partially from AHEC-IITR, "1.1-General: Small Hydropower Definitions… Ministry of New and Renewable Energy," Roorkee, September 2013.

2.3 How Small Scale Hydro Is Utilized World Wide

Today's world is on the verge of drastic change … a change in the low carbon era. There is an all-around effort in advocating ideas of green development of small hydropower. Environmental changes, energy

TABLE 2.3

Type of Turbine to be Selected by Head

	Head % of Designed Head		
Sl No.	**Max**	**Min**	**Type 1 of Turbine to be Assessed**
1	125	65	Axial flow, Kaplan, Propeller, Cross flow, Francis
2	110	90	Kaplan, Propeller, Francis
3	125	60	Kaplan, Turgo, Pelton

Source: Adopted from AHEC-IITR, "3.1 Electro-Mechanical–Selection of Turbine and Governing System," standard/manual/guideline with support from Ministry of New and Renewable Energy, Roorkee, June 2012.

security, and volatile fuel prices are major challenges that pose a great threat to industrial and economic development. World leaders and strategic thinkers have already decided to shift from traditional energy sources to renewable ones. It is clear that access to economically viable, environmentally sensible, socially responsible and reliable energy brings changes in industrial competitiveness while creating employment and equilibrium in the society.

It is proven that small hydropower is a befitting cooler solution to a hotter Earth. It can be used as an effective means of electrification of rural areas in the world. Hydropower is considered to be a mature technology. It can be designed, constructed, and maintained locally as it is a flexible, affordable, sensible and reliable energy source which is not subjected to the market fluctuation like other sources of energy.

Today, about 17% of the world's population is still lacking access to electricity. The United Nations has recognized that clean energy and electricity is the key to development.

The total installed capacity of small hydropower is 78 GW in 2016. It has increased about 45 GW in data from a 2013 report furnished by the United Nations Industrial Development Organization (UNIDO). Now the total estimated potential has increased to 217 GW.

SHP represents about 1.9% of world's power capacity. Seven percent of total renewable energy capacity and 6.5% (<10 MW) of total hydropower capacity. Small hydropower is fifth in development.

Despite many benefits, the potential of small hydropower remains untapped in many developing countries.

UNIDO has taken up the campaign to make awareness amongst the leaders of countries about the use of renewable energy like small hydropower in industries and small enterprises. It is needless to say that when it is supported by the environmental protection policies and concrete supervision from regulatory authority, small hydropower can be considered as the most important renewable energy technology.

2.4 Planning of Small Hydropower (SHP)

Planning of small hydropower depends on the site condition of a respective project because each site is unique. The character of the site depends on topography, geological and hydrological feature. A hydel project, large or small, needs careful study and extensive investigation before planning for any project. The conceptual footprint shall be made to take up extensive investigation and exploration of the site in order to examine all collected data for implementation. Adequate exploration of geological and geotechnical characteristics of a proposed site is one of the vital aspects of hydraulic structure safety evaluation.

The concept is put on the drawing board and a conceptual drawing is prepared so that the project authority can go for a *reconnaissance survey* of the site which includes access to the site, along with the basic concept of the site topography, hydrology such as flow and discharge of river, available head, geologic features of the site, social and environmental aspects.

A hydropower project is generally constructed in a remote area where access to the site is always a problem. If proper infrastructure along with in-plant road network is not in place from the ZERO date of the project, the project starts slipping the schedule from the zero date, so the reconnaissance survey group should emphasize this aspect to make the project more viable from the point of view of constructability.

The second phase of investigation is the *prefeasibility study* of the proposed site, where further exploration activities shall be taken up based on data collected in the reconnaissance survey. This feasibility study will educate about the first hand idea of engineering and geological as well as hydrological characteristics of the proposed site. These studies shall be interpreted in conjunction with all data being collected in the reconnaissance survey so as to establish the technical feasibility of the project.

Once the proposed project acquires the status of a technically feasible project after the prefeasibility study, the project authority gives the green signal to the project group to go ahead with the detailed *investigation and survey* of the site. It includes the following investigative activities.

- *Topographical survey*: The survey group should move to the site with topographical map made by Survey of India in the prescribed scale for the entire country which will provide the group a fairly good idea about the site topography. The group undertakes further requirement-specific surveys like a contour survey of the area, detailed route survey, layout survey of water conducting system, or power house.
- *Geological survey*: Surface and sub surface investigation including sub soil foundation investigation in the power house, water conducting systems and other important structures and ground water tables.

- *Geotechnical survey*: This survey is conducted to obtain data on physical characteristics of the soil and rock of water conducting system and power house and the stability of slope for protection for safe design of the structures.
- *Hydrological survey*: This is conducted to assess *in situ* flow determination, runoff generation, discharge and duration of flow and sediment analysis also to assess requisite head.
- *Load survey*: Load survey shall be conducted within a 4–10 km radius from the location of SHP. Data is to be collected by interacting with common villagers, teachers, doctors of health centers, and Gram Pradhan. Data should include number of villages and its houses, population and its projected connections and average consumption, number of schools, health centers, community centers, small scale industry and their demand.
- *Socio-economic survey*: The socio-economic survey shall be conducted in the influence area of the project with the latest census report which will provide details of population and sex ratios. The surveyor should cover various requirements of surveys such as community, demography, settlement pattern and housing structures, source of livelihood and income, source of water, health and sanitation, and physical infrastructure.
- *Environmental and ecological survey*: EES shall be conducted broadly on the land and land cover along with the number of displaced persons, hydro-meteorology, floristic and forest type, flora and fauna. This includes identification and prediction of impact, impact evolution and mitigation systems.
- *Survey for availability of construction material*: A survey shall be conducted for construction material like stones and sand by conducting various field and laboratory tests for the quality of materials confirming to project specification.
- Survey for nearest railways heads or highways to facilitate transportation of construction materials, equipment, and work force. The survey shall be conducted to locate nearby railheads/ports to carrying construction materials and equipment smoothly to the project area. A detailed survey shall also be made inside the road network to facilitate transportation of materials and equipment to the respective location.

2.4.1 Feasibility/Detailed Project Report

A feasibility/detailed project report is made based on data collected from the detailed investigation to assess technical feasibility and financial viability. This report is ultimately used as the main document to get approval from various authorities for implementation.