Pan African University
Institute of Water
and Energy Sciences

# PAN-AFRICAN UNIVERSITY
## INSTITUTE FOR WATER AND ENERGY SCIENCES
## (including CLIMATE CHANGE)

# Master Dissertation

Submitted in partial fulfillment of the requirements for the Master degree in

Water Engineering

Presented by

***Salah Eddine SALAH***

## A Study of Hydroelectric Power Supply in the West of Algeria

***Defended on 02/09/2019***

***before the Following Committee:***

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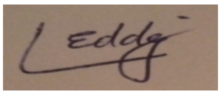
# Declaration

I, SALAH Salah Eddine, hereby declare that this thesis represents my personal work, realized to the best of my knowledge. I also declare that all information, material and results from other works presented here, have been fully cited and referenced in accordance with the academic rules and ethics

Signature :



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# Dedication

It is with the help of all powerful that I come to term of this modest work that I dedicate:

To those who have cared for me since my birth in order to make me a person full of love for science and knowledge; my dear parents who have been able to give me happiness, who knew how to guide my steps towards a safe future, who have never stopped encouraging me to undertake these studies and achieve this goal.

To my brothers and sisters and especially

To my friends and to all  my 2019 graduating class of water engineering

*SALAH Salah Eddine*

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Abstract

There is a growing awareness that climate change is causing major disruptions to the environment with rising sea levels, disruptions to wildlife and plants, and impacting agriculture, health and countries' economies. Huge amounts of fossil fuels (such as coal, oil and gas) are being burnt causing the release of record levels of carbon dioxide into the atmosphere.

Presently, Algeria has enough hydrocarbon reserves that cover its present energy needs. Alternative energy resources, namely renewable energies have to be developed in order to both provide for its future energy needs and as alternative sources of income as well.

One of the renewable energy resources that can be developed is hydroelectric energy from water supply networks. In this thesis, a study is presented of the performance of a micro-hydropower plant by using supply water system. A water supply network in the west of Algeria with high enough piezometric head is considered to be an important source of hydroelectric power generation. The Belgaid-Kristel water supply system is taken as the present case study. Both design and cost analyses have been carried out of a micro hydro power station mounted on this supply system.

If 100% efficiency is considered, the generated power reaches 136KW. However, if total head loss is deducted and considering an overall efficiency of 95%, the generated power reaches 135 KW. The Pelton turbine was selected according to the head an flow rate available The major design parameters are the number of buckets Nozzle diameter, and rotational speed.

An experimental study was performed in order to compare the performances of both impulse and reaction turbines have shown the following:

Both efficiency and power output for both types of turbines show an increase with increasing flow rate. They also increase with increasing turbine speed reaching a maximum value before decreasing.

It was noted that for a given pump speed, maximum efficiency and brake power for the impulse turbine always occur at the same turbine speed at all flow rates.

**Keywords:** micro-hydro-electric power plant, hydro-turbines, drinking water supply system, hydro project cost, renewable energy.

## Résumé

On s'aperçoit de plus en plus que le changement climatique est en train de causer des perturbations majeures de l'environnement avec l'élévation du niveau de la mer, des perturbations de la faune et de la flore, ainsi que des répercussions sur l'agriculture, la santé et les économies des pays. D'énormes quantités de combustibles fossiles (tels que le charbon, le pétrole, le gaz) sont en train d'être brûlées, entraînant la libération de niveaux record de dioxyde de carbone dans l'atmosphère.

À l'heure actuelle, l'Algérie dispose de suffisamment d'hydrocarbures pour couvrir son énergie actuelle. Il faut développer des sources d'énergie alternatives, notamment les énergies renouvelables, afin de subvenir à ses besoins énergétiques futurs et de générer des sources de revenus alternatives. L'une des sources d'énergie renouvelable pouvant être développée est l'énergie hydroélectrique issue des réseaux d'approvisionnement en eau.

Dans cette étude, vous visualisez les performances attendues d'une micro-centrale hydroélectrique à l'aide d'un système d'alimentation en eau. Nous considérons le vaste réseau d’approvisionnement en eau dans l’ouest de l’Algérie avec une hauteur de charge piézométrique suffisante pour permettre la production d’énergie hydroélectrique. Nous avons choisi l'adduction entre Belgaid et Kristel. Où une seule buse a été utilisée au volant. En considérant une efficacité de 100%, la puissance générée atteint 136 kW, mais en déduisant la perte de charge totale et en considérant une efficacité globale de 95%, la puissance générée atteint 135 KW. Nous choisissons la turbine Pelton en fonction de la hauteur de la tête et du débit disponible. Les principaux paramètres sont les suivants : le nombre de seaux, le diamètre de la buse et la vitesse de rotation.

Une étude expérimentale visant à comparer les performances des turbines à impulsion et à réaction a montré ce qui suit :

Le rendement et la puissance des deux types de turbines croient en fonction du débit. Ils augmentent également lorsque la vitesse de la turbine augmente, atteignant une valeur maximale avant de diminuer. On peut noter que, pour une vitesse de pompe donnée, le rendement maximal et la puissance de freinage de la turbine à impulsion sont toujours obtenus à la même vitesse de la turbine, quel que soit le débit.



**Mots-Clés**: microcentrale hydroélectrique, turbines hydroélectriques, système d'alimentation en eau potable, coût du projet hydroélectrique, énergie renouvelable.

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## Abbreviations

| | |
|---|---|
| TWh | Terawatt-hour. |
| GW | Gegawatt. |
| SHP | Small Hydro Power. |
| EU | Europe Union. |
| LCOE | Levelized cost of Electricity. |
| IFC | International Finance Corporation. |
| NG | Natural Gas. |
| LNG | Liquefied Natural Gas. |
| GDP | Gross Domestic Product. |
| RE | Renewable Energy. |
| EE | Energy Efficiency. |
| OS | Operator System. |
| NDC | National Determined Contributions. |
| GHG | Green House Gas. |
| MEM | Ministry of Energy and Mining. |
| Hg | Gross head. |
| Hn | Head Net. |

## Nomenclature

| | |
|---|---|
| Q | Water flow rate (l/min) |
| P | Turbine inlet pressure (kPa) |
| n | Turbine rotational speed (rpm) |
| F | Brake force (N) |
| T | Brake Torque (Nm) |
| $P_b$ | Brake Power (W) |
| Ph | Hydraulic power (W) |
| E | Efficiency (%) |
| h | Turbine head (m water) |

# Chapter I
# General introduction

# INTRODUCTION

Energy is one of the most fundamental elements of our universe. It is inevitable for survival and indispensable for development 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 [1].

Electric power is an important element of infrastructure required for the development of a country. The use of electric power has therefore seen a remarkable rise since the Second World War, especially after the oil crisis of 1973.

The problem of resources supply and climate change is recognized worldwide, especially since the ratification of the Kyoto protocol [2]. Through this protocol, each participating state is committed to reducing emissions of pollutants, most responsible for climate change. This has led to and involved the use of incentive policies towards renewable energy sources. Renewable energy sources can produce energy without sacrificing natural resources. Hydropower currently has some advantages over other renewable sources such as wind, solar and biomass, due to some of its key benefits [3]. This generally includes a lower cost of installation to equal installed capacity, higher reliability, energy production, and more intensity and consistency over time. Currently, hydropower technologies in the field have reached full maturity and, after almost two centuries of exploitation, the industrial use of water resources has almost reached its technical limit.

In Algeria hydroelectric power plants have already been built and the water resources exploited and some are still in operation, thus confirming the renewability of the resource. Recent years have witnessed the reopening of old small plants, which previously were not economically feasible. The hydropower plants can be an excellent source of economic gain also for small and medium size plants.

The water that is turned in a small power station and from which we draw the electrical energy can have several origins:

- Stream: The water of a river or stream can be diverted from its bed and brought to a turbine. In this case, the turbine flow will vary more or less strongly depending on the seasons, precipitation and temperature.

- Irrigation water: To irrigate crops, pipes are sometimes installed bringing water from high elevations. Here again, the pipes must be laid and financed in any case and they can be adapted to the turbines.
- Endowment water: When a dam is built across a river, the law requires not to dry the watercourse but to pass what is called a flow of staffing or residual flow. When the dam water level is high, the water that is released at its base has energy that can be used to drive a turbine. And again, a large part of the installation serves other purposes than the mini-plant, which reduces costs.
- The water of an industrial process: In industrial plants, especially those of chemical engineering, it is not uncommon to require water, or any other liquid, under pressure for one operation or another. At the end of such a process, the pressure may still be high but no longer useful; instead of dissipating this energy in a pressure reducer, it may be benefitted from in a turbine.
- Potable water. This is one of the most advantageous cases for a small plant because a large part of the equipment, especially the catchment, pipe, and tank are used primarily to supply the drinking water supply and must be built anyway, even if the water is not turned. Thus, the hydroelectric plant must cover only the additional costs that it generates. However, the safety of the drinking water supply must be guaranteed, even in the event that the electricity network is de-energized or if the turbine is down or overhauled.

In all the installations mentioned above, it is important to dimension well its elements taking into account the turbines. The pipes, in particular, must be able to withstand the pressure and must not cause high energy losses.

In 2016, the installed electricity generation capacity of hydropower was 1096GW [4]. Actual electricity generation, however, was estimated at only 4.1PWh, much lower than the potential global annual generation of 52.0PWh [3].

A water supply system (WSS) is a set of civil infrastructures (tanks, pipes and others), hydro-mechanical facilities, electrical equipment and services that extracts, conveys and distributes water to consumers. This distribution must be compatible with the demand in both quantity and quality [2].

The economic sector of energy occupies a predominant place in the economy of Algeria: Hydrocarbons alone represent 60% of budget revenues and 98% of operating revenue.

In 2015 Algeria is the 18th largest oil producer, the 10th largest natural gas producer and the 6th largest natural gas exporter in the world.

Energy production and consumption, including in the electricity sector, are derived from hydrocarbons at over 99%.

However, the Algerian state begins to consider ecological solutions by investing in new and renewable energies. According to the 2012 Algeria's Program for the Development of Renewable Energy and Energy Efficiency, Algeria is aiming for a renewable installed capacity of 22,000 MW by 2030.

It is clear that politically, Algeria has invested ideologically and financially in all areas that safeguard the environment and the ecosystem on a scale that are termed global. The notion of sustainable development should be reported at the national level and ensure that the Algerian population can benefit from the reforms of energy policy by guaranteeing a continuous service and a quality of life without limiting its economic development and technology.

In 2002, the government began to put in place a legislative and regulatory framework to liberalize the energy sector in Algeria, although the aim was the introduction of competition in the energy production and sales sectors.

The advantages that a micro-hydro-electric power plant has over the fossil and nuclear power plant are [5]:

- It has the ability to generate power near when it is needed, reducing the power inevitably lost during transmission.
- It can deal more economically with varying peak load demand, while the fossil-fuel or nuclear power plants can provide the base load only, due to their operational requirements and their long start-up times.
- It is able to both start up quickly and make rapid adjustments in output power.
- It does not cause air or water pollution.
- It has low failure rate, low operating cost and is reliable.

This present study investigates and analyzes the possibilities of using a small micro hydropower plant in a rural area close to the consumer. It aims to estimate the quantity of energy that can be produced by using this type of installation for a specific area, providing more energy stability, reliability and increase in power output delivered.

A very important water supply pipeline named MAO (Mostaganem-Arzew-Oran) situated in the west of Algeria was selected as a major source of hydro power, because of its high enough piezometric head. Estimates are made of quantities of electricity that may be produced from a micro-hydropower plants (MHP) using a water supply system (WSS).

A case study was carried out aiming at designing and optimizing an MHP capable to generate the maximum electricity requirement. Cost estimates of the installation of such an MHP are obtained.

This study is mainly divided into three parts:

- Part one presents a theoretical approach into the system design and the percentage of hydropower plants use in the world by citing both their advantages and efficiencies.
- Part two deals with the design, technical implementation and cost of an MHP using data provided by the Oran water board (SEOR).
- Part three deals with a laboratory experimental study carried out on two types of water turbines, namely the impulse turbine and the reaction one. Results of power, efficiency and torque are obtained and discussed for both types of turbines for variable turbine speed and water flow rate.

# Chapter II

# Literature Review

## 2.1. Introduction

Society's energy consumption worldwide has increased by up to 600% over the last century[1]. This increase has been a direct result of population growth since the industrial revolution, in which energy has been provide mainly by fossil fuels. Nevertheless, today and in the near future, renewable energies are expected to be more widely implemented to help maintain sustainable growth and quality of life and, by 2040, to reduce energy consuption down to the 2010 levels [1].

Sustainability must be achieved by using strategies that do not increase the overall carbon foot print, considering all levels of production (macro – and micro-scale) of the different supplies. These development strategies have to be unequivocally linked to new technologies [2]. Special attention must be paid to those new strategies that are related to energy recovery. These new techniques have raised interesting environmental and economic advantages. Therefore, a deep knowledge of the water energy nexus is crucial for quantifying the potential for energy recovery in any water system [3], and defining performance indicators to evaluate the potential level of energy savings is a key issue for sustainability, environmental, or even management solutions [4].

Energy recovery, with the aim of harnessing the power dissipated by valves (in pressurized flow) or hydraulic jumps (in open channels), is becoming of paramount importance in water distribution networks. Recovery will allow the energy footprint of water. The energy unit cost needed to satisfy each stage of the water cycle: Catchment, pumping, treatment, and distribution to be reduced, even considering that energy generation, is not a priority for these systems [5, 6].

Although this recovery contributes to the development of more sustainable systems, this production could also contribute to the exploitation cost reductions in these systems, increasing the feasibility of drinking and irrigation water exploitation.

Among all of the different types of renewable energy (e.g., photovoltaic, solar thermal, tidal, and wind) the hydropower plant stands out for its feasibility. Historically, large installations can be found in dams around the world to take advantage of the potential energy created by different water levels. The most important hydropower plants are located in countries such as China, the United State, Brazil and Canada. Currently, China has the greatest installed capacity (exceeding 240 GW), with production greater than 800 TWh in 2012 and an average growth of capacity of 20 GW/year [7].

In Brazil and Canada, hydropower plants represent 84% and 56% of the total energy consumption, respectively. The production of this type of energy in these countries reaches 16% of the total consumed energy [8, 9].

## 2.2. Definition of Hydropower Energy

The generation of energy from water can be explained by the law of conservation of energy. The potential energy of flowing water is converted to kinetic energy in the penstock. The kinetic energy of the flowing water turns the blades of the turbine, where it is converted to mechanical energy. Finally, the turbine shaft rotates the generator and the final product which is electrical energy is generated [9].

The power generated by using the potential energy of flowing water is given by the following formula:

$$\mathbf{P = g\, Q\, H\, \eta \rho} \qquad (2.1)$$

Where;

**P:** Power in Watts,

**η:** General efficiency of the plant,

**ρ:** Density of water in $kg/m^3$,

**g:** Gravitational acceleration in $m/s^2$,

**Q:** Discharge passing through the turbine in $m^3/s$,

**H:** Gross head of the water in m (elevation difference between the forebay and tailwater).

## 2.3. Potential Resource

Hydropower potential can be derived from total available flow multiplied by head and a conversion factor. Since most precipitation usually falls in mountainous areas, where elevation differences (head) are the largest, the largest potential for hydropower development is in mountainous regions, or in rivers coming from such regions. The total annual runoff has been estimated as 47,000 km3, out of which 28,000 km3 is surface runoff, yielding a theoretical potential for hydropower generation of 41,784 TWh/yr (147 EJ/yr) [10] This value of theoretical potential is similar to a more recent estimate of 39,894 TWh/yr (144 EJ/yr) [11].

## 2.4. Global Technical Potential

The International Journal on Hydropower & Dams 2010 World Atlas & Industry Guide (IJHD) provides the most comprehensive inventory of current hydropower installed capacity and annual generation, and hydropower resource potential. The Atlas provides three measures of hydropower resource potential, all in terms of annual generation (TW/yr): gross theoretical, technically feasible, and economically feasible. The total worldwide technical potential for hydropower is estimated at 14,576 TWh/ yr (52.47 EJ/yr) [11], over four times the current worldwide annual generation.

This technical potential corresponds to a derived estimate of installed capacity of 3,721 GW. Technical potentials in terms of annual generation and estimated capacity for the six world regions. Pie charts included in the figure provide a comparison of current annual generation to technical potential for each region and the percentage of undeveloped potential compared to total technical potential. These charts illustrate that the percentages of undeveloped potential range from 47% in Europe and North America **to 92% in Africa,** indicating large opportunities for hydropower development worldwide.1 have been developing their hydropower resources for more than a century, still have sufficient technical potential to double their hydropower generation, belying the perception that the hydropower resources in these highly developed parts of the world are

**Table II.1** | Regional hydropower technical potential in terms of annual generation and installed capacity (GW); and current generation, installed capacity, average capacity factors in percent and resulting undeveloped potential as of 2009. Source: [12].

| World region | Technical potential, annual generation TWh/yr (EJ/yr) | Technical potential, installed capacity (GW) | 2009 Total generation (TWh/yr) | 2009 installed capacity (GW) | Un-developed potential (%) | Average regional capacity factor (%) |
|---|---|---|---|---|---|---|
| North America | 1,659 (5.971) | 388 | 628(2.261) | 153 | 61 | 47 |
| Latin America | 2,856(10.283) | 608 | 732(2.635) | 156 | 74 | 54 |
| Europe | 1,021(3.675) | 338 | 542(1.951) | 179 | 47 | 35 |
| Africa | 1,174(4.226 | 283 | 98(0.351) | 23 | 92 | 47 |
| Asia | 7,681(27.651) | 2,037 | 1,514(5.451) | 402 | 80 | 43 |
| Australia/Ocenia | 185 (0.666) | 67 | 37(0.134) | 13 | 80 | 32 |
| World | 14,576(52.470) | 3,721 | 3,551(12.783) | 926 | 75 | 44 |

Understanding and appreciation of hydropower technical potential can also be obtained by considering the current (2009) total regional hydropower installed capacity and annual generation shown in Figure 5.3. The reported worldwide total installed hydropower capacity is 926 GW producing a total annual generation of 3,551 TWh/yr (12.8 EJ/yr) in 2009. Figure 5.3 also includes regional average capacity factors calculated using current regional total installed capacity and annual generation (capacity factor = generation/(installed capacity x 8,760 hrs)).

It is interesting to note that North America, Latin America, Europe and Asia have the same order of magnitude of total installed capacity while Africa and Australasia/Oceania have an order of magnitude less—Africa due in part to the lack of available investment capital

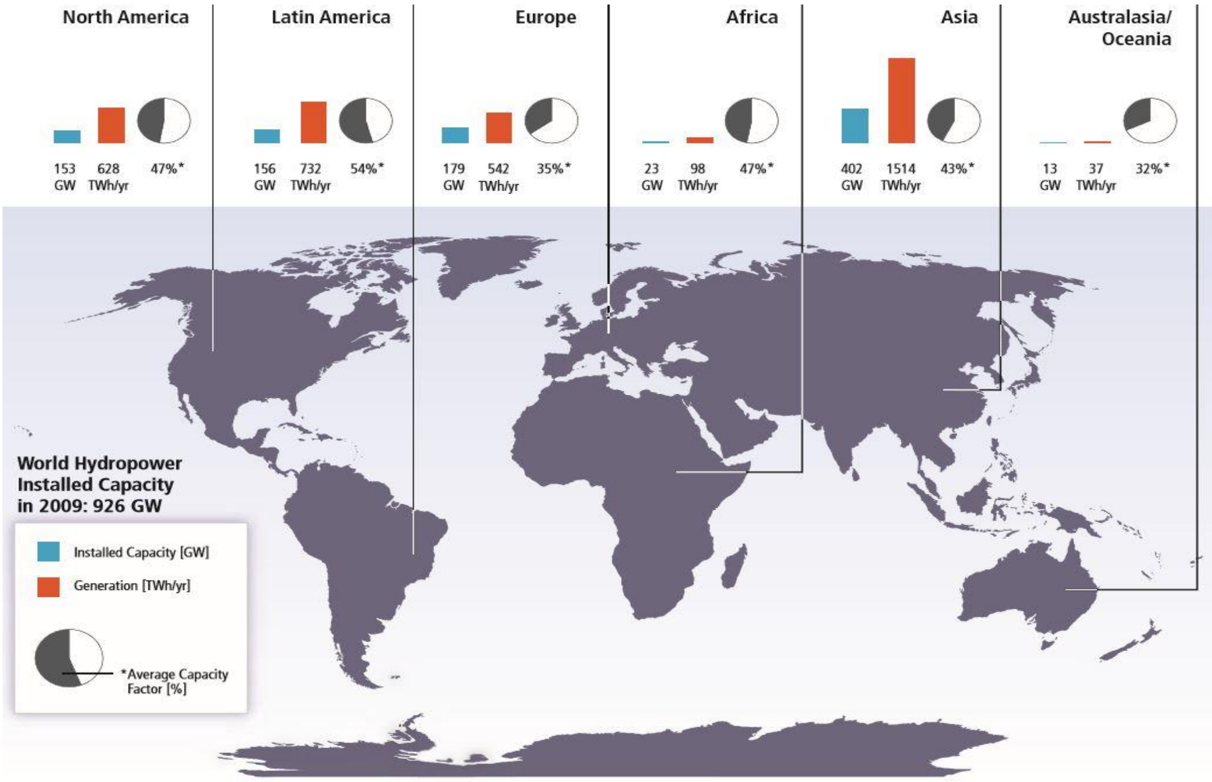



**Figure II.1** | Total regional installed hydropower capacity and annual generation in 2009, and average regional capacity factors (derived as stated above). Source: [12].

## 2.5. Efficiency

The potential for energy production in a hydropower plant is determined by the following parameters, which are dependent on the hydrology, topography and design of the power plant:

- The amount of water available;
- Water loss due to flood spill, bypass requirements or leakage;
- The difference in head between upstream intake and downstream outlet;
- Hydraulic losses in water transport due to friction and velocity change; and
- The efficiency in energy conversion of electromechanical equipment.

The total amount of water available at the intake will usually not be possible to utilize in the turbines because some of the water will be lost or will not be withdrawn. This loss occurs because of water spill during high flow when inflow exceeds the turbine capacity, because of bypass releases for environmental flows, and because of leakage.

In the hydropower plant the potential (gravitational) energy in water is transformed into kinetic energy and then mechanical energy in the turbine and further to electrical energy in the generator. The energy transformation process in modern hydropower plants is highly efficient, usually with well over 90% mechanical efficiency in turbines and over 99% in the generator. The inefficiency is due to hydraulic loss in the water circuit (intake, turbine and tailrace), mechanical loss in the turbo generator group and electrical loss in the generator. Old turbines can have lower efficiency, and efficiency can also be reduced due to wear and abrasion caused by sediments in the water. The rest of the potential energy is lost as heat in the water and in the generator.

In addition, some energy losses occur in the headrace section where water flows from the intake to the turbines and in the tailrace section taking water from the turbine back to the river downstream. These losses, called head loss, reduce the head and hence the energy potential for the power plant. These losses can be classified either as friction losses or singular losses. Friction losses depend mainly on water velocity and the roughness in tunnels, pipelines and penstocks.

The total efficiency of a hydropower plant is determined by the sum of these three loss components. Hydraulic losses can be reduced by increasing the turbine capacity or by increasing the reservoir capacity to get better regulation of the flow. Head losses can be reduced by increasing the area of headrace and tailrace, by decreasing the roughness in these and by avoiding too many changes in flow velocity and direction. The efficiency of electromechanical equipment, especially turbines, can be improved by better design and also by selecting a turbine type with an efficiency profile that is best adapted to the duration curve of the inflow. Different turbine types have quite different efficiency profiles when the turbine discharge deviates from the optimal value [12].

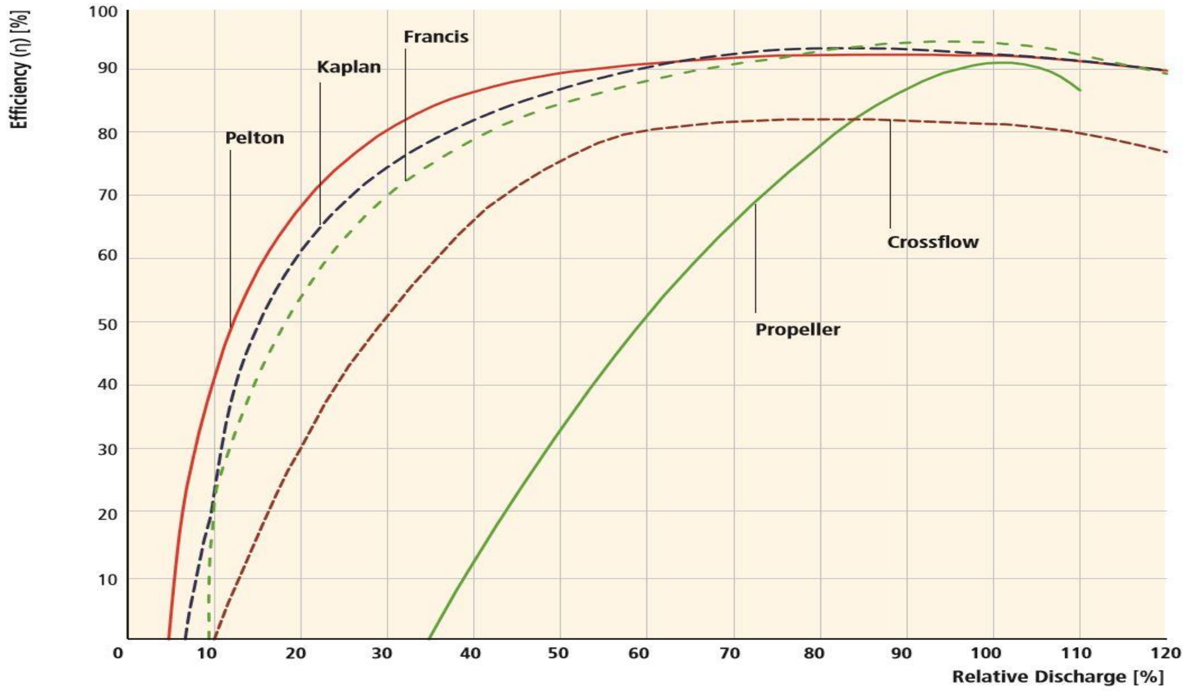



**Figure II.2:** Typical efficiency curves for different types of hydropower turbines (Vinogg and Elstad, 2003).

## 2.6. Classification by head and size

A classification by head refers to the difference between the upstream and the downstream water levels. Head determines the water pressure on the turbines that together with discharge are the most important parameters for deciding the type of hydraulic turbine to be used. Generally, for high heads, Pelton turbines are used, whereas Francis turbines are used to exploit medium heads. For low heads, Kaplan and Bulb turbines are applied. The classification of what 'high head' and 'low head are varies widely from country to country, and no generally accepted scales are found.

Classification according to size has led to concepts such as 'small hydro' and 'large hydro', based on installed capacity measured in MW as the defining criterion. Small-scale hydropower plants (SHP) are more likely to be run-of-river facilities than are larger hydropower plants, but reservoir (storage) hydropower stations of all sizes will utilize the same basic components and technologies. Compared to large-scale hydropower, however, it typically takes less time and effort to construct and integrate small hydropower schemes into local environments [13]. For this reason, the deployment of SHPs is increasing in many parts of the world, especially in remote areas where other energy sources are not viable or are not economically attractive.

**Table II.2:** Small-scale hydropower by installed capacity (MW) as defined by various countries. [13]

| Country | Small-scale hydro as defined by installed capacity (MW) | Reference Declaration |
|---|---|---|
| **Brazil** | ≤30 | Brazil Government Law No. 9648, of May 27, 1998 |
| **Canada** | <50 | Natural Resources Canada, 2009: canmetenergy-canmetenergie.nrcan-rncan.gc.ca/eng/renewables/small_hydropower.html |
| **China** | ≤50 | Jinghe (2005); Wang (2010) |
| **EU Linking Directive** | ≤20 | EU Linking directive, Directive 2004/101/EC, article 11a, (6) |
| **India** | ≤25 | Ministry of New and Renewable Energy, 2010: www.mnre.gov.in/ |
| **Norway** | ≤10 | Norwegian Ministry of Petroleum and Energy. Facts 2008. Energy and Water Resources in Norway; p.27 |
| **Sweden** | ≤1.5 | European Small Hydro Association, 2010: www.esha.be/index.php?id=13 |
| **USA** | 5-100 | US National Hydropower Association. 2010 Report of State Renewable Portfolio Standard Programs (US RPS) |

## 2.7. Advantages and disadvantages of hydropower

Compared with other technologies, the most important advantages of hydropower are the following:

• Hydropower generation is based on a reliable proven technology that has been around for more than a century and hydropower plants can be easily rehabilitated or upgraded utilizing recent advances in hydro technologies.

• Hydropower generation is renewable because it does not reduce the water resources it uses and does not require fuel.

• In most cases, hydropower is an economically competitive renewable source of energy. The levelled cost of electricity (LCOE) is usually in the range of US$0.05 to US$0.10 per kWh [14]

. Rehabilitating or upgrading existing hydropower schemes provides opportunities for cost-effective capacity increases.

• Hydropower exploits domestic water resources, thereby achieving price stability by avoiding market fluctuations.

• Storage hydropower schemes (dams, pumped storage) offer operational flexibility because they can be easily ramped up or shut down, creating potential for immediate response to fluctuations in electricity demand. Thus storage hydro are valuable to meet peak demand or to compensate for other plants in the grid (especially solar and wind), which can experience sudden fluctuations in power output.

• The creation of reservoirs also allows water to be stored for drinking or irrigation, reducing human vulnerability to droughts. Reservoirs can provide flood protection, and can improve waterway transport capacity. Further, HPPs with reservoirs can generate energy during dry periods and regulate fluctuations in the energy supply network by using the stored water.

• When compared with other sources of electricity, small hydropower is very much environmental friendly [15]. One GWh of electricity produced by small hydropower means a reduction of 480 tonnes of emitted carbon dioxide". What this implies is that,.

➢ Environmental impacts triggered by implementing hydropower schemes are well known and manageable. Disadvantages of hydropower include the following:

• High up-front investment costs compared to other technologies, such as thermal power (but low operational costs since no fuel is required).

• Reservoirs may have a negative impact on the inundated area, damage river flora and fauna, or disrupt river uses such as navigation. However, most negative impacts can be mitigated through project design. The IFC and other multilateral financial institutions have strict mandatory requirements for assessment and mitigation of social and environmental impacts.

For more information, refer to the IFC Performance Standards on Environmental and Social Sustainability or the IFC Environmental, Health and Safety Guidelines for construction works and transmission lines.1

## 2.8. Investment cost of hydropower projects and affecting factors

Basic ally, there are two major cost groups for hydropower projects: *the civil construction costs*, which normally are the major costs of the hydropower project, and *the cost related to electromechanical equipment* for energy transformation. Additionally, investment costs include the costs of planning, environmental impact analysis, licensing, fish and wildlife mitigation, recreation mitigation, historical and archaeological mitigation and water quality monitoring and mitigation.

## 2.9. Civil construction costs

The civil construction costs follow the price trend of the country where the project is going to be developed. In the case of countries with economies in transition, the civil construction costs are usually lower than in developed countries due to the use of local labour and local construction materials.

Civil construction costs are always site specific, mainly due to the inherent characteristics of the topography, geological conditions and the construction design of the project. This could lead to different investment cost and LCOE even for projects of the same capacity.

## 2.10. Cost related to electromechanical equipment

The costs of electromechanical equipment—in contrast to civil construction cost—follow world market prices for these components. [16] Presents the typical cost of electromechanical equipment from various hydropower projects in **Figure I.3.**

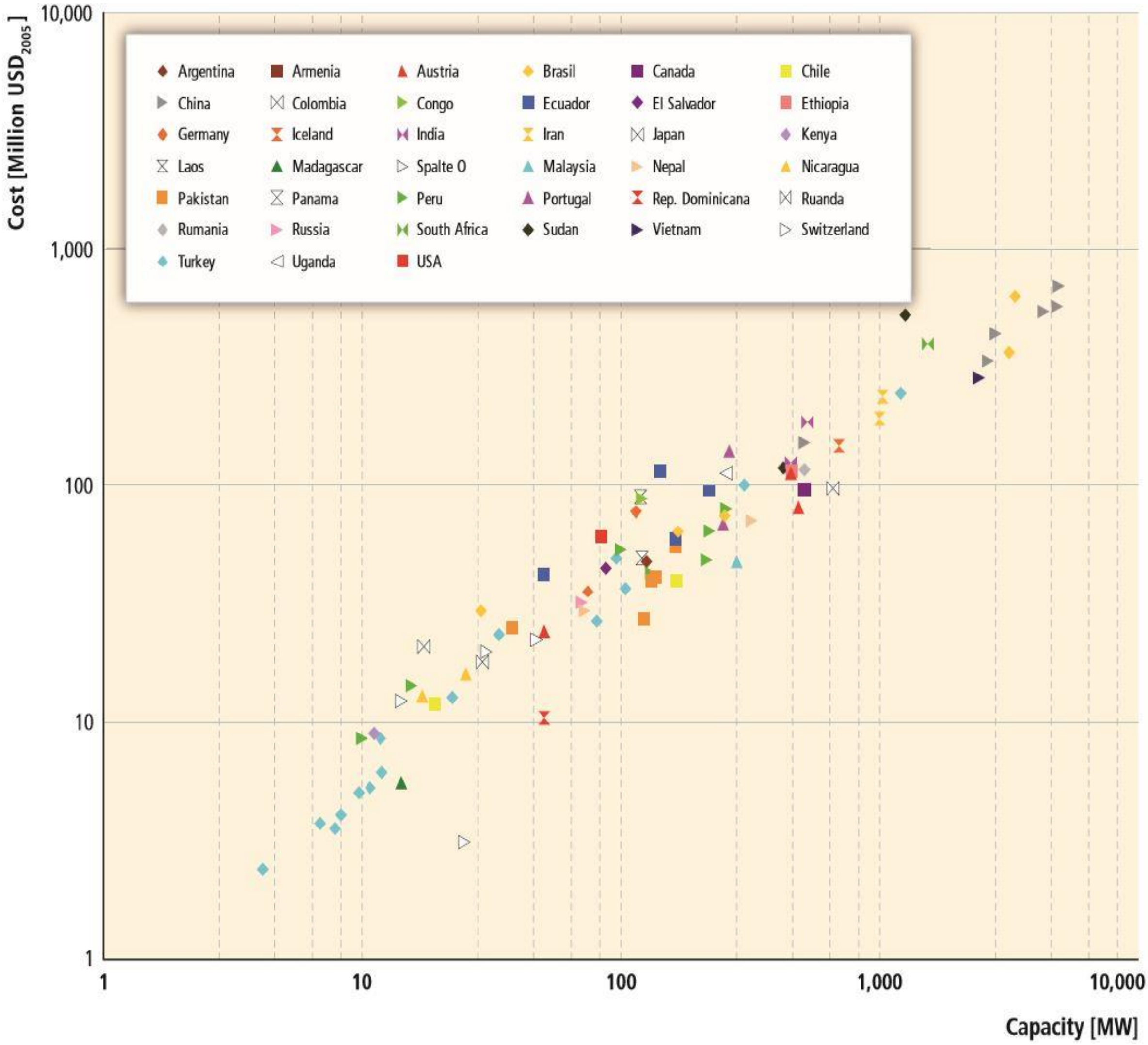



**Figure II.3:** Costs of electrical and mechanical equipment as a function of installed capacity in 81 hydropower plants in America, Asia, Europe and Africa in USD2008. Source: [16].

## 2.11. Electricity Sector in Algeria

Its large oil and gas reserves as well as its mere size of 2,381,741 km$^2$ and 42.2 million inhabitants (17.7 inhabitant/ km$^2$) make Algeria an important player in northern Africa as well as on international level. Algeria is one of the top 10 economies in Africa and plays a central role in the energy world, as it is a major producer and exporter of oil, natural gas (NG) and liquefied natural gas (LNG). Oil and gas export revenues account for more than 95% of Algeria's total export revenues, around 70% of total fiscal revenues, and 40% of gross domestic product (GDP). Algeria exports NG through gas pipelines (to Italy via Tunisia and to Spain via Morocco and the Mediterranean Sea) and relies on it for domestic consumption. Algeria is the world's fourth-largest supplier of LNG, delivering 10% of the gas consumed by Europe. Algeria's energy mix is almost exclusively based on fossil fuels, especially natural gas (93%)

in which the electricity system is presently based on fossil resources using natural gas to generate electricity, mainly due to its availability and low cost. In addition as hydrocarbons producer, Algeria is also enjoying enormous potential of renewable energy (RE) namely solar, wind, geothermal and biomass which the government is trying to harness by launching an ambitious RE and Energy Efficiency (EE) Program (February 2011). Moreover, the revolution in RE in terms of technological development and costs may help reduce the consumption of fossil fuels and ensure reserves for future generations by fostering decentralised renewable energy projects. Algeria has thus set itself by 2030 a share of RE in the national energy balance of 27%. The share of RE power by 2023 will represent about 17% of installed capacity (5539 MW) compared to 4.74% in 2011 (540 MW) [17].

In Algeria, the forecast for electricity demand is established by operator system (OS) Sonelgaz Subsidiary (state electricity and gas utility company). Based on the country's energy policy, the OS matches supply to demand in two steps:

1. Study electricity demand;
2. Define an equipment program in order to satisfy that demand at the lowest possible cost.

Information on electricity and energy sector [18, 19] is estimated and shown in figure 1 below.

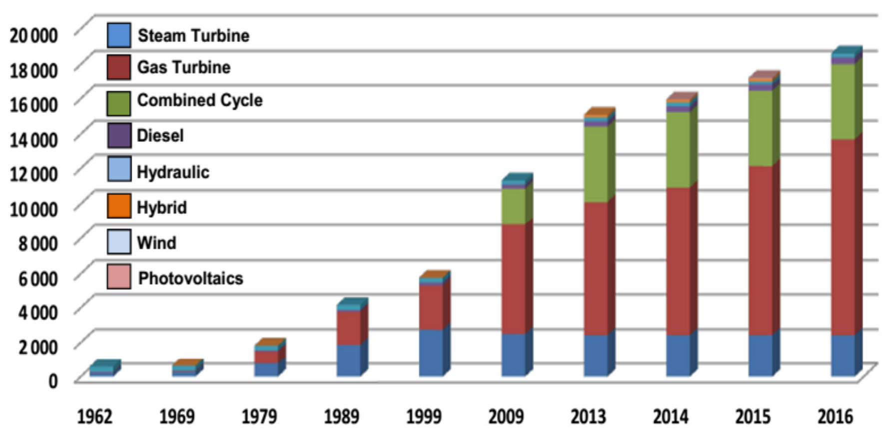



**Figure II.4:** Evolution of installed power by technology over the period (1962 -2016) – MW.

The electricity market in Algeria is very important and electricity consumption has grown by almost 10%/year since 2009, bringing it to 59,000 GWh in 2016. The electrification rate is currently 99% - urban areas: 100% - rural areas: 97% (2016 est.)[20,21].

Total installed power generation capacity amounts to 17.12 GW, approximately 50% of which are open cycle gas turbines, 12% combined cycle gas turbines, 35% conventional steam turbines and 3% hydraulic. Over 98% of the electricity production is based on natural gas, the balance originating from fuel oil/diesel and hydropower. Electricity prices are low in Algeria, especially for residential customers, mainly due to low internal prices for natural gas: around 6 USc/kWh for residential customers and a little over 3 USc/kWh for industrial users.

The growth in consumption at the various dates is summarized in **table II.3**.

**Table II.3:** Projected electricity demand, in TWh, by Sonelgaz [22].

| **Date** | **2018** | **2020** | **2030** |
|---|---|---|---|
| Exhaustion scenario | 74.32 | 93.18 | 110.67 |
| Emergence scenario | 76.79 | 101.42 | 124.58 |
| Efficiency scenario | 80.40 | 112.40 | 146.90 |

The Algerian Government is adopting an ambitious RE programme. It envisions the installation of 22 GW of RE by 2030, which is almost double than what was set as a target before (12 GW) and equals a share of about 27% RE in total electricity production. Of these 22 GW, about 4.5 GW are supposed to be installed by 2020. The targets per technology are set according to two phases as it's outlined in **tableI.4** [23, 24]. As for the Geographical distribution, the following has been adopted:

- Southern Region: Hybridisation of existing power stations, Supply of scattered sites;
- High Plateau region: for their potential for sunshine and wind;
- Coastal Region: depending on the availability of land with roof and terrace exploitation.

**Table II.4:** RE development program 2015-2030.

| **Date** | **2015-2020** | **2021-2030** |
|---|---|---|
| Photovoltaic | 3000 MW | 10375 MW |
| Wind | 1010 MW | 4000 MW |
| CSP | | 2000 MW |
| Cogeneration | 150 MW | 250 MW |
| Biomass | 360 MW | 640 MW |
| Geothermal | 5 MW | 10 MW |
| TOTAL | 4525 MW | 17475 MW |

Competition from RE power generation is expected to limit gas consumption as of 2020. One of the major objectives of the National RE programme is to save 300 billion m$^3$ of natural gas which is equivalent to 8 times the national electricity consumption of 2014 [25]. In its National

Determined Contributions (NDC), the country announced its aim, through the RE programme, to reduce GHG emissions by 7% by 2030 [26].

The former Algerian Minister of Energy Noureddine Boutarfa has revealed that the reference price for the upcoming tender for 4 GW of solar capacity will not exceed 4 DZD/kWh (approximately $0.04/kWh).

## 2.12. Small Hydropower Sector (SHP)

### 2.12.1. SHP overview

The definition of small hydropower (SHP) in Algeria is defined as any plant with a capacity of 5 MW to 10 MW. Algeria also defines micro hydropower as any plant with a capacity of 100 kW to 5 MW and Pico hydropower as any plant less than 100 kW [27]. The installed capacity of SHP is 42.12 MW, while its potential capacity is not available [28]. According to the Ministry of Energy and Mining, 103 dam sites have been recorded and more than 50 dams are in operation1 [24]. Algeria has approximately 269 MW of installed hydropower capacity (622 GWh/year) with plants of capacities between 1 MW and 100 MW. However, this energy source only plays a marginal role due to limited precipitation and high evaporation. Following the SHP definition of 10 MW upper limit capacity, there are at least 42.12 MW of SHP installed. Approximately 13 per cent of the total hydropower consists of SHP.

In the period between 1971 and 2010, the average contribution percentage of hydropower to the total electricity production was 4 %. The highest value was registered in 1973 (26.8 %) and the lowest value in 2002 (2 %) [30]. Hydropower is expected to account for 1.2-1.3 % of electricity generation by 2025 [31].

**Table II.5:** Installed hydropower capacity in Algeria (MW).

| Dam Name | Hydropower capacity (MW) | Dam Name | Hydropower capacity (MW) | Dam Name | Hydropower capacity (MW) |
|---|---|---|---|---|---|
| Mansouria | 100.0 | Souk El Djemaa | 8.1 | Tessala | 4.2 |
| Darguina | 71.5 | Ghrib | 7.0 | Beni Behdel | 3.5 |
| Ighil Emda | 24.0 | Gouriet | 6.4 | Ighzern Chebel | 2.7 |
| Erraguene | 16.0 | Bouhanifia | 5.7 | | |
| Oued Fodda | 15.6 | Tizi Meden | 4.5 | | |

In 2014, the Government declared its intention to halt operation of electricity production from hydroelectric dams and devote existing dam resources to irrigation and drinking water supply. The Ministry of Energy and Mining (MEM) stated that the needs of the population for water supply outweighed the electricity generated by the dams [32]. This sentiment was also echoed in the New National Programme for Renewable Energy Development (2015-2030), which excludes hydropower from its roadmap for RE development [33].

## 2.13. Renewable energy policy

Algeria's renewable electricity goals are set out as percentage values of overall power generation. Algeria has a nationwide environment strategy, a national plan for environmental action and sustainable development (Plan national d'action environnementale ET de développement durable, adopted in 2002) [34], focusing on reducing pollution and noise, preserving biodiversity and natural spaces, training and raising of public awareness on environmental issues. To face the territorial disparities in Algeria and to create conditions for sustainable and harmonious growth countrywide, a national development plan (Schéma national d'aménagement du territoire, SNAT, adopted in May 2010) sets out the long-term vision between now and 2025, aimed at gradually reducing regional inequalities and enhancing the attractiveness of areas lagging behind in development [35]. The integration of renewable energies into the national energy mix constitutes a major challenge in the preservation of fossil resources, the diversification of electricity production ways and the contribution to sustainable development. The National Program for the Development of Renewable Energy 2011-2030 adopted by the government in February 2011. This program saw a first phase dedicated to the achievement of pilot and test projects of the different available technologies, during which relevant elements concerning technological evolutions in the concerned sectors appeared in the energy arena and led to the review of this program. The renewable energy program aims to use extended renewable sources, mainly solar power and photovoltaic systems and, to a lesser extent, wind power. It provides to install 22 GW (between 2011 and 2030, 12,000 MW for domestic consumption and 10,000 MW for export) which represents 40% of whole energy consumption from renewable source by 2030. The review of this program is on the large-scale development of photovoltaic and wind fields, on the introduction of biomass field (waste valuation), of the cogeneration and geothermal. The renewable consistency of the program to realise for national market needs over the period 2015-2030 is 22 GW, among whom more than 4500 MW will be realised before 2020 [35]. Achieving this program will allow to reach by 2030 a part of renewable of about 27% in the national report of electric production [35].

❖ Traditionally, this energy is broken by hydraulic systems, either by breeze loads or by choke valves. But current technology allows us to use turbines to transform it into usable electrical energy for self-consumption, or to sell it to the electric company.

Developing a small hydropower site is not a simple task. There are many aspects which have to be taken into consideration, covering many disciplines ranging from business, engineering, financial, legal and administration. These will all be necessary at the different development stages from, first choosing a site until the plant goes into operation.

Electricity production from hydropower has been, and still is today, the first renewable source used to generate electricity. What doesn't mean small hydropower? And what is the Technical concept of this station?

## 2.14. Operation of a hydroelectric plant

A hydroelectric plant has many equipment but only one product of electricity and it is the alternator. To ensure its production, the alternator must be rotated by a turbine which turns itself thanks to the force of the water. The electricity generated by the alternator will be raised at high voltages by a transformer and sent to the transmission lines.

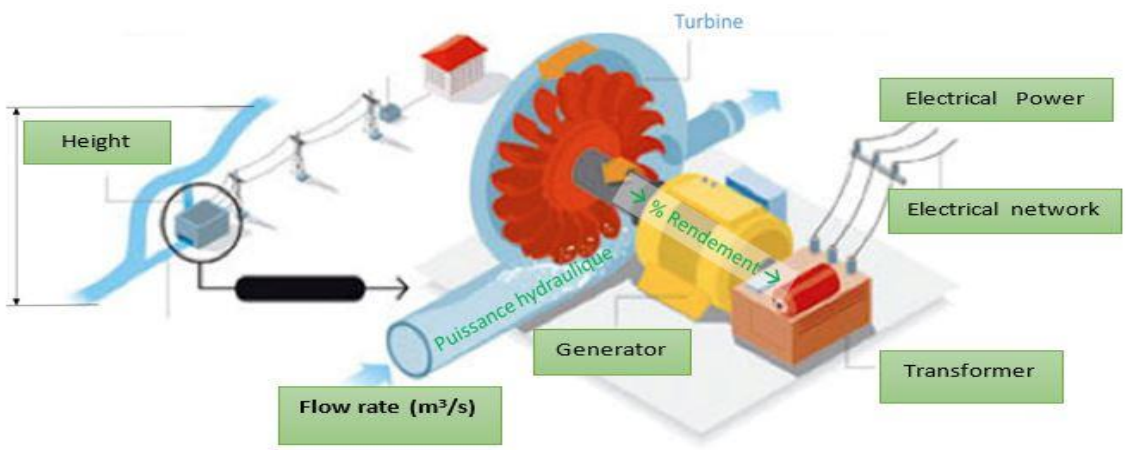



**Figure II.5:** Operating principle of a hydroelectric plant.

## 2.15. Definition of turbine

The turbine is an assembly consisting of a nozzle or stator, runner, and shaft that collectively convert momentum and pressure in a water flow into rotational mechanical work. [36] The nozzle or stator directs the flow to the runner it may be an orifice that creates a high speed jet, or it may be a set of vanes. The runner is a mechanism that converts the hydraulic energy into mechanical power by redirecting fluid flow. The runner is typically equipped with cups or blades that interact with the moving water and cause the runner to rotate; the mechanical work is transferred by the shaft to a generator.

### 2.15.1. The alternator

It consists of two main parts: the rotor and the stator. As the name suggests, the rotor is the moving part while the stator is fixed. The rotor consists of electromagnets which are in fact wires wrapped around a metal core. The stator consists of a winding of copper bars. Rotating the rotor causes electrons to move inside the stator. The movement of the electrons thus creates an electric current.

### 2.15.2. The transformer

It is a device that increases the voltage (voltage) of the alternating current produced by the alternator. But it does not have any moving part that is why a transformer is referred to as a static machine a transformer has three main parts two winding are in the form of coil made of a good conductor of current and a metallic core which the winding are wound

.The transformer consists of two coils, one primary where the electric current enters at low voltage and the other secondary, where is produced the very high voltage current that is routed to the transmission lines.

Higher voltage electricity is easier to transport and experiences fewer losses when transmitted over long distances.

## 2.16. Classification and types of hydroelectric plants

The characteristic quantities of small hydropower plants (SHP):

Four characteristic variables make it possible to evaluate the importance of a hydroelectric installation:

• Equipment flow.

• The height of fall.

• The power of development.

• The electrical energy produced.

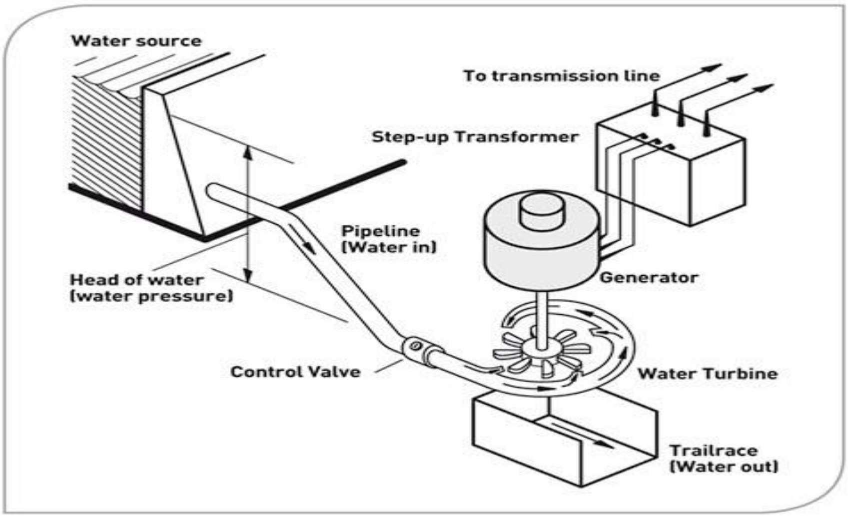



**Figure II.6 :** classification and types of hydroelectric plants.
**Source :** http://www.veoliawater2energy.com/en/references/micro-hydro-power-plants/

-The equipment flow (Q) is the maximum flow rate that can be pumped by the plant, ie the maximum flow rate absorbed by all the turbines when they work together at full power. It is expressed in $m^3/s$.

-The gross head of height (Hg) is the difference in altitude, expressed in meters, between the water level at the intake (free surface area in medium waters) and the water level at the right restitution.

-The net drop height (Hn) takes into account hydraulic head losses in the supply and return structures.

-Power is a combined function of equipment flow and fall height. It is expressed in kilowatts (kW) or megawatts (MW).

We usually distinguish:

• The maximum gross power that expresses the potential power of the development

$$Pb = 9.81 \times Q \times Hb \quad (2.2)$$

• The installed capacity that represents the effective power of the development

$$Pi = 9.81 \times Q \times Hn \times R \quad (2.3)$$

R: efficiency of the turbine-generator set, which varies mainly between 0.6 and 0.9 depending on the power.

• The electrical energy produced indicates the generating capacity of a hydroelectric facility. It depends on the installed capacity and the regime of the watercourse.

$$W = Pi \times T \times F \quad (2.4)$$

T = operating time of the layout in hours.

F = Seasonal flow rate coefficient for run-of-river facilities.

## 2.17. Types of Hydropower Plants

There are three types of hydropower facilities: impoundment, diversion, and pumped storage. Some hydropower plants use dams and some do not. The images below show both types of hydropower plants.

Many dams were built for other purposes and hydropower was added later. In the United States, there are about 80,000 dams of which only 2,400 produce power. The other dams are for recreation, stock/farm ponds, flood control, water supply, and irrigation.

Hydropower plants range in size from small systems for a home or village to large projects producing electricity for utilities. The sizes of hydropower plants are described below. [37]

### 2.17.1. Impoundment

The most common type of hydroelectric power plant is an impoundment facility. An impoundment facility, typically a large hydropower system, uses a dam to store river water in a reservoir. Water released from the reservoir flows through a turbine, spinning it, which in turn activates a generator to produce electricity. The water may be released either to meet changing electricity needs or to maintain a constant reservoir level.

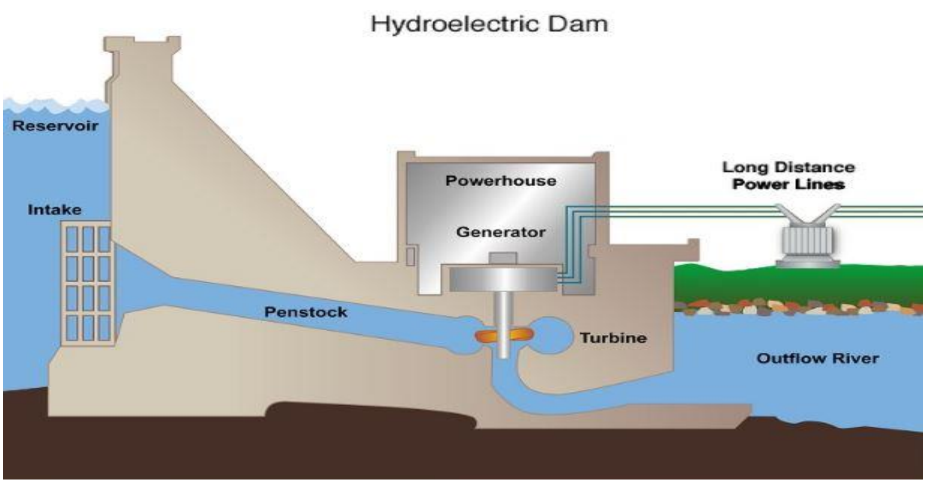



**Figure II.7 :** Impoundment system.
**Source :** https://www.e-education.psu.edu/earth104/node/1067

### 2.17.2. Diversion

A diversion, sometimes called run-of-river, facility channels a portion of a river through a canal or penstock. It may not require the use of a dam.

If you have a small stream located on your property, this type of electric generation may be right for you. Micro-hydro electrical systems use turbines to convert the rotational energy of water into electricity using a generator.

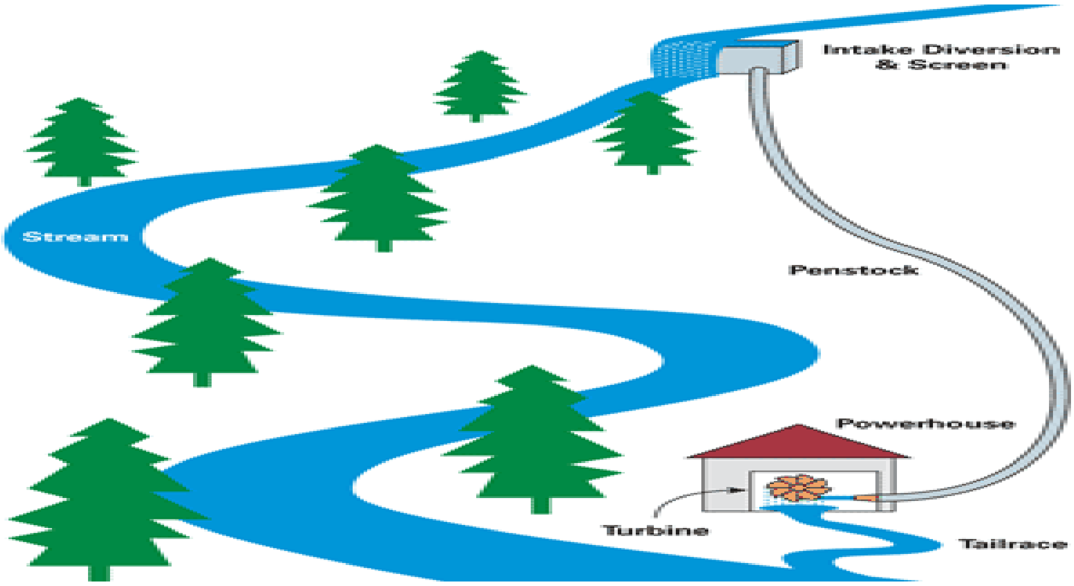



**Figure II.8 :** Diversion system.
**Source:** http://www.kclarson.com/Micro-Hydro-Electrical-Power.php

### 2.17.3. Pumped storage

Another type of hydropower called pumped storage works like a battery, storing the electricity generated by other power sources like solar, wind, and nuclear for later use. It stores energy by pumping water uphill to a reservoir at higher elevation from a second reservoir at a lower elevation. When the demand for electricity is low, a pumped storage facility stores energy by pumping water from a lower reservoir to an upper reservoir. During periods of high electrical demand, the water is released back to the lower reservoir and turns a turbine, generating electricity.

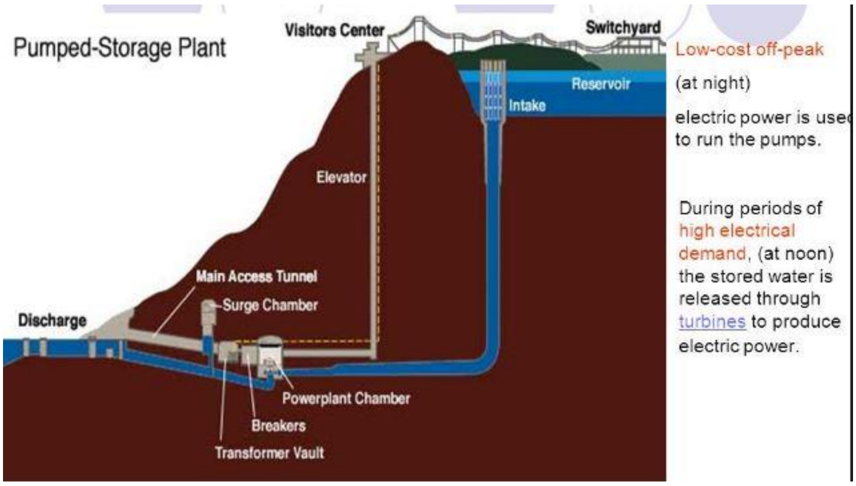



**Figure II.9 :** pumped storage system.
**Source :** https://www.e-education.psu.edu/earth104/node/1067

## 2.18. Size of a hydroelectric plant

The classification of hydro power plants depend on the capacity of production that the plant can generated the table below show this general classification:

**Table II.6.** General classification of hydro power plants.

| Type | Capacity |
|---|---|
| **Large –Hydro** | More than 100 MW |
| **Medium – Hydro** | 15 up to 100 MW |
| **Small – Hydro** | 1 up to 15 MW |
| **Mini – Hydro** | Above than 100KW, but below than 1 MW |
| **Micro- Hydro** | From 5KW up to 100KW |
| **Pico – Hydro** | From few hundred watts up to 5 KW |

**Source:** D. Singh: “Micro Hydro Power”, Resource Assessment Handbook (2009).

## 2.19. Civil structures

Various possibilities exist for the general lay-out of a hydro scheme, depending on the local situation. Possibilities are:

a. Low head with a river barrage.

b. Low head with a channel.

c. High head with no channel.

d. High head with channel.

Different essential factors must be kept in mind when designing a micro hydropower system. These factors include [38]:

### 2.19.1. Use of available head

The design of the system has effects on the net head delivered to the turbine. Components such as the channel and penstock cannot be perfectly efficient. Inefficiencies appear as losses of useful head of pressure.

### 2.19.2. Flow variations

The river flow varies during the year but the hydro installation is designed to take a constant flow. If the channel overflows there will be serious damage to the surroundings. The weir and intake must therefore divert the correct flow whether the river is in low or in high flow. The main function of the weir is to ensure that the channel flow is maintained when the river is low. The intake structure is designed to regulate the flow to within reasonable limits when the river is in high flow. Further regulation of the channel flow is provided by spillways.

### 2.19.3. Sediment

Flowing water in the river may carry small particles of hard abrasive matter (sediment); these can cause wear to the turbine if they are not removed before the water enters the penstock. Sediment may also block the intake or cause the channel to clog up if adequate precautions are not taken.

### 2.19.4. Turbulence

In all parts of the water supply line, including the weir, the intake and the channel, sudden alterations to the flow direction will create turbulence which erodes structures and causes energy losses.

### 2.19.5. Weir and Intake

A hydro system must extract water from the river in a reliable and controllable way. The water flowing in the channel must be regulated during high river flow and low flow conditions. A weir can be used to raise the water level and ensure a constant supply to the intake. Sometimes it is possible to avoid building a weir by using natural features of the river. A permanent pool in the river may provide the same function as a weir.

The intake of a hydro scheme is designed to divert a certain part of the river flow. This part can go up to 100 % as the total flow of the river is diverted via the hydro installation. For small systems only a tiny fraction of a river might be diverted, this also has the advantage that MHP output can be kept constant even when the flow of the river is strongly fluctuating.

The following points are required for an intake:

Different types of intakes are characterised by the method used to divert the water into the intake. For micro hydro schemes, only the small intakes will be necessary the main type of intake for such purposes will be the side intake since it is cheap and simple to construct.

Channels

The channel conducts the water from the intake to the forebay tank.

The length of the channel depends on local conditions. In one case a long channel combined with a short penstock can be cheaper or necessary, while in other cases a combination of short channel with long penstock suits better.

Most channels are excavated, while sometimes structures like aqueducts are necessary. To reduce friction and prevent leakages channels are often sealed with cement, clay or polythene sheet.

Size and shape of a channel are often a compromise between costs and reduced head. As water flows in the channel, it loses energy in the process of sliding past the walls and bed material. The rougher the material, the greater the friction loss and the higher the head drop needed between channel entry and exit.

Incorporated in the channel are the following elements: settling basin (removes sediments from water), spillways (used for controlled overflow) and forebay tank.

The forebay tank forms the connection between the channel and the penstock. The main purpose is to allow the last particles to settle down before the water enters the penstock. Depending on its size it can also serve as a reservoir to store water.

Penstock

The penstock is the pipe which conveys water under pressure from the forebay tank to the turbine. The penstock often constitutes a major expense in the total micro hydro budget, as much as 40 % is not uncommon in high head installations, and it is therefore worthwhile optimising the design. The trade-off is between head loss and capital cost. Head loss, due to friction in the pipe, decreases dramatically with increasing pipe diameter. Conversely, pipe costs increase steeply with diameter. Therefore a compromise between cost and performance is required.

## 2.20. Types of Hydro-Turbines

For hydroelectric power stations, the amount of electrical energy that can be generated from a water source depends primarily on two main parameters:

• The distance the water has to fall

• The quantity of water flow

As the water source varies according to the geographical location of the plant, water turbines are designed subsequently to suit these different locations. The design and selection of water turbine is mainly based on the principle of energy conversion, available water head on the machine, the specific speed of the turbine and the quantity of water that can be utilized for continuous power generation. Accordingly these turbines are grouped under two main categories, [39].

• Impulse turbines - For example: Pelton, Cross-flow and Turgo turbines

• Reaction turbines - For example: Francis, Kaplan and Bulb turbines

The classification of turbines is essential to differentiate the failure mechanism that the turbine may experience. Depending on the type of turbine used for converting mechanical energy into electrical energy, in general, the four failure modes of cavitation, erosion, fatigue and material defect may affect the impulse and reaction turbine differently, [39]. For example, a reaction turbine is likely to fail mostly due to cavitation while an impulse turbine is most probable to fail due to erosion, [40]. Moreover the failure due to material fatigue and material defect may depend on the operating condition of the power plant. So, it is essential to give a brief account of most widely used hydropower turbines before concentrating on different failure mechanisms.

It also is important to emphasize that material defects refer to defects generated in the turbine components during the installation process and not during the manufacture of turbine. It is assumed that once the hydro turbine left the manufacturing site, it is fully checked and all quality specifications and requirements are met and satisfied. [39, 40, 41]

### 2.20.1. Impulse turbines

There are three basic types of impulse turbines which can be distinguished and which have different physical principles and characteristics. These are the Pelton turbine, the Turgo-turbine and the Crossflow-turbine (also known as Banki-Mitchell or Ossberger – turbine. [42]

- **Pelton Turbines**

The Pelton turbine as shown in (Figure II.6.a) is used where there is a small water discharge with a large available water head on the turbines. It is similar to the water wheels used in the past. Pelton turbines constitute a series of runners/buckets aligned around the rim of the shaft. Water from the dam is fed through the nozzles at high speed, hitting the blades of the turbine, converts potential energy of the water in mechanical energy (Shaft rotation), which is ultimately transformed into electrical energy through generator.

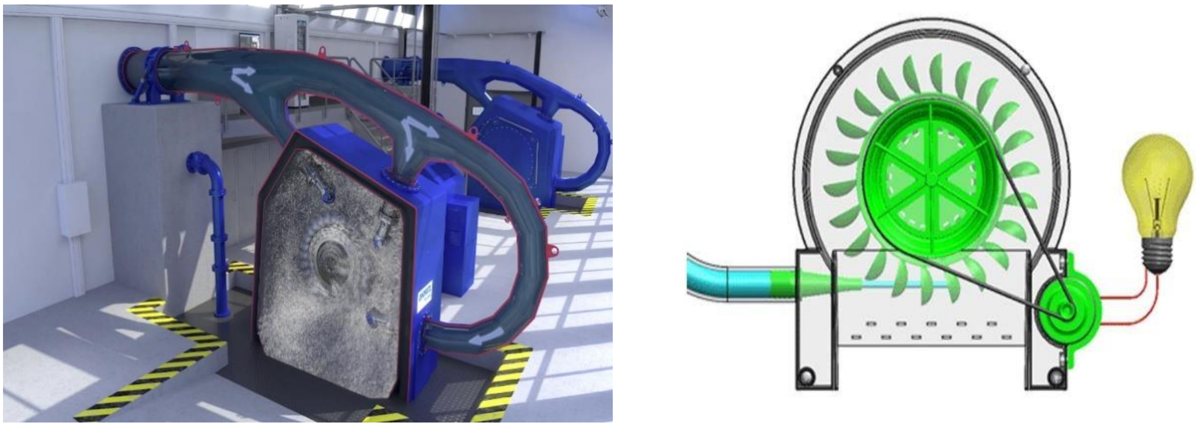


**Figure II.10.a:** shape of Pelton turbine.
**Source:** https://vimeo.com/111935236

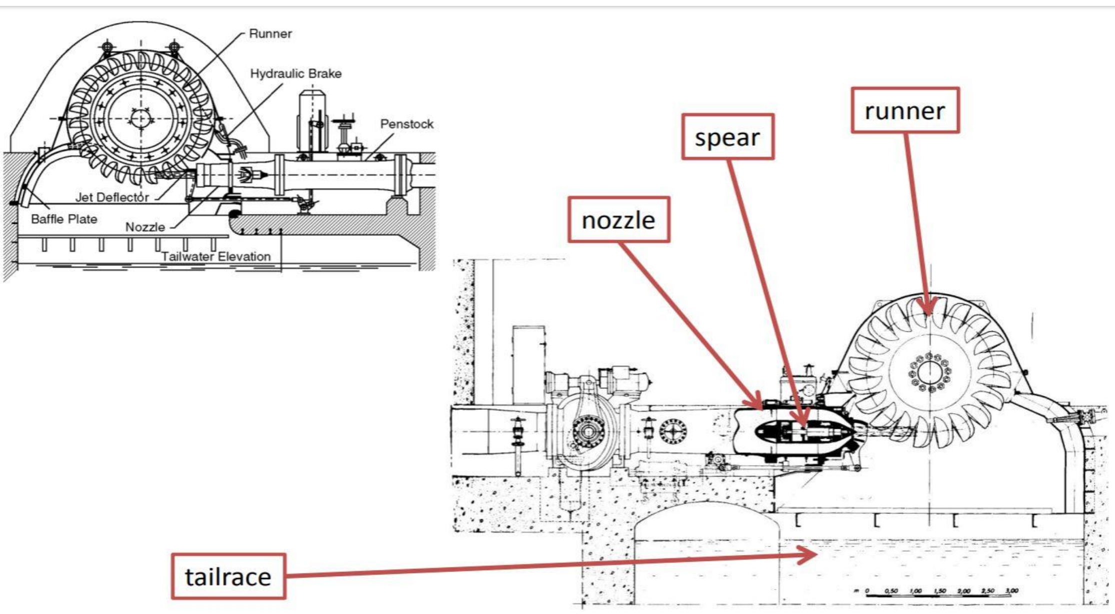



**Figure II.10.b:** Technical design of Pelton turbine.
**Cross-Flow https://www.energy.gov/eere/water/types-hydropower-turbines**

❖ **Cross-flow turbine**

A cross-flow turbine is drum-shaped and uses an elongated, rectangular-section nozzle directed against curved vanes on a cylindrically shaped runner. It resembles a "squirrel cage" blower. The cross-flow turbine allows the water to flow through the blades twice. The first pass is when the water flows from the outside of the blades to the inside; the second pass is from the inside back out. A guide vane at the entrance to the turbine directs the flow to a limited portion of the runner. The cross-flow was developed to accommodate larger water flows and lower heads than the Pelton.

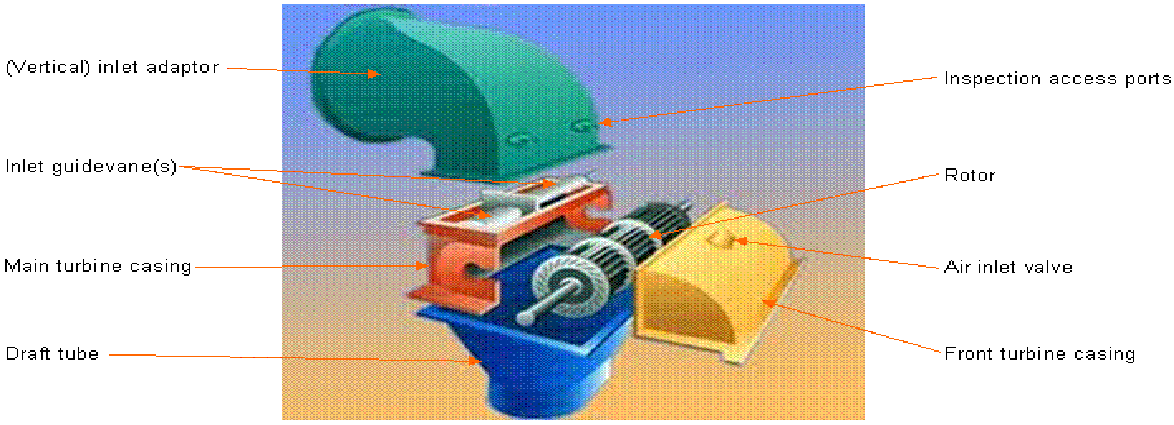



**Figure II.11:** Shape of a Cross-flow turbine.

❖ **Turgo Turbine**

Turgo turbines are similar to Pelton turbines; however nozzles are angled with respect to the runner directing water flow to enter on one side and to exit the other to avoid interference between flows. This translates to smaller runner diameters and higher rotational speeds when compared to Pelton turbines. The higher speeds make it more feasible to directly connect the turbine shaft to the generator and therefore eliminate the need for transmission systems in medium head environments [43].

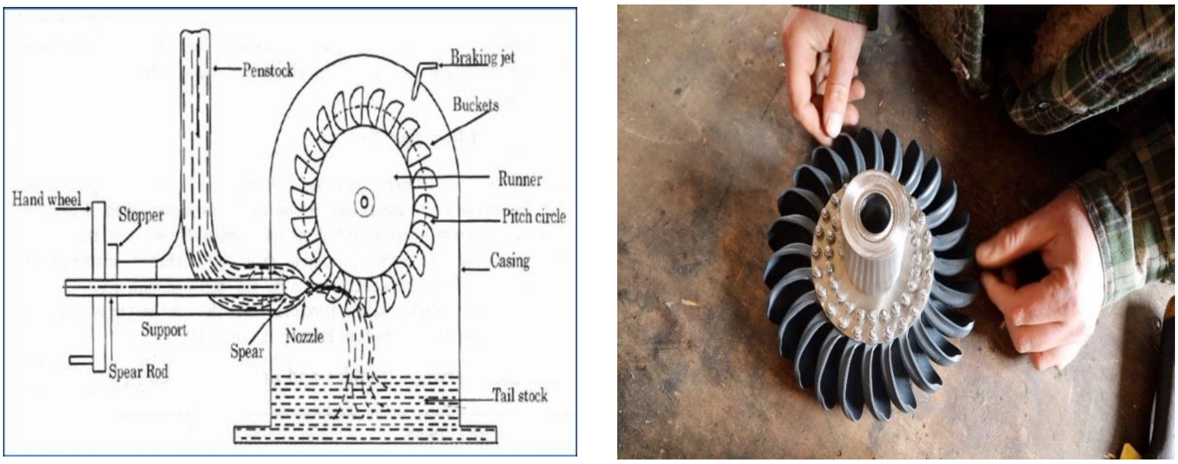



**Figure II.12**: Turgo turbine.

**Source:** https://grabcad.com/library/turgo-turbine-runner-1

2.20.2. Reaction turbine

The reaction turbine operates when the rotor is fully submerged in water and is enclosed in a pressure casing.

- **Francis turbine**

The Francis turbine is used where a large flow and a high or medium head of water is involved. (Figure II.9) given below shows a Francis turbine mechanism used in a hydropower station. The Francis turbine is also similar to a waterwheel, as it looks like a spinning wheel with fixed blades in between two rims. This wheel is called a 'runner'. A circle of guide vanes surround the runner and control the amount of water driving it. Water is fed to the runner from all sides by these vanes causing it to spin.

As reported by [44], Francis turbine operates with a water head of 30-60 meters. The Francis turbine runner has a high operating efficiency (approximately 90%) over a wide range of head heights and flow rates. The size of a Francis turbine runner can range from less than one metre to over fifteen metres in diameter.

**Figure II.13**: Francis turbine.

❖ **Kaplan turbines**

Propeller type turbines, such as Kaplan turbines are designed to operate where a small head of water is involved. For Kaplan turbines as shown in Figure II.14, the angle (or pitch) of the blades can be altered to suit the water flow. The adjustable pitch feature of Kaplan turbines allows these types of turbines to operate efficiently at a wider range of water head, allowing a provisional variation in the water level in the dam. Kaplan turbines can be used in sites having a typical head range of 2m to 40m with 15% to 100% efficiency at full discharge for double regulated type and about 30% to 100% at maximum discharge for single regulated types.

[45, 46]

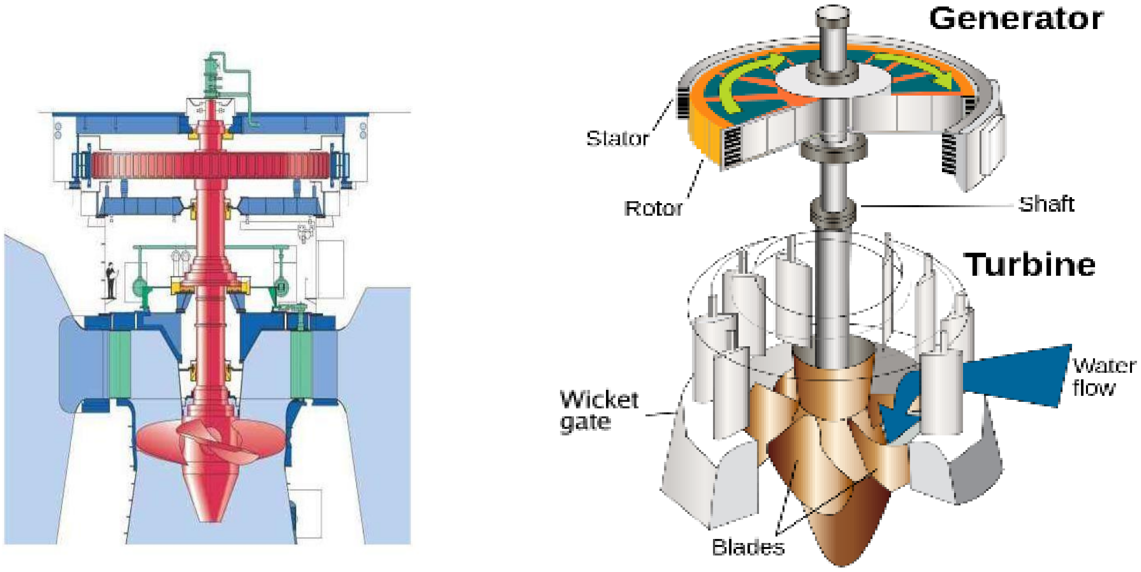



**Figure II.14**: Kaplan turbine.

To make small resume of all what we saying before the table below give clear idea about all the types

**Table II.7:** operational range of different turbines (ESHA, 2004). **Source:** European Small Hydropower Association (ESHA) (2004) Guide on How to Develop a Small Hydropower Plant. URL: www.esha.be

| | Type of turbine | Head range(m) | Acceptance of flow variation | Acceptance of head variation | Maximum efficiency (%) |
|---|---|---|---|---|---|
| Reaction turbine | Kaplan/propeller | 2-40 | high | Low | 91-93 |
| | Francis | 25-350 | Medium | Low | 94 |
| Impulse turbine | Pelton | 50-1300 | High | High | 90 |
| | Cross-flow | 2-200 | High | Medium | 86 |
| | Turgo | 50-250 | Low | low | 85 |

## 2.21. Theoretical design

- To build the turbine, it will be necessary to know the 3 following characteristic sizes:
  - Flow Q
  - Height of fall H
  - Rotation speed N
- Q and H being the starting data of a project, it is necessary to find N. three factors intervening in the choice of N:
  - Limit the dimensions of wheel components and electrical appliances.
  - Limit N to avoid cavitation.

### 2.21.1. Hydraulic power

Symbol: P Unit: Watt (W) or more generally: (kW)

The flow and the net drop make it possible to calculate the hydraulic power available:

$$P_{hyd} = Q_t \, H_n \, \rho \, g \tag{2.5}$$

P: Power, in (W)

$Q_t$: turbine flow, in ($m^3/s$)

$H_n$: net drop, in (m)

$\rho$: density of the water = 1000 ($kg/m^3$)

g: acceleration due to gravity = 9.81 ($m/s^2$)

The hydraulic power must be converted into mechanical power that will be used directly (mills, pumps, etc.) or will in turn be transformed into electrical power.

The hydraulic power - mechanical power passage is through a turbine that is rotated by the flow of water.

There are four main types of turbines:

- Pelton
- Francis
- Kaplan
- Cross Flow

In addition, for small plants with a sufficiently constant flow throughout the year, it is also possible to use pumps operating in reverse regime.

❖ Calculation of the maximum rotation speed:

$$N_{max} = \frac{H^{2/3}}{P^{1/2}} \tag{2.6}$$

$N_{max}$: Maximum speed (rpm)

H: Gross fall height (m)

P: Power (HP) (1 HP = 746 W)

• Once $N_{max}$ is known, we choose a speed of rotation compatible with the alternator (speed of synchronism) by limiting the number of pairs of poles:

$$N = \frac{60.f}{P} \tag{2.7}$$

N: rotation speed (rpm)

f: frequency of the network (Hz)

P: number of pole pairs

• The specific speed is then given by the formula:

$$Ns = N.P^{1/2}.\ H^{-5/4} \tag{2.8}$$

$N_s$: Specific speed (rpm)

N: Rotational speed (rpm)

P: Power (HP)

H: gross fall height (m)

## 2.22. Generator

The electric generator converts the mechanical energy of the turbine into electrical energy. The two major components of the generator are the rotor and the stator. The rotor is the rotating assembly to which the mechanical torque of the turbine shaft is applied. By magnetizing or “exciting” the rotor, a voltage is induced in the stationary component, the stator. The principal control mechanism of the generator is the exciter-regulator which sets and stabilizes the output voltage. The speed of the generator is determined by the turbine selection, except when geared with a speed increaser. In general, for a fixed value of power, a decrease in speed will increase the physical size and cost of the generator [47].

### 2.22.1. Synchronous Generator Construction

A DC current is applied to the rotor winding, which then produces a rotor magnetic field. The rotor is then turned by a prime mover (e.g. Steam, water, etc.) producing a rotating magnetic field. This rotating magnetic field induces a 3-phase set of voltages within the stator windings of the generator.

"Field windings" applies to the windings that produce the main magnetic field in a machine, and "armature windings" applies to the windings where the main voltage is induced. For synchronous machines, the field windings are on the rotor, so the terms "rotor windings" and "field windings" are used interchangeably.

Generally a synchronous generator must have at least 2 components:

a) Rotor Windings or Field Windings

 a. Salient Pole

 b. Non Salient Pole

b) Stator Windings or Armature Windings

The rotor of a synchronous generator is a large electromagnet and the magnetic poles on the rotor can either be salient or non salient construction. Non-salient pole rotors are normally used for rotors with 2 or 4 poles rotor, while salient pole rotors are used for 4 or or more poles rotor [48].

### 2.22.2. The asynchronous generator

Experience showed that without any special measures the machine can supply electrical energy into the mains when it is driven mechanically beyond its no-load speed. Additionally it is known what to consider for the electrical design obtaining optimum results for generator operation as well.

As already mentioned at the beginning one of the many advantages of the asynchronous machine is that it can be used as generator without any additional devices, which means an exciter or voltage controller, when it is operated at an existing rigid three-phase mains.

The asynchronous generator comprises a rotor without winding. The current flowing therein is produced, by induction, from the stator windings.

It is essentially used:

• When the production of the plant is planned for sale to the national operator, because in this case the generator is controlled by the network that regulates the frequency and the voltage of the current produced.

• For powers below 2000 kW.

The asynchronous generator is simpler to implement and easier to couple to the network in average powers. On the other hand, it is less interesting than the alternator with regard to the reactive energy.

Now the frequency of the alternating current of the network to which one is connected imposes the speed of rotation of the generator (cf preceding paragraph; for 80hz the speed of rotation of the generator must be of 3000, 1500 or 1000 revolutions / minute according to the rotor has 1, 2 or 3 pairs of poles).

The speed multiplier, placed between the turbine and the generator, makes it possible to synchronize the operation of the different equipment.

This multiplication can be performed by belts for powers below 200 or 300 kW. Gearbox gearing is used for turbines of about 100 kW up to several MW.

### 2.22.3. Comparison of Some Characteristics of Synchronous and Asynchronous Generators

However, before selecting the generators, it is mandatory to study the operation of the generator and the status of the host power network of which the generator will be a component. Following is a comparison of the characteristics of each type of generator, with a view of on the case that the asynchronous generator is connected to the power network [49].

• Capacity: Synchronous generators are suitable for high capacities and asynchronous ones that consume more reactive power are suitable for smaller capacities.

• Speed: Higher speeds create no problems other than difficulties in manufacturing of synchronous generators with large capacities.

• Excitation: Electrical excitation of synchronous generators require coils for exciting field whereas asynchronous ones do not need any coils for excitation because the necessary power for excitation the armature coils should be drawn from the power network. The synchronous generators with permanent magnet are also free from exciting coils.

• Independent Operation: Synchronous generators can be utilized independently while the operations of asynchronous ones need to be fed with an exciting current from the power network.

• Voltage Regulation: The output voltage of the synchronous generator terminals can be regulated but the voltage of the asynchronous generators is always the same as the voltage of the power network.

• Power Factor Control: In Synchronous generators, the power factor of the front and rear phases and the reactive power can be controlled. The asynchronous generators works with the power factor of rear phase and a condenser is required for any correction of the power factor.

Impact on Power Network during Paralleling: For synchronous generators, no impact is generated during connection to the network, but some additional currents will flow in asynchronous generators that produce no voltage before connection to the network and this necessitates consideration of any drop in the network.

• Cost: The synchronous generators with electrical exciter are more expensive than asynchronous ones, but in the ranges less than 750 kw, the synchronous generators of the with permanent magnet are less expensive than their asynchronous equivalents; and for above 750kW, their price is slightly higher, nevertheless, with respect to other advantages, their use may find long-term economical justification. Another point to be considered is that low-speed asynchronous generators are generally expensive.

### 2.22.4. The efficiency of the generators

The transformation of mechanical power into electrical power causes losses.

As with turbines, some of the power is dissipated as noise and heat.

The output of a generator is defined as:

$$\eta g = P_{el} / P_{mec} \qquad (2.9)$$

with $\eta g$: rendement of the generator (%)

The efficiency of the generators varies with the power and therefore with the flow. However, this variation is less than the turbines.

Indicative values for generator yields:

At maximum load

**Table II.8:** Generator Output at Total Load.

| $P_{el}$ | $\eta g_{max}$ (%) |
|---|---|
| 1 to 5 | 80 - 85 |
| 5 to 20 | 85 - 90 |

| | |
|---|---|
| 20 to 100 | 90 - 95 |
| >100 | 95 |

At partial load:

**Table II.9:** Performance of Partial Load Generators.

| $\frac{P_{el}}{P_{el\,max}}$ **(%)** | $\frac{\eta_g}{\eta_{gmax}}$ **(%)** |
|---|---|
| **>50** | 100 |
| **25** | 95 |
| **10** | 85 |

## 2.23. Selection of one or more types of turbines

The selection of a turbine type will be a function not only of the net drop and the flow, but also of the specific data at the site where the machine will be installed.

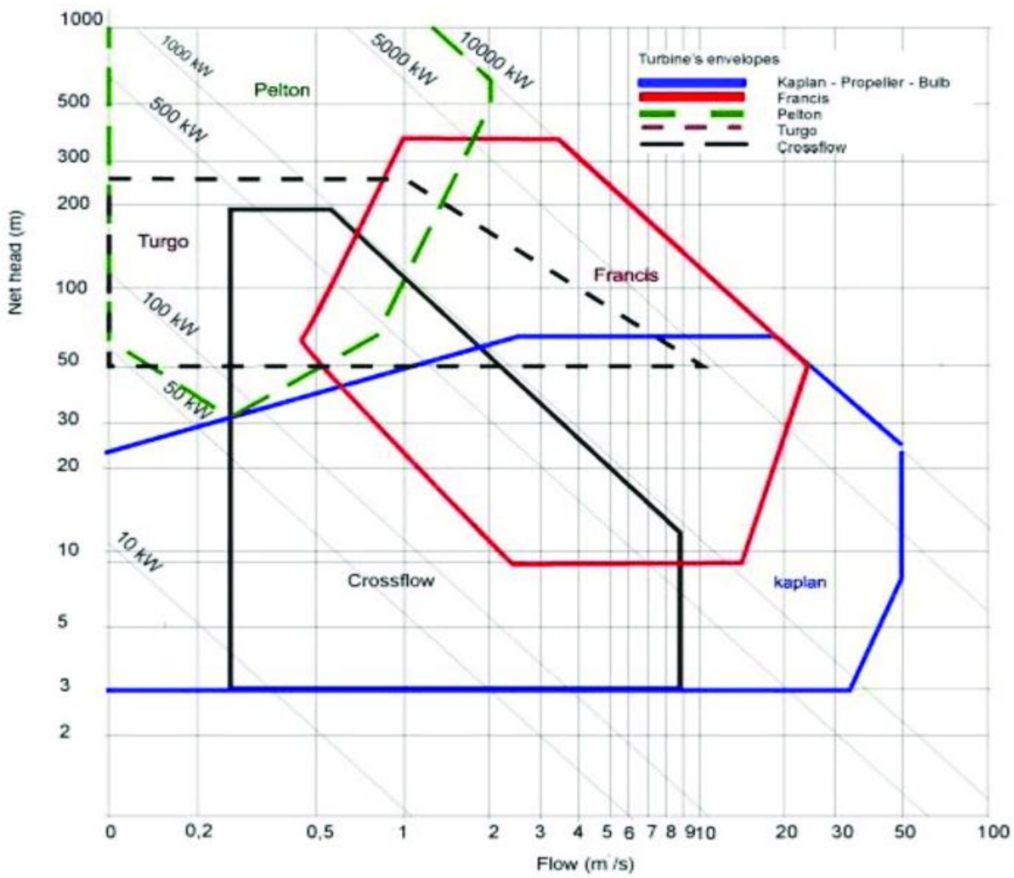
2.23.1. Gross fall and net fall as a function of flow

To what extent will the fall vary?

- Depending on the flow rate (head loss);
- Depending on the extreme hydrological conditions (e.g. elevation of the downstream level in case of flood);
- Depending on the design concept (variable fall height in an accumulation tank, for example).

It is therefore useful to establish the operating conditions as accurately as possible, bearing in mind that a Francis or Kaplan type reaction turbine is better adapted to strong relative drop variations than a turbine with action, Pelton or Crossflow.

The abacus shown in Figure II.11 allows to preselect a turbine type according to the fall and the flow rate.




**FigureII.15:** Area of use of the different types of turbines (net drops, flows, powers).

### 2.23.2. Turbine efficiency versus flow relationship

The flow available and its annual variation will also influence the choice of the turbine:

- **Constant flow** (permanently surplus water) fixed aperture turbine, for example inverted pump, impeller with fixed blades, Pelton with fixed injector;
- **Low flow rate**, the turbine runs few hours per year at low load. In this case, a Francis turbine or a Kaplan turbine with a fixed distributor, with an excellent efficiency at the nominal and unfavourable flow rate below 40% of this flow, may have a better economic balance sheet than for example a cheaper Cross flow turbine, but with a lower peak efficiency;
- **Very variable flow**, the turbine often runs at low flow. In this case, a Crossflow turbine may be more favourable than a Francis turbine, despite its lower maximum efficiency. A multi-jet Pelton turbine is superior to a Francis turbine, a dual-tuned Kaplan turbine better than lower-cost single-setting machines.

In some cases, the installation of two turbines can be the energy and economically most favourable solution (2 turbines coupled to a generator or 2 independent groups).

The shape of the yield curves, as well as the maximum values shown (Figure II.16) allow a first comparison between the various types of turbines.

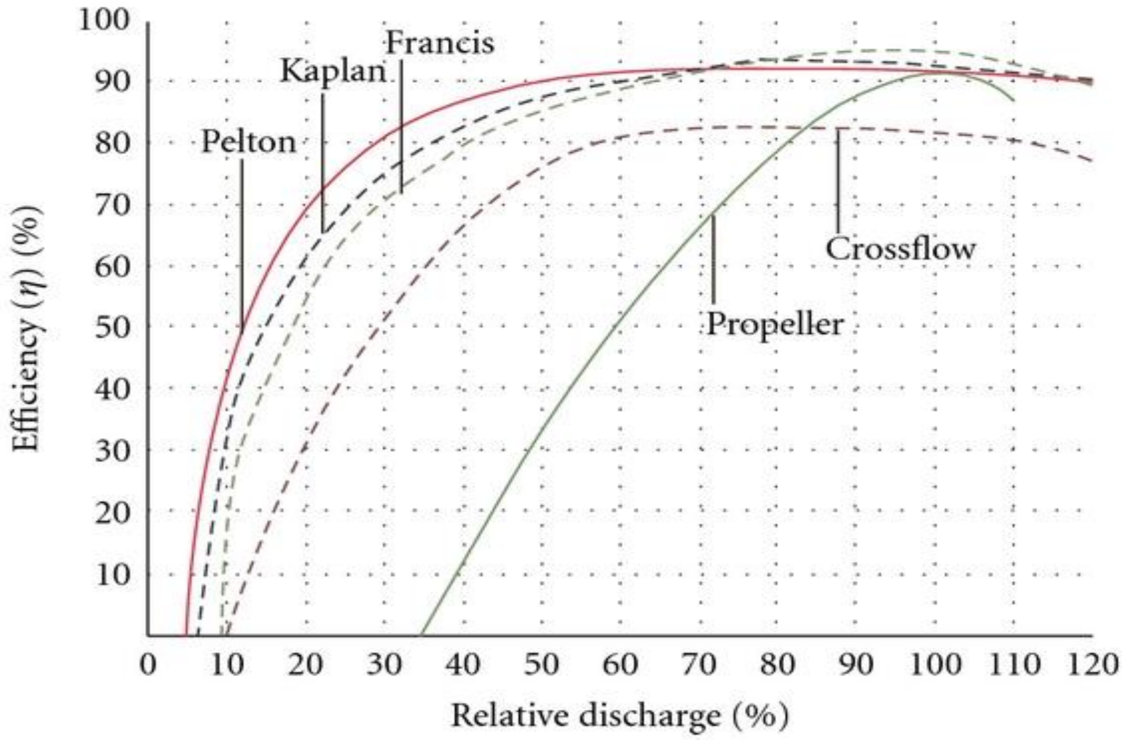



**Figure II.16:** Shape of the yield curves of different turbines for variable flow rates.
**Source:** IPCC—Intergovernmental Panel on Climate Change, Renew-able Energy Sources and Climate Change Mitigation: Special Report of the Intergovernmental Panel on Climate Change—Chapter 5, Hydropower, Cambridge University Press, New York, NY, USA, 2007.

### 2.23.3. Order of magnitude of the maximum yields ηmax:

| Curve N° and Turbine Type | $\eta_{max}$ (%) |
|---|---|
| Curve 1: Pelton Turbine | 84 - 90 |
| Curve 1: 2-Cell Cross Flow Turbine | 78 – 84 |
| Curve 2: Kaplan Turbine | 84 – 90 |
| Curve 3: Francis Turbine | 84 – 90 |
| Curve 3: 1-cell Cross Flow Turbine | 78 – 84 |
| Curve 4: Inverted pump | 75 - 90 |

### 2.23.4. Rotational speed of the turbine-generator group

The rotational speed, n, of a generator is related to the constant frequency of the 50 Hz network.

The synchronous generators, according to their number of poles, will rotate at the following speeds:

| Number of pole pairs | n (rpm) |
|---|---|
| 1 | 3000 |
| 2 | 1500 |
| 3 | 1000 |
| 4 | 750 |
| 5 | 600 |
| 6 | 500 |

The rotational speeds of the asynchronous generators will be 1 to 2% higher than the values indicated, a slight over speed being necessary to create the magnetic field in the machine.

In practice, the maximum speed is limited to 1500 rpm (2 pairs of poles), to take account of the over speeding of the runaway which causes considerable mechanical stress beyond. For the values of runaway speeds, see § 2.1 and § 3.3. As a result, single pole pair generators are only rarely installed (runaway speed 6000 rpm).

a. Under 600 rpm(6 pairs of poles and more), the volume of the generator, so its price compared to the installed power, increases in parallel with a fall of the yield due to an increase of the losses, in particular magnetic.
b. When the rotational speed of the turbine is less than 600 rpm, it generally drives a generator with a low number of poles (1000 or 1500 rpm) via a belt transmission or a gear multiplier. For example.

The chart (Figure II.12) allows selection and comparison of the various types of turbines taking into account their rotational speed.

This chart shows that two or even three types of turbines can be considered for a given site: - Pelton / Francis / Cross flow for medium falls - Francis / Cross flow / Kaplan for low fall.

2.23.5. Group layout

There are three main possible provisions:

a. Impeller of the turbine mounted on the axis of the generator, horizontal or vertical configuration (monobloc). This arrangement is the least expensive and the most compact. It nevertheless requires a good precision in the assembly and a particular dimensioning of the bearings of the generator, which are very solicited. A flywheel can be mounted at the other end of the generator on a second shaft end.

b. Turbine directly driving the generator, the two machines having their own bearings and connected by an elastic coupling. Traditional arrangement that allows to separate the mechanical and electrical components of the installation. It allows a better standardization; the turbine can also be used with a transmission at other speeds than synchronous.

- Low speed turbine driving the generator via a speed multiplier (belt or gears). As far as it is technically possible, the flat belt transmission will be preferred to the gearbox (quieter, virtually no maintenance and no periodic oil draining).

## 2.24. Conclusion

Development of hydraulic turbines during the last 30 years has been concentrated in the following main area:

1. Increasing size of the machines, which are designed for higher heads with improved efficiency for a given specific speed.
2. With the environmentalist´s protection of rivers by avoiding big dams in industrialised countries, a new trend in the turbine design has also occurred:

- ✓ The development of mini turbines with simplified designs and low cost without sacrificing reliability and with acceptable efficiency when operating off the design point.
- ✓ The efficiency of hydro turbines has been constantly improved. Today more than 92 per cent efficiency for low specific speed Pelton turbines and 96 per cent for large Francis turbines has been obtained for prototype turbines made by skilled manufacturers.
- ✓ The both, impulse and reaction, turbines are applicable, depending on the specific site conditions. Generally, impulse turbines work at higher head and lower flow rates, while the reaction turbines normally need lower head but higher flow rates for the same energy output. The civil structures of reaction turbines have to be able to stand higher flow values and therefore are more complex and expensive to build.

# Chapter III
# Methods

## 3.1. Introduction

The increase in demand of electricity in both the medium and long terms has identified more production needs. In order to meet those needs, the mobilisation of all renewable and alternative energy resources is needed. Demand forecasts are based on assumptions of both population growth rates and housing occupancies.

Today, 85% of primary energy comes from the non-renewable and fossil sources (coal, oil, etc). These reserves are continually diminishing with increasing consumption and will become scarcer and scarcer for the future generations.

For the year 2011, the total production of electric power reached 48,871.8 GWh against 45,172.5 GWh in 2010, an increase of 8.2% [50].

In 2013, 96% of electricity produced in Algeria came from natural gas, 3% from diesel (for isolated southern regions) and 1% from water.

The conversion of hydraulic energy into mechanical energy takes place in hydraulic turbines. Furthermore this energy is converted to electrical energy with the help of generators and then supplied to consumer. With increasing demand, efficiency of every machine plays vital role. When water is stored at very high head, hydraulic energy can be converted efficiently into mechanical energy with the help of a water turbine.

Algeria has decided to invest heavily upstream for new discoveries and it is expected that over the next five years it will be the third largest energy investor in the Middle East and North Africa (MENA) region with $ 71 billion in planned spending in the energy sector.

Over the period 2013-2020, Algeria is to be ranked third after Saudi Arabia ($165 billion investment planned) and the United Arab Emirates ($107 billion), according to Bloomberg.

In this chapter, the methodology used to develop a micro hydropower plant is presented. Reasons for choosing the study site and a presentation of the company that provided both the data and the software used in the analysis are also given.

### 3.2. Why this study zone?

The Wilaya (region) of Oran was chosen as the present study zone for two reasons:

1. A rising demand in energy due to significant industrial consumption, expanding household and agricultural needs).
2. Insufficient Local energy resource calling for increased dependence on regional transfers.

The Wilaya of Oran presents a good example of the expansion of its water supply network since the 1950s with a call for transfers of water from within a region of radius of 175 km.

The water supply to the Wilaya of Oran has necessitated more and more distant resources: Beni Bahdel dam, Fergoug dam Tafna catchment, Chelif catchment and the Gargar system as well as several desalination plants. These daily transfers are variable and depend on the actual mobilized resource. A projection of demand by 2020 based on population growth is summarized in the table III.1.

**Table III.1**: Daily water demand for the Wilaya of Oran.

| **Year** | **1995** | **2000** | **2005** | **2010** | **2015** | **2020** |
|---|---|---|---|---|---|---|
| **Daily Water Demand ($m^3$)** | 188,134 | 219,308 | 248,248 | 281,007 | 318,089 | 360,064 |

Source: Algerian Water Board (Algérienne des Eaux, ADE)

The Wilaya of Oran imports 90% of its consumption water from neighbouring Wilayas and the remainder from wells, springs and Bredeah groundwater.

- Following the numerous break-ups in a connection to the downstream MAO line supplying the Kristel area.
- The connection located at the place called The cottage is made with a support collar DN 20 PEHD PE80 PN10 and cannot withstand the pressure exceeding 10 bar at this location.
- On the other hand, the site is concerned with the realization of a small tourist extension zone with the realization of bungalows. This represents an increase in demand in the near future.
- In addition, a pressure reducing valve is installed upstream of this stitching. We propose to put small hydropower where there in the same place and produce the electricity at list for this new agglomeration.

### 3.2.1. Geographical location of the Wilaya of Oran

Oran, the second largest city of the country is the chief town of a Wilaya (Department) of the same name located northwest, 430 km from Alger the capital.

The Wilaya of Oran is limited to the North by the Mediterranean Sea, to the East by the Wilayates of Mostaganem and Mascara and to the Southwest by the Wilayates of Sidi Bel Abbes and Aïn Temouchent. The territory of the Wilaya of Oran covers a total area of 2,144km$^2$.

Its administrative organization is based on 26 communes spread over 09 daïras.

Position:

Latitude: 35° 42' 00 N

Longitude: 00° 38' 30 W


**Figure III.1** Geographical location of the Wilaya of Oran.

## 3.3. Presentation of the company SEOR

3.3.1. Creation of the SEOR

The Water and Sanitation Company of Oran (Société de l’Eau et de l’Assainissement d’Oran, SEOR), whose shareholders are the Algerian Water Board (Algérienne des Eaux, ADE) and the

National Office for Sanitation (Office National d'Assainissement, ONA), was created on April 1st 2008.

Logo of the SEOR Company.

SEOR is responsible for water and sanitation management in the Wilaya of Oran.

The Spanish Water Board, AGBAR (AGUA DE BARCELONA, subsidiary of the French Water Board SUEZ) obtained, by contract, the delegated management of the SEOR for a period of 6 and a half years and a technical assistance of 3 years ending on June 30, 2017

### 3.3.2. Organization of SEOR

The SEOR SPA, governed by a board of directors, opted for a local organization, setting up 09 territorial officials for each management corresponding to the 9 Daïras (Departments) of the Wilaya. Its organization chart is composed of 09 management offices:

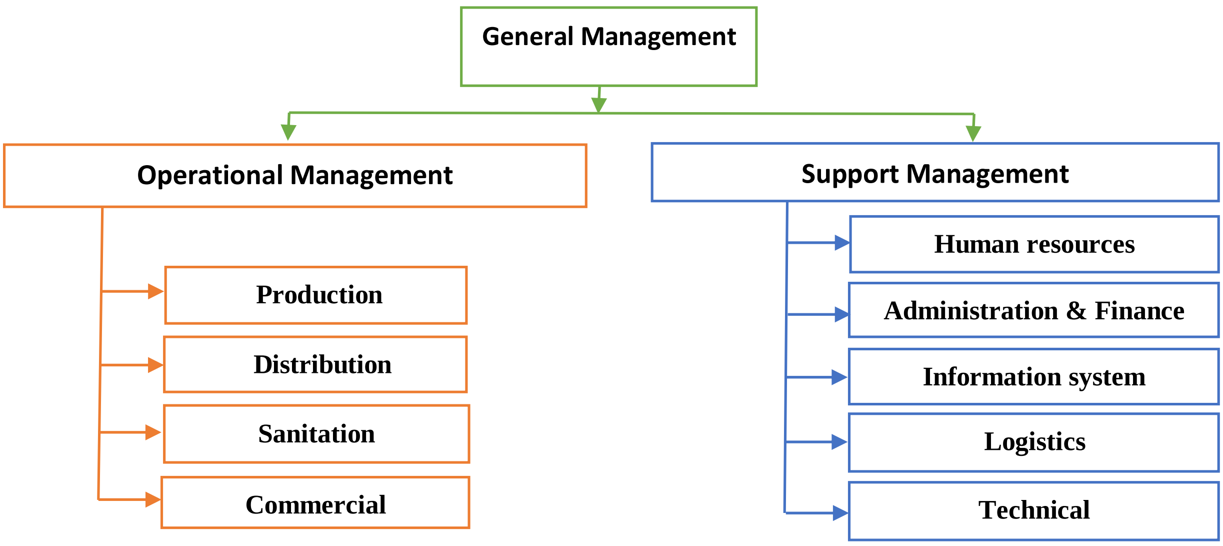



**Figure III.2:** Organization chart of the 09 management offices of SEOR.

### 3.3.3. Operating scope of SEOR

SEOR is responsible for the management of drinking water and sanitation networks in the 26 municipalities of the Wilaya of Oran. It also ensures the supply of a large part of desalinated drinking water to other neighbouring Wilayas, namely:

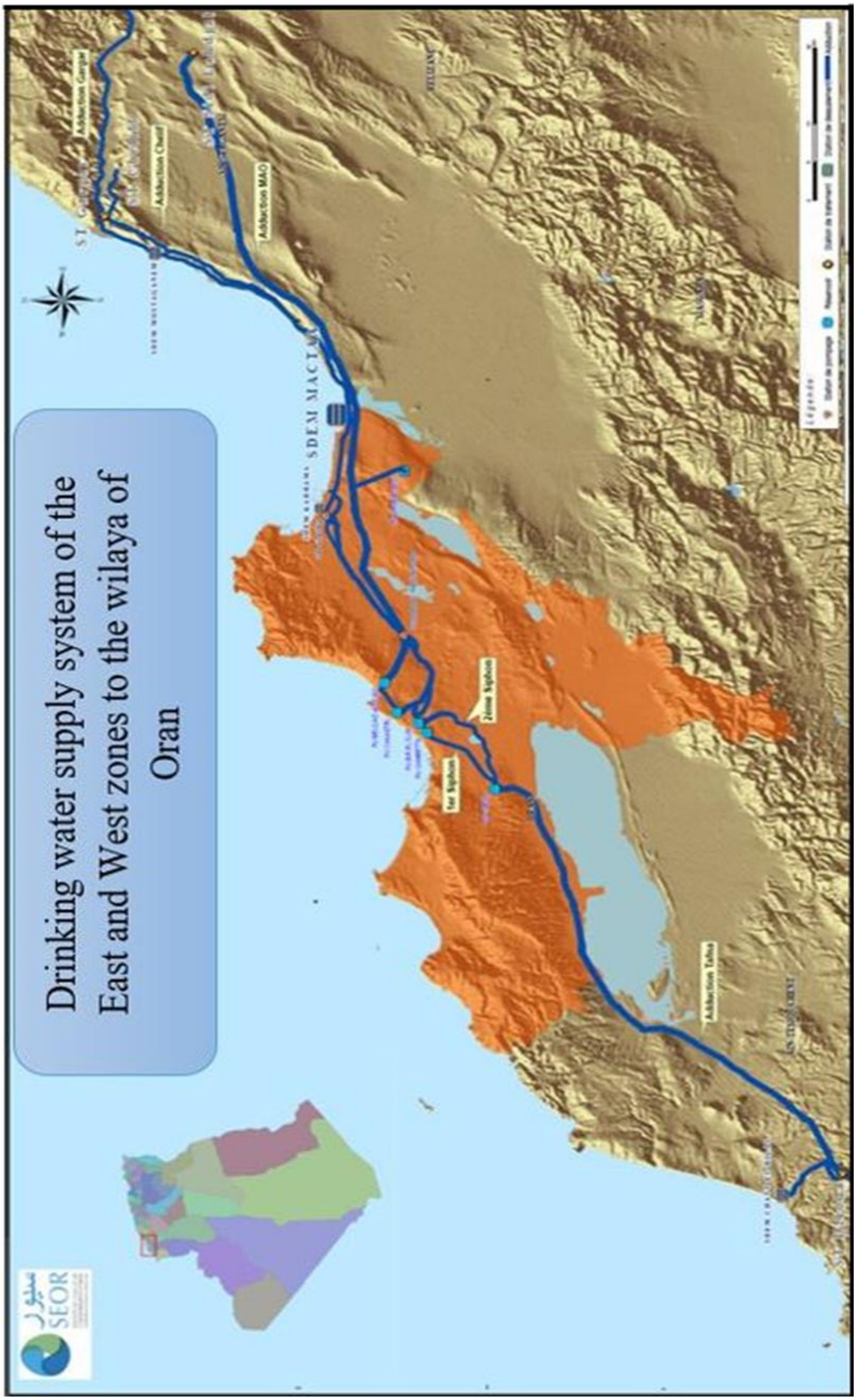
- MOSTAGANEM: 180 000 m³/day
- RELIZANE: 50,000 m³/day (Forecast of 80,000 m³/day)
- MASCARA: 100,000 m³/day (Forecast of 122,000 m³/day)
- AIN TEMOUCHENT: 140 000 m³/day

### 3.3.4. SEOR perspective

- Total population to be served: 1,989,805
- Population served in H24 is: 1,950,009 inhabitants (i.e. 98% of the total population)
- distributed volume to Oran: 480,000 m³ / day
- Volume produced outside Wilaya: 470 000m³ / day

In order to provide satisfactory supply of drinking water, the following network lengths and equipment are called for:

- Distribution networks: 2 989 Km
- Production networks: 1,004 Km
- Number of Pumping stations: 56




**FigureIII.3:** The big transfer of the drinking water supply system from the east and west zones to the Wilaya of Oran.

The following table shows the various water resources to the Wilaya of Oran.

| Superficial Waters | Underground Waters | Non-Conventional Waters |
|---|---|---|
| - Transfer TAFNA<br>- Transfer MAO | 70 wells and boreholes spread over all municipalities | Stations from: Kahrama, Benisaf, Bousfer, The Dunes, Bredeah and MACTAA. |

### 3.3.5. The Mostaganem-Arzew-Oran (M.A.O) drinking water transfer system

#### 3.3.5.1. Presentation of the layout

The development of the Chéliff - Kerrada water production system called M.A.O provides 155 million m3/year of the drinking water supply through the Mostaganem-Arzew-Oran corridor, which is distributed as follows:

- 45 $Mm^3$ / year for the Wilaya of MOSTAGANEM.
- 110 $Mm^3$/year for the Wilaya of ORAN.

The main components of the transfer system are:

- Cheliff diversion dam
- Kerrada storage dam
- Water treatment plant of Sidi Hadjel
- Pumping station
- Discharge line between the pumping station and the treatment plant
- Conduct (reversible) between the pumping station and the Kerrada dam
- Adduction pipeline of the Mostaganem-Arzew-Oran corridor and reservoirs

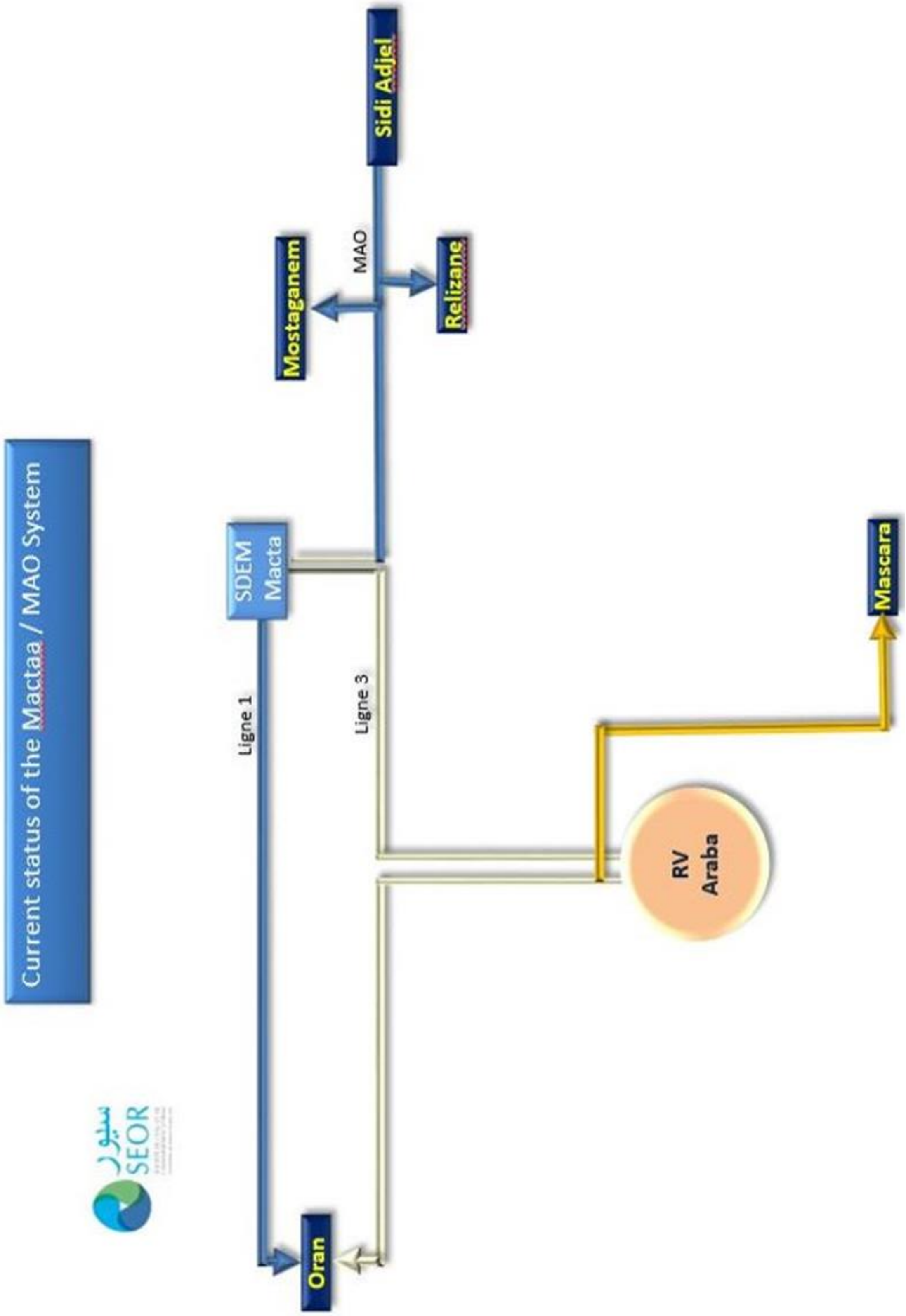



**Figure III.4**: Current status of the Mactaa/MAO system


**Figure III.5:** The MAO Water Supply system

As a whole, the system put in place is composed of four lots, namely the Cheliff dam with a capacity of 50 million $m^3$, a Cheliff-treatment station adduction, a mixed diversion dam on the Oued Cheliff and a water intake system. The second batch is the Kerrada dam with a capacity of 70 million $m^3$ and the Cheliff-Kerrada water supply of length 8,200 m, while the third batch is the Sidi Ladjel treatment plant with a capacity of 6.5 $m^3$/second and finally the supply corridor ‘Mostaganem-Arzew-Oran’ of length 90 km.

In addition to these two major western urban centres, its commissioning will also benefit the north-western part of the Wilaya of Mascara. The city of Mohammadia, long confronted with the water deficit, is currently experiencing an improvement in the distribution of drinking water estimated at more than 6,000 $m^3$/day coming from the Gargar dam (Relizane), through the corridor portion supplying the Wilaya of Oran.

The volume of water supplies nearly 98% of households and industrial zones totalling 2,178 km of networks.

This important project, started in 2005 and ended in 2009 after a few years of delay. The total cost of the project was estimated at $15 billion.

## 3.4. Study Area for the Hydropower Plant.

### 3.4.1. Location of the site

The site is located in the Daïra (department) of Bir el Djir and more precisely in the municipality of Belgaid. The hydropower plant will be located at a site near the village of Ain Franine on the supply pipeline to the village of Kristel as shown in figure III.6.


**Figure III.6:** Location of the hydropower plant

### 3.4.2. Overview of the Water Supply Conditions

Water flows from the upstream Belgaid reservoir (indicated by Rv-Belgaid in figure III.6) situated at an elevation of +256 m down to the Kristel reservoir (indicated by Rv-Kristel in figure III.6) situated at an elevation of 162m.

The lowest elevation of the pipeline is at + 50m

The total length of the corridor is 10,859m.

The downstream cast iron MAO water supply has a nominal diameter of 350mm It supplies the Kristel agglomeration and operates at only 10% of its full transport capacity, with a flow rate of 60m³/h and a water velocity of around 0.17m/s

With the available hydraulic gradient it can convey a maximum flow exceeding 745m³/h with a velocity approaching 2 m/s and with minimum pressure losses of the order of 1.26 m/km. in order to avoid overflowing a valve is fitted at arrival at Rv Kristel reservoir, knowing that the upstream flow rate does not exceed 60 m³/h at peak conditions.

### 3.4.3. Initial Data

The following data provided by SEOR is used in dimensioning of the proposed hydropower plant:

- Elevation difference between Belgaid reservoir and Kristel Reservoir : 94m.
- Current maximum flow rate: 60 $m^3$/h
- Maximum admissible flow rate: 745$m^3$/h.
- Nature and diameter of the pipe: Cast iron DN=350mm.
- System operating rate: 12%.

## 3.5. Methodology

Developing a small hydropower site is not a simple task. There are many aspects which have to be taken into consideration, covering many disciplines. The essential parts of a technical hydropower design system include the penstock, valve, nozzle, turbine and the generator (Induction motor).

When installing a hydro-turbine at any other point in a water supply line, the pressure head could be removed from the system without causing pressure below its minimum value and the excess energy will be converted into useful electrical energy.

In the present study hydraulic data was provided by the Oran water board (SEOR) and by using the EPANET hydraulic software, the Piezometric profile of the hydraulic pipeline is plotted. Using different simulations, variables used in the calculations may derived in order to optimise the hydropower production.

At each node, the head higher than or equal to a minimum pressure $P_{min}$, is estimated. Such an optimum head is usually imposed by regulators to guarantee a service quality to the population.

Data needed in the present study is:

- Network geometry,
- Minimum pressures to be assured at every node,
- Available consumption data (discharge distributed along the water supply line).

Using the COVADIS software topography points, method interpolation call it the Triangulation with Linear Interpolation Method is used to plot different triangles between each topography point and each triangle. Automatically will give you the elevation at that point.

Triangles can have different sizes. At every vertex of the triangle, a value of the elevation is attributed. These point values are obtained by interpolating the known values at points (x, y). Using this method the pipeline profile may plotted and the elevation at any point in the pipeline is automatically obtained.

The water Pelton turbine required in this area is designed and cost estimates are obtained of the major electromechanical components of the designed power plant, namely: turbine, generator, control and protection equipment and transformer

### 3.5.1. Interpolation Method

Spatial interpolation can be classified in accordance with their basic hypotheses and mathematical nature such as: geometric method, statistical method, geostatistical method, stochastic simulation method, physical model simulation method and combined method.

The application areas, special algorithm, advantages and disadvantages of each interpolation method are introduced and compared in many studies. The comparison shows that there is no absolute optimal spatial interpolation method and there is only a relatively optimal interpolation method for each special situation. Hence, the best spatial interpolation method should be selected in accordance with the qualitative analysis of the data, exploratory spatial data analysis and repeated experiments.

Eleven different interpolation methods may be cited:

1. The Inverse Distance to a Power method.
2. The Kriging Method.
3. The Minimum Curvature Method.
4. The Modified Shepard's Method.
5. The Natural Neighbour Method.
6. The Nearest Neighbour Method.
7. The Polynomial Regression Method.
8. The Radial Basis Function Interpolation Method.
9. The Triangulation with Linear Interpolation Method.
10. The Moving Average Method.
11. The Data Metrics Methods.

In the present study the Triangulation with Linear Interpolation Method is used.

**3.5.1.1. The Triangulation with Linear Interpolation Method:** This algorithm creates triangles by drawing lines between data points. The original points are connected in such a way that no triangle edges are intersected by other triangles. The result is a patchwork of triangular faces over the extent of the grid. This method is an exact interpolator. Each triangle defines a plane over the grid nodes lying within the triangle, with the tilt and elevation of the triangle determined by the three original data points defining the triangle. All grid nodes within a given triangle are defined by the triangular surface. Because the original data are used to define the triangles, the data are honored very closely. The Triangulation with Linear Interpolation technique works best when data are evenly distributed over the grid area. Data sets containing sparse areas result in distinct triangular facets on the map.

- **The Triangulated Irregular Network (TIN mode)**

The TIN methodology is a triangle-based system of Digital Terrain Model (DTM). The TIN method has been developed over the past several years by a group at Simon Fraser University (SFU) at Burnaby, British Columbia, under Professor Thomas K. Peucker's supervision [51].

TIN mode is based on the triangular terrain distribution. We are just concerned about triangulation. Triangles can have different sizes. At every vertex of the triangles a value of the elevation is attributed. These point values are obtained by interpolating the known values at points (x, y). Triangulation has been used for NTMs since the 1970s.

The Digital Elevation Model (DEM) represents the terrain in the form of a grid, whose cells are squares. This representation is carried out by a grid which is projected or draped over a part of the ground, after assigning values to any point located at an intersection of the grid.

A file containing regularly distributed points on a grid which would have been wedged virtually on a part of the ground. Each point located at an intersection of the grid is indicated by an altitude: that of its counterpart on the ground.

DTMs are based on a finite number of measured values, from which the other values are interpolated.

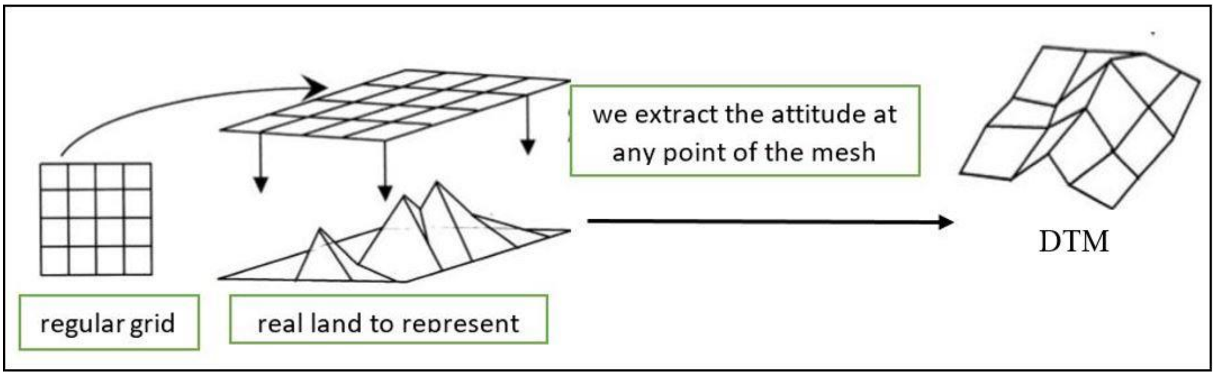



**Figure III.7:** Principle of DTMs.

The advantage of this mode is that you can represent any natural parameter; not only altitude, but also temperature, air pressure or hypsometry.

## 3.6. Topographic survey

Figure III.8 shows a high resolution image obtained using global mapping. This image shows contour lines passing through the present study area where both high altitudes and high slopes are indicated.

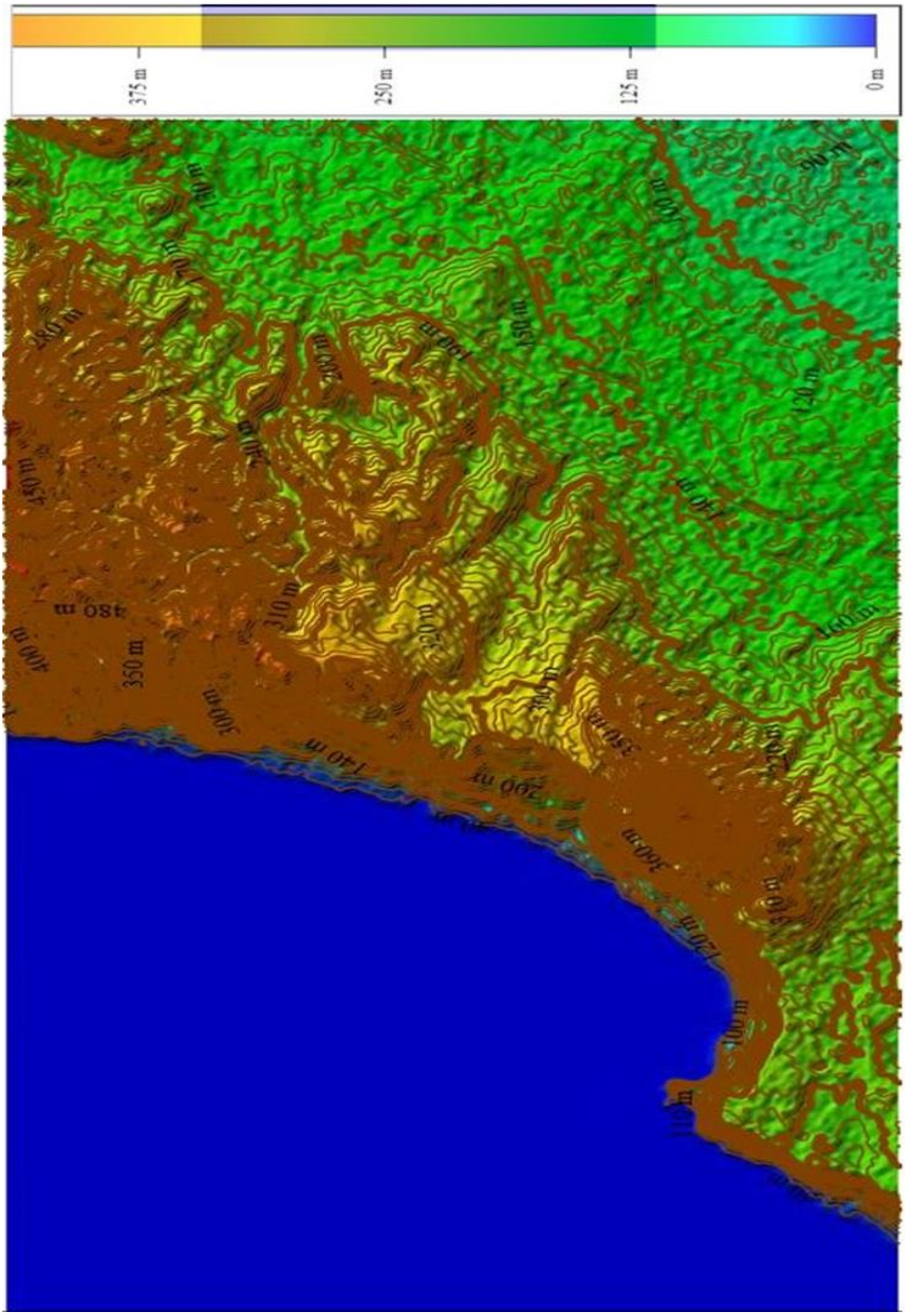



**Figure III.8:** Elevation contour lines of the present case study

## 3.7. Electrical Equipment

3.7.1. Control systems and electrical equipment

Turbine design and selection are based on the premise that operating conditions will be within the turbine's capacity in terms of flow and head. It will be necessary to regulate the conditions using devices such as gates, guide vanes, nozzles and valves if one of the design parameters changes. Small hydropower schemes often make use of automated control systems which have three significant advantages in that they can decrease maintenance costs, increase reliability and increase turbine efficiency (ESHA, 2004).

Various other electrical components are necessary, including a plant service transformer, backup power supply, sensors for the measurement of head and tail-water levels and an outdoor substation (ESHA, 2004). Transmission lines transfer the generated power from the plant to where the demand for electricity exists. If it is possible to connect to the grid at a location very close to the transmission lines, then this will be a minor consideration. If, however, the site is more remote, the significance of transmission lines can greatly increase. The cost of transmission lines varies with distance, terrain and voltage requirements.

### 3.7.2. Generator

The generator transforms mechanical energy into electrical energy using an excitation system. The types of generators and classification depend on the required runner speed and power station characteristics. Generator are classified as follows:

- Horizontal and vertical hydro generators: these are classified by their axis locations. Usually, large and medium-sized units adopt a vertical layout; medium and small-capacity units adopt horizontal layouts.
- Brushless excitation generator and excitation with brush generator.
- Synchronous generators: they are equipped with a DC electric or permanent magnet excitation system associated with a voltage regulator that controls output voltage before the generator is connected to the grid. Synchronous generator excitation is independent of the grid so synchronous generators can produce power even without grid connection. Asynchronous generators are unable to regulate voltage output and run at a speed related to system frequency; if isolated from the grid they cannot produce power because their excitation current comes from the grid.

### 3.7.3. Alternator

The transformation of mechanical energy into energy is ensured by synchronous machines single-phase or three-phase.

A synchronous machine is an electrical machine that produces an electric current whose frequency is determined by the speed of rotation of the rotor: "generator" operation in two quadrants of the torque-speed plane. The alternator is a particular application of the synchronous machine, operating as a generator in a single quadrant of the torque-speed plane. Either absorbing an electric current whose frequency determines the rotational speed of the rotor: "motor" operation

Beyond a few kilowatts, synchronous machines are generally three-phase machines. The rotor, often called the "pole wheel", is powered by a DC power source or equipped with permanent magnets.

As part of the present project the synchronous machine is used for transforming the mechanical energy of a turbine into electrical energy. The electrical machine in three-phase alternator is used. The alternators are of the horizontal type when they are driven by gas or steam turbines or diesel engines, or of vertical type when generally used by the hydro-electric installations.

### 3.7.4. Rotational speed of the turbine-generator group

The rotational speed of a generator is related to both the constant frequency of the 50 Hz network. The synchronous generators will rotate at the following speeds according to their number of poles as shown in the table below.

| Number of pole pairs | n (rpm) |
|---|---|
| 1 | 3000 |
| 2 | 1500 |
| 3 | 1000 |
| 4 | 750 |
| 5 | 600 |
| 6 | 500 |

The rotational speeds of the asynchronous generators will be 1 to 2% higher than the values indicated, a slight over speed being necessary to create the magnetic field in the machine.

In practice:

• The maximum speed is limited to 1500 rpm (2 pairs of poles). To take into account the over speeding of the runaway which causes considerable mechanical stress beyond. For the values of runaway speeds. As a result, generators with 1 pair of poles are only rarely installed (speed of runaway 6000 rpm).

## 3.8. Feasibility study of a hydroelectric power plant

3.8.1. Financial considerations

Determining the feasibility of a retrofitted hydropower project requires analysing the monetary value of all the different components and works in terms of initial installation costs as well as maintenance and running costs and balancing these against potential incomes.

### 3.8.2. Types of Electromechanical Equipment

Electromechanical equipment is more considered to be the equipment and system required to develop the energy available in impound or flowing water to convert it into electrical energy, to control it and to transmit it to the power grid. The major electromechanical components of power plants ~~is~~ are: the turbine, generator, control and protection equipment and transformer. The major items in terms of cost are the turbine and the generator. The turbine could either be a conventional one or a pump as turbine.

### 3.8.3. Overview of existing estimating techniques to estimate the cost of EM equipment

Several mathematical correlations were proposed in the literature over the past years for the estimation of the electro-mechanical equipment costs, $C_{EM}$, most of them being dependent on power, P and net head, H, according to the following equation model:

$$C_{EM} = a \times P^b H^c \qquad (19)$$

Where a, b and c are coefficients statistically determined on the basis of the available database of small hydro power plants.

The electromechanical components include:

1. Turbine with governing system;
2. Generator with excitation system, switch gear, control and protection equipment;
3. Mechanical and electrical auxiliaries; and
4. Main transformer and switchyard equipment.

Most cost correlations used to estimate the cost of EM equipment in PHS that have been developed in the literature and are presented in Table III.2

**Table III.2** Cost correlations found in the literature with author reference

<table>
<tr><th colspan="4">Cost correction</th><th>Year</th><th>Rang of power (MW)</th><th>Author</th></tr>
<tr><td colspan="4">$C_{EM,\,£} = 9000P^{0.7}H^{-0.35}$</td><td>1979</td><td>P ≤5 MW</td><td>Gordon 1979 [52]</td></tr>
<tr><td colspan="4">$C_{EM,\,£} = 97.436P^{0.53}H^{-0.53}$</td><td>1979</td><td>-</td><td>Lasu 1979 [53]</td></tr>
<tr><td colspan="4">$C_{EM,\,£} = 9600P^{0.82}\,H^{-0.35}$</td><td>1984</td><td>-</td><td>Gulliver 1984 [54]</td></tr>
<tr><td colspan="4">$C_{EM,\,£/kW} = 31.500P^{0.25}H^{-0.75}$</td><td>1988</td><td>-</td><td>Whittington 1988 [55]</td></tr>
<tr><td colspan="4">$C_{EM,\,£} = 40{,}000P^{0.70}H^{-0.35}$</td><td>2000</td><td>-</td><td>Voros 2000 [56]</td></tr>
<tr><td colspan="4">$C_{EM,\,FRS} = 10^{3}(34.12+16.99P^{0.91}H^{-0.3})$</td><td>2000</td><td>-</td><td>Chenal 2000 [57]</td></tr>
<tr><td colspan="4">$C_{I.ATS} = 9600P^{0.82}H^{-0.3}$</td><td>2001</td><td>P<2 MW and H<15m</td><td>Doujak and Angerer 2001[58]</td></tr>
<tr><td colspan="4">$C_{EM,\,£} = 9600P^{0.82}H^{-0.35}$</td><td>2001</td><td>P≤10 MW</td><td>Papantonis [59]</td></tr>
<tr><td colspan="4">$C_{EM,\,£/kW} = 12.9P^{0.82}H^{-0.246}$</td><td>2003</td><td>-</td><td>Gordon 2003 [60]</td></tr>
<tr><td colspan="4">$C_{EM,\,£/kW} = 3{,}300P^{-0.122}H^{-0.107}$</td><td>2007</td><td>-</td><td>Kaldelis 2007 [61]</td></tr>
<tr><td colspan="4">$C_{EM,\,£/kW} = 63346P^{-0.1913}H^{-0.2171}$</td><td>2008</td><td>-</td><td>Singal and al [62]</td></tr>
<tr><td colspan="4">$C_{EM,\,£} = 12000P^{0.56}H^{-0.112}$</td><td>2008</td><td>-</td><td>Companies [63]</td></tr>
<tr><td colspan="4">$C_{EM,\,£/kW} = K_1\,P^{k}{}_2\,H^{k}{}_3$</td><td rowspan="5">2009</td><td rowspan="5">P≤2 MW</td><td rowspan="5">Ogayar 2009 [64]</td></tr>
<tr><td>Turbine</td><td>$K_1$</td><td>$K_2$</td><td>$K_3$</td></tr>
<tr><td>Pelton</td><td>17,693</td><td>-0.3644725</td><td>-0.281735</td></tr>
<tr><td>Francis</td><td>25698</td><td>-0.560135</td><td>-0.127243</td></tr>
<tr><td>Kaplan</td><td>33,236</td><td>-0.58338</td><td>-0.113901</td></tr>
<tr><td>Pelton</td><td colspan="3">$C(£) = 2600\,(P^{0.54})\,(£)$</td><td rowspan="3">2010</td><td rowspan="3">-</td><td rowspan="3">Aggidis [65]</td></tr>
<tr><td>Francis (£)</td><td>0.5≤Q<2.5 m³/s<br>$C=122{,}000(P/H^{0.5})^{0.07}$</td><td>2.5≤Q<10 m³/s<br>$C=223{,}000(P/H^{0.5})^{0.11}$</td><td>Q >10m³/s<br>$C=16{,}500(P/H^{0.5})^{0.52}$</td></tr>
<tr><td>Kaplan (£)</td><td>0.5≤Q≤5<br>$C= 3500\,(P^{0.68})$</td><td colspan="2">5≤q≤10 m³/s<br>$C=14000\,(P^{0.35})$</td></tr>
</table>

**3.8.4. Development of cost correlations to estimate the cost of electromechanical equipment**

The mathematical model used in the literature to estimate the cost of EM equipment in terms of identified parameters is selected which is is given by equation 19 above [4, 20]:

A best-fit analysis should be carried out for diverse cost to estimate these coefficients.

3.8.5. Cost Correlations Methodology

Using equation 19 and applying logarithms, the following expression is obtained:

$$log(C) = log(aP^b.H^c) = log(a) + b.log(P) + c.log(H) \quad (20)$$

Using the following variable changes:

$$Z = log(C)$$
$$X = log(P) \qquad (21)$$
$$Y = log(H)$$

The following expression is obtained:

$$Z = log(a) + bX + cY \quad (22)$$

Substituting data of cost, power and head of every plant whose data are known in the previous expression, the following set of equations is obtained:

$$Z_1 = log(a) + bX_1 + cY_1$$
$$Z_2 = log(a) + bX_2 + cY_2 \qquad (23)$$
$$Z_n = log(a) + bX_n + cY_n$$

Then a search of the plane $AX + BY + CZ + D = 0$ with the best fit to data (Xn, Yn, Zn) is carried out using multiple regression between the independent variables X, Y and Z:

$$AX + BY + CZ + D = 0 \qquad (24)$$

Constants a, b and c are obtained by comparing Equations (21) and (24) through the following expressions:

$$a = e^{-\frac{D}{C}} \qquad (25)$$

$$b = -\frac{A}{C} \qquad (26)$$

$$c = -\frac{B}{C} \qquad (27)$$

Therefore, the function of cost can be expressed as:

$$C = aP^b H^c$$

The constants a, b and c are determined by using enough data of costs depending on net head and power. Costs are dependent not only on head and power but on the typology of turbines as well.

## 3.9. Experimental Study

For the purpose of the present experimental study, it was first envisaged to design and build a custom test rig. However, due to financial and time constraints, it was decided to use a readymade test rig built by the company ARMFIELD and provided by the Hydraulics Department of The University of Sciences and Technology-Mohamed Boudiaf of Oran, Algeria.

In the present experimental study two types of turbines are tested in order to examine the differences in performance:

1. The Impulse Turbine
2. The Reaction Turbine

### 3.9.1. Impulse Turbine

#### 3.9.1.1 Description of the impulse turbine

The Impulse turbine consists of an inlet manifold, which supplies water to four jets which are equally spaced around the turbine runner. Each of the jets can be individually controlled using ball valves. The runner itself is mounted on a horizontal shaft with a clear acrylic splash guard to enable maximum visibility of the workings.

The unit incorporates a pressure sensor to measure the inlet condition of the water. This pressure can be accurately controlled using the software supplied with the service unit.

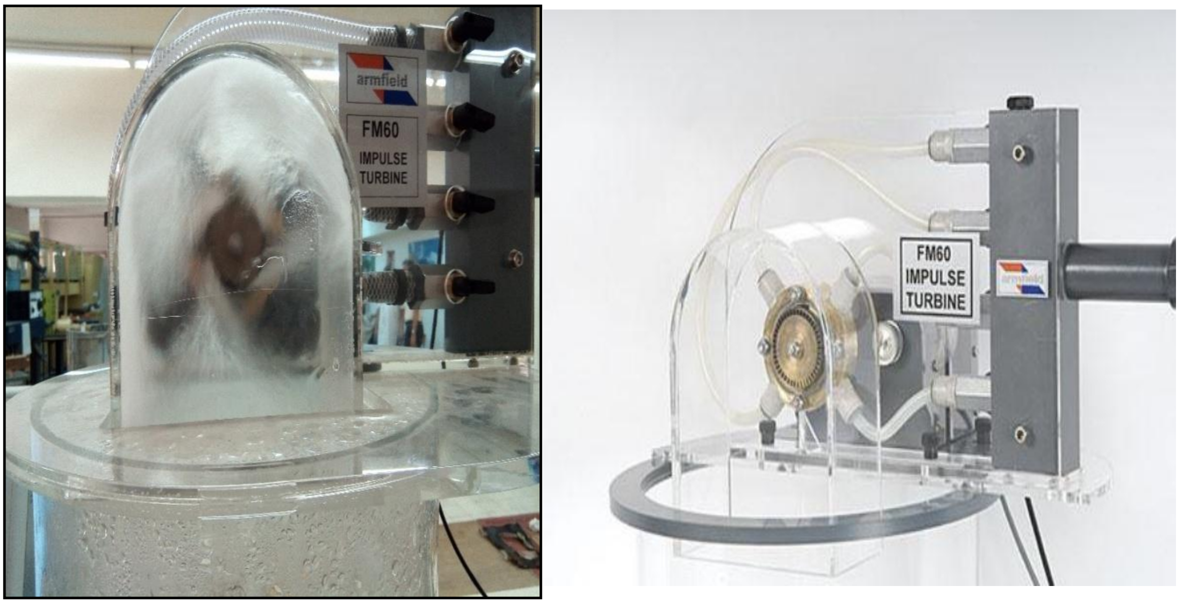



**Figure III.9:** Photographes of the Impulse Turbine tested.

**3.9.1.2. Overview**

The Impulse Turbine shown in figure III.9 was built the company ARMFIELD and designated with the code FM60. It consists of a clear acrylic housing and base plate which are designed to amount on the service unit and is held in place by two thumb nuts.

Water enters the unit via a union connector which is sealed with an 'O'-ring. It then flows through a manifold which routes it to four nozzles contained within a brass hub. The flow to each nozzle can be individually controlled using four valves. Flow exits the nozzles as a jet which impact onto the blades of a rotor. It then falls back into the main reservoir on the service unit.

The pressure of the fluid in the manifold is measured using an electronic sensor which connects to the socket on the base of the service unit.

In an impulse turbine (figure III.10), the kinetic energy of a jet leaving a high-pressure stationary nozzle is converted on impact with the turbine blades to rotational mechanical energy. As the water, exiting the jet is at atmospheric pressure, the force exerted on the rotor is entirely due to changes in the direction of the flow of water. The impulse turbine is therefore associated with considerable changes of kinetic energy but little change in pressure energy.

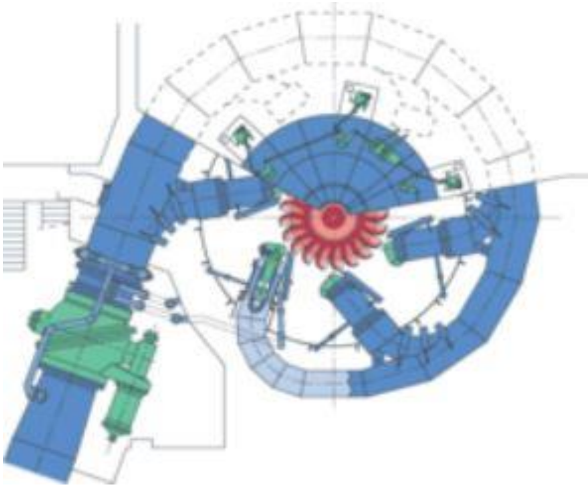


**Figure III.10:** Rotor and nozzle arrangement on impulse turbine.

In the case of the impulse turbine tested in this study, four independently controlled nozzles are installed around the rotor.

The operation characteristics of a turbine are often conveniently shown by plotting torque T, brake power, $P_b$, and turbine efficiency, E, against turbine rotational speed, n, for a series of volume flow rate, Q, as shown in (figure III.11). It is important to note that the efficiency reaches a maximum and then falls, whilst the torque falls constantly and linearly. In most cases a turbine is used to drive a generator in the production of electricity. The optimum condition for operation occurs when the maximum turbine efficiency coincides with the rotational speed of the generator. As the load on the generator increases then flow of water to the turbine must increase to maintain the required operating speed.

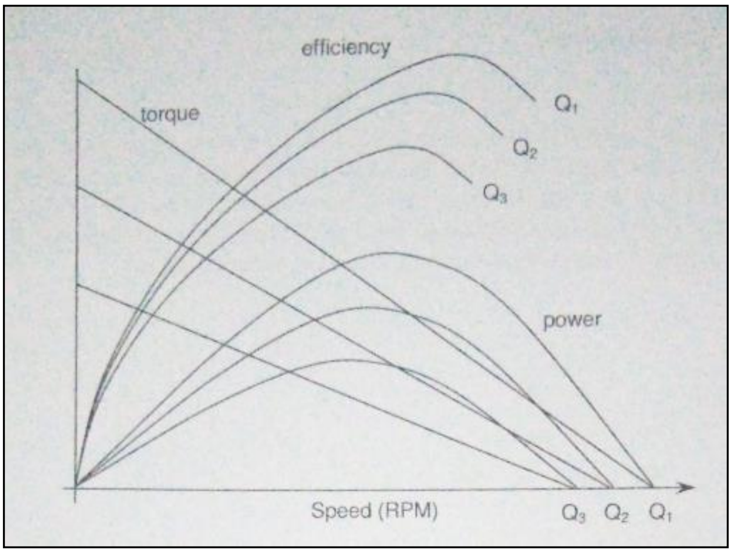



**Figure III.11:** Example characteristics of a turbine at different flow rates.

### 3.9.2. Reaction Turbine

#### 3.9.2.1. Description

The Reaction turbine consists of an inlet manifold, which supplies water to a central hub. Water exits the hub radially through two square orifices. The hub is connected to the manifold using a graphite face seal. The turbine is mounted on a horizontal shaft with a clear acrylic splash guard to enable maximum visibility of the workings.

The unit incorporates a pressure sensor to measure the inlet condition of the water. This pressure can be accurately controlled using the software supplied with the service unit

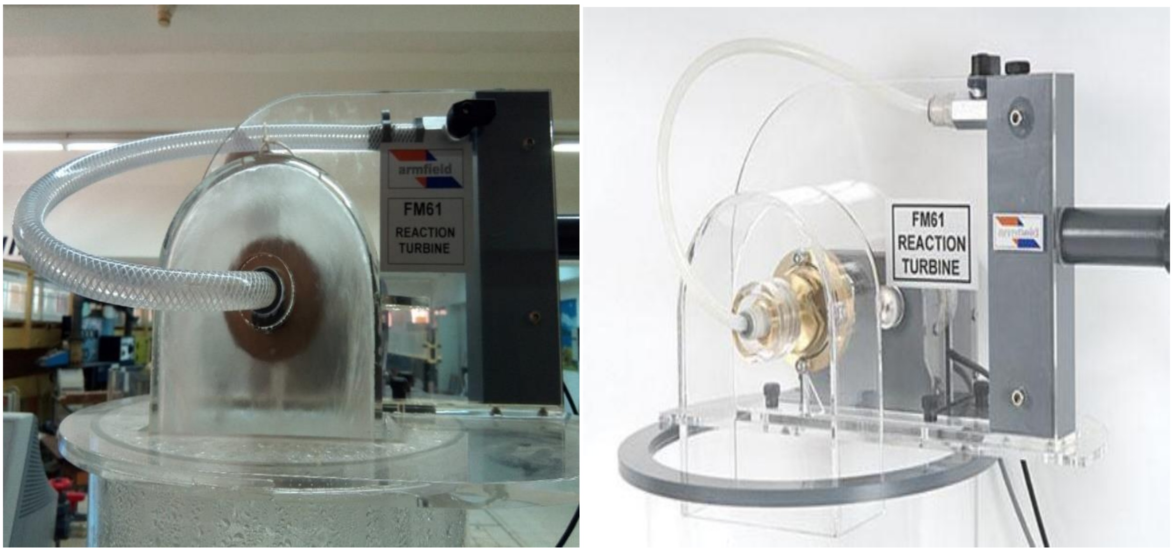



**Figure III.12:** Reaction Turbine parts.

#### 3.9.2.2. Overview

The tested reaction turbine, also built by ARMFIELD and named FM61, consists of a clear acrylic housing and base plate which are designed to amount on the service unit. It is held in place by two thumb nuts.

Water enters the unit via a union connector which is sealed with an 'O'-ring. It then flows through a manifold which routes it through a control valve to a brass hub. A graphite face seal connects the hub to a rotor where the water is forced out through two opposing nozzles. The reaction from this flow causes the rotor to move.

The pressure of the fluid in the manifold is measured using an electronic sensor which connects to the socket on the base of the service unit.

Figure III.13 show a schematic representation of the Reaction Turbine. Water is subject to a pressure drop as it flows through the rotor. The reaction turbine is therefore associated with considerable change in pressure energy but little change in kinetic energy and is sometimes called a pressure Turbine. In the case of the tested reaction turbine, water enters the rotor via a face seal and is discharged tangentially through two nozzles at the periphery of the rotor.

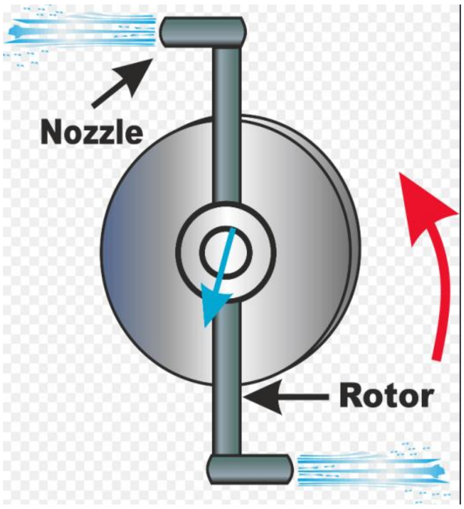



**Figure III.13:** Rotor and nozzle arrangement on reaction turbine

The operation characteristic of a turbine are often conveniently show by plotting torque T, brake power $P_b$, and turbine efficiency, E, against turbine rotational speed, n, for a series of volume flow rate, Q**.** It is important to note that the efficiency reaches a maximum and then falls, whilst the torque falls constantly and linearly.

### 3.9.3. Energy transfer in a turbine

Turbines are classified in two general categories: impulse and reaction. In both types, the fluid passes through a runner which deflects the flow. The momentum of the fluid in the tangential direction is changed and so a tangential force on the runner is produced. The runner therefore rotates and performs useful work, while the fluid leaves it with reduced energy. For any turbine the energy held by the fluid is initially in the form of pressure (i.e. a high level reservoir in a hydro-electric scheme).

➢ The impulse turbine has one or more fixed nozzles, in each of which this pressure is converted to the kinetic energy of an unconfined jet. The jets of fluid then impinge on the moving blades of the runner where they lose practically all their kinetic energy.

➢ The important feature of the impulse machine is that there is no change in static pressure across the runner.

- In a reaction turbine, the changes from pressure to kinetic energy takes place gradually as the fluid moves through the runner, and for this gradual change of pressure to be possible the runner must be completely enclosed and the passages in it entirely full of the working fluid.

**3.9.4. Presentation of the equipment (See figures III.14 and III.15)**

The impulse turbine tested (FM60) is a compact unit which is designed to be used in conjunction with the Turbine Service Unit (FM6X).

- The impulse turbine consists of an inlet manifold which supplies water to four nozzles, the jet from which act on the turbine rotor. The flow from each nozzle is independently controlled. The turbine shaft connects to a dynamometer supplied with the service unit allowing the power output to be measured.
- The reaction turbine consists of an inlet manifold which supplies water directly to the turbine rotor. The reaction turbine against the flow from two nozzles causes the rotor to spin. The turbine shaft connects to a dynamometer supplied with the service unit allowing the power output to be measured.

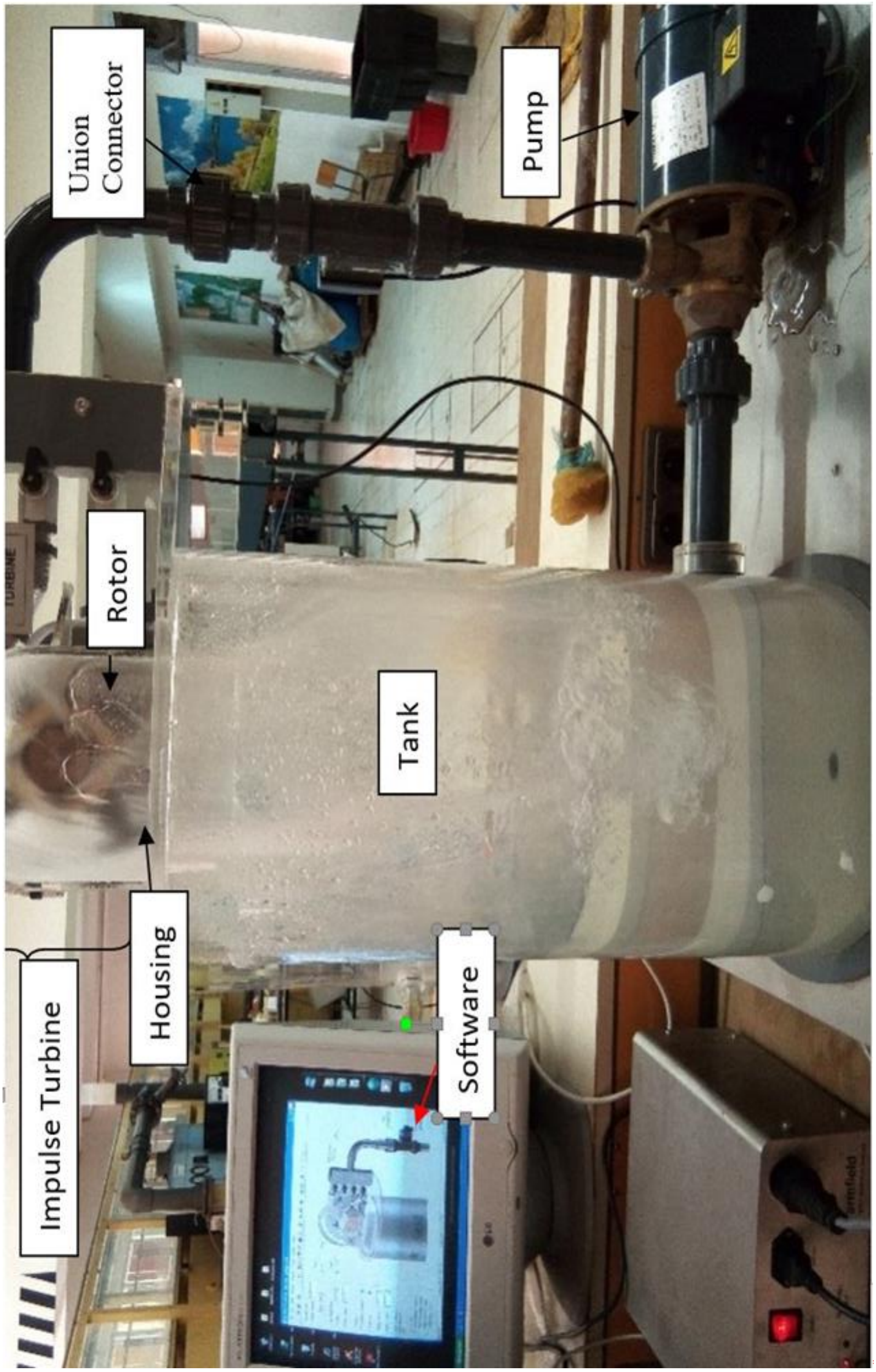



**Figure III.14:** Impulse Turbine installed on the Turbine Service Unit

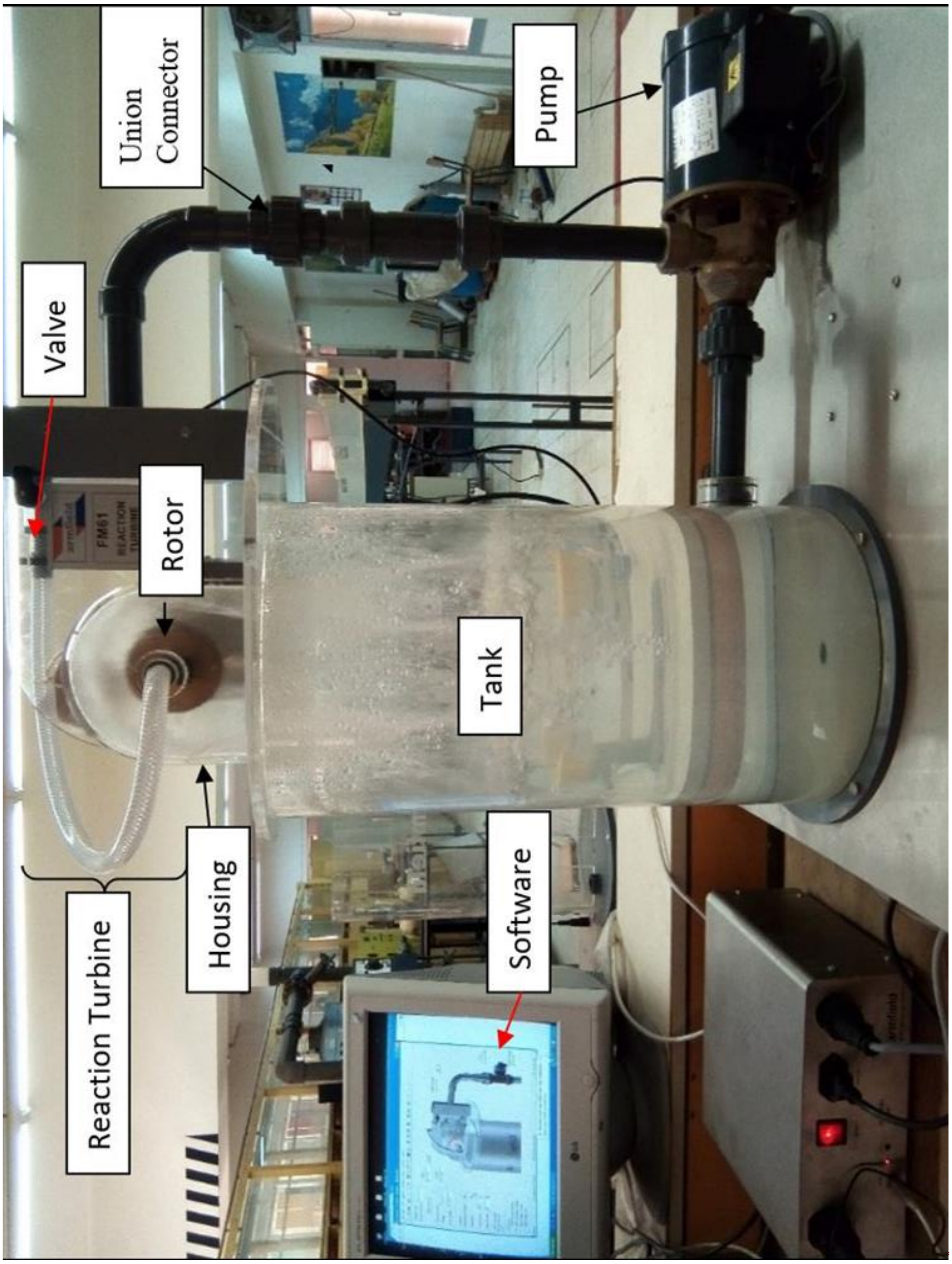



**Figure III.15:** Reaction Turbine installed on the Turbine Service Unit.

### 3.9.5. Operation

#### 3.9.5.1. Fitting the turbine accessory

Each turbine accessory may be fitted to the top plate of the reservoir. To fit the accessory:

- Loosen the two thumb nuts holding the dynamometer.
- Remove the two thumb nuts from the turbine fixings.
- Place the accessory on top of the reservoir, over the two studs. Replace the thumb nuts.
- Tighten the union fitting above the flow meter to join the pipe work. Ensure that the rubber 'O'-ring is in place.
- Place the drive belt over both pulleys.
- Slide the dynamometer module back to tension the belt. Just enough tension is required to take out slack in the belt. Do not over tighten.
- Tighten the dynamometer thumb nuts.
- Connect the pressure sensor to socket on the base plate.

Reverse this procedure to remove the turbine accessory. Unused accessories should be stored in the original packaging to avoid damage.

### 3.9.6. Specifications

3.9.6.1. Overall Dimensions

The geometrical dimensions of both water turbines tested are shown in the following table:

| | **Impulse turbine** | **Reaction turbine** |
|---|---|---|
| Height (mm) | 285 | 280 |
| Width (mm) | 560 | 560 |
| Depth (mm) | 130 | 180 |

#### 3.9.6.2. Electrical Supply

The unit must be powered using the Interface device shown in figures III.14 and III.15. The instruction manual supplied with the experimental rig shows details of the electrical supply requirements.

#### 3.9.6.3. Water Supply

The service unit is self- contained but requires filling with cold, clean water before use.

#### 3.9.6.4. Connection to Drain

The service unit is self- contained but should be drained for storage and cleaning. Drainage requires connection to cold water drain.

### 3.9.7. Routine Maintenance

To preserve the life and efficient operation of the equipment it is important that the equipment is properly maintained. Regular maintenance of the equipment is the responsibility of the end user and must be performed by qualified personnel who understand the operation of the equipment.

#### 3.9.7.1. General

The equipment should be disconnected from the electrical supply when not is use. Water should be drained from the equipment when not in use.

#### 3.9.7.2. Cleaning the Exterior

The exterior of the equipment should be periodically cleaned using a soft, dramp, non-lint cloth. A mild detergent may be used if required. Avoid use of solvent, abrasives and bleach that will not attack or craze the plastic components.

#### 3.9.7.3. Cleaning the housing

The housing may be periodically cleaned to remove debris and deposits on the walls, a mild descaler may be used if required. Always follow the manufacturer’s instructions when handing any cleaning/ descaling chemicals. Avoid the use of solvents, abrasives and bleach that will not attack or craze the plastic components.

## 3.10. Turbine Characteristics

### 3.10.1. Objective

To obtain the characteristic curves for a turbine operating at a range of fluid flow rates.

### 3.10.2. Theoretical Background

The basic terms used to define, and therefore measure turbine performance in relation to rotational speed, include:

i) Volume flow rate,

ii) Head,

iii) Torque,

iv) Power output and

v) Efficiency.

Each of these parameters is considered in turn.

i) Volume Flow Rate:

The volume flow rate of fluid through the turbine, O, is the volume passing through the system per unit time. The is expressed in litres per minutes (l/min) But converted to cubic metres per second ($m^3/s$) for further calculations.

ii) Head:

The term 'head' refers to the elevation of the free surface of water above or below a reference datum. In the case of a turbine we are interested in the head of the water entering the rotor, which of course has a direct effect on the characteristics of the unit.

The input head to the turbine, H, is the head used by the turbine in performing work.

The inlet pressure sensor on the FM60 measures a gauge pressure. As the outlet of the turbine is at atmospheric pressure, it can be assumed that the reading given by P is the pressure difference across the turbine.

Therefore, the inlet head is given by:

$$H = P/pg$$

iii) Power Output:

The brake drum on the FM6X is free to rotate but is restrained by a torque arm which is connected to a load cell. The force, F, measured by the load cell can be converted to a torque T:

$$T = F\ r$$

Where, r is the length of the torque arm. r = 0.045m.

The brake power $P_b$ produced by the turbine in creating a torque T on the brake at rotor speed n I is given by:

$$P_b = 2\pi\ nT/60$$

The hydraulic power of the fluid is defined by:

$$P_b = p\ g\ h\ Q$$

iv) Efficiency:

Therefore, an overall efficiency can be defined as:

$$E = \frac{\text{Power absorbed by brake}}{\text{'Useful' fluid power supplied}} = \frac{Pb}{Ph}.100\%$$

The best way to describe the operating characteristics of a turbine is through the use of characteristic curves. (Figure IV.5) this figure shows the interrelation of torque **T,** brake Power, $P_b$, turbine efficiency, E, and turbine rotational speed, n, for a given turbine running at constant fluid flow rate.

3.10.3. Equipment Set-Up

Ensure the turbine is installed and set-up as described in the operation section of the manual. Load the unit software and select FM60 as the option.

The control valve will remain open of the duration of the experiment and for impulse turbine be sure that all four nozzles valve should be open normal use. Control of volume flow rate will be performed by the pump speed control in the software.

3.10.4. Procedure for both turbine type

Check that the brake force indicated in the software is Zero. If not click the Zero button then confirm that the reading is Zero.

Click the 'pump on' button on the software. Set the pump speed to 100% for normal operation.

If desired, the built in controller can be used to automatically vary the pump speed to maintain a constant pressure (this can be useful when comparing results from the two different turbines).

Allow the turbine to reach a steady speed, and check that the flow measurement reading is stable. Use the IFD History window to view the sensor reading if necessary.

Choose a suitable increment for the speed, to give 10 to 15 reading. Click 'GO' to record a sample. Increase the brake setting to reduce the turbine speed by your chose increment, allow the readings to stabilize and click 'GO' to record a sample. Repeat until the turbine is stalled.

And for impulse turbine when the turbine was stalled we close one nozzle and we repeat same procedure but we reduce the number of nozzle until we finish with one nozzle.

## 3.11. Environmental

An analysis of the initial state of the site and its environment, including the natural resources and natural areas of agriculture, forestry, marine or recreation, affected by developments or works;

An analysis of the direct and indirect, temporary or permanent effects of the project on the environment and health, and in particular on fauna and flora, sites and landscapes, soil, water, air, climate, natural environments and balances, biological balances, the protection of cultural heritage and property and, where appropriate, the convenience of the neighbourhood (noise, vibration, odours, light emissions) or hygiene, safety and public health;

The reasons for which, in particular from the point of view of environmental concerns, among the envisaged parties, the project presented was selected;

The measures envisaged by the contracting authority or the petitioner to eliminate, reduce and, if possible, offset the damaging consequences of the project on the environment, as well as the estimate of the corresponding expenses;

An analysis of the methods used to evaluate the effects of the project on the environment, mentioning the possible difficulties of a technical or scientific nature encountered to establish this assessment.

### 3.11.1. Impact on the physical environment

#### 3.11.1.1. Water quality

(See physicochemical and bacteriological analysis bulletin) We refer here to the impact study which deals more specifically with the physicochemical quality of water.

However, it should be noted that the development itself does not have an impact on the quality of the water.

In the present study, a chlorination is done upstream, at the level of the tank Belgaid, and these waters are conveyed towards the tanks of Kristel where a control of the chlorination is carried out.

**Table III.3:** Analysis Bulletin.

LABORATOIRE ÉMETTEUR Cité administratif, siège USTO ORAN:
DATE DE DÉBUT DE L'ANALYSE: 8/05/2018.

| PARAMETRES | MÉTHODE | Décret n° 14-96 | RÉSULTATS | UNITÉS |
|---|---|---|---|---|
| **Paremetres In Situ** | | | | |
| (0) Chlore combiné in situ | PS-TL/ES 19-3 Méthode Spéctrométrique | | 0.04 ±29.36 | mg/L |
| (0) Chlore résiduel in situ | PS-TL/ES 19-2 Méthode Spéctrométrique | | 1.05 ±20.86 | mg/L |
| (0) Chlore total in situ | PS-TL/ES 19-1 Méthode Spéctrométrique | | 1.09 ±20.66 | mg/L |
| **Paramètres Organoleptiques** | | | | |
| (0) couleur | PS-TL/ES 05 Méthode Spectrométrique | | < 5.0 ±12.54 | mg/L Pt/Co |
| (0) Odeur | PS-TL/ES 20 Détermination d'Odeur | | 1 | Taux dilution |
| (0) Saveur | PS-TL/ES 21 Détermination de saveur | | 1 | Taux dilution |
| (0) Turbidité | NA 746:2006 (ISO 7027:99) | | 1.68 ±14.26 | NTU |
| **Paramètres physico-chimiques** | | | | |
| (0) Calcium | PS-TL/ES 32 Détermination du Calcium | 200 | 130.1 ±12.86 | mg/L |
| (0) Chlorures | PS-TL/ES 25 Par Potentiométrie | | 544.7 ±12.81 | mg/L |
| (0) Conductivité 20°C | NA 749:1989 | | 2070 ±12.19 | µS/cm |
| (0) Dureté Totale | PS-TL/ES 32 Détermination de la Dureté Totale | | 470.9 | mg/L |
| (0) pH à 20°C | NA 751:1990 | | 8.29 ±0.061 | UPH |
| (0) Residu sec | PS-TL/ES 31 Gravimétrie | 1500 | 1159 ±14.3 | mg/L |
| (0) Sulfates | PS-TL/ES 29 Methode Spectrophotometrique | | 167.72 ±12.39 | mg/L |
| (0) Titre Alcalimétrique Complet | PS-TL/ES 28 par Titrage | | 106.1 ±14.21 | mg/L |
| **Qualité chimique de pollution** | | | | |
| (0) Ammonium | ISO 7150-1:1984 | 0.5 | < 0.06 ±13.85 | mg/L |
| (0) Nitrates | PS-TL/ES 26 Méthode Spéctrométrique | 50 | 20.05 ±13.57 | mg/L |
| (0) Nitrites | NA 1657:1994 (ISO 6777:84) | 0.2 | < 0.04 ±13.67 | mg/L |
| (0) Ortho-Phosphate | PS-TL/ES 03 Méthode Spéctrométrique | | < 0.05 ±13.31 | mgPO₄/L |
| (0) Oxidabilité | PS-TL/ES 30 Détermination par Permanganométrie | 5 | 1.12 ±12.67 | mg/L |
| **Aluminium** | | | | |
| (0) Aluminium | PS-TL/ES 02 Détermination spectrométrique | 0.2 | < 0.05 ±12.31% | mg/L |
| (0) Mangnesium | PS-TL/ES 32 Détermination du Magnesium | | 35 | mg/L |
| **Qualité microbiologique** | | | | |
| (0) Bactéries coliformes | ISO 9308-1:2000 | 10.0 | 0 | c.f.u./100 mL |

### 3.11.1.2. Impact on groundwater

There are no groundwater effects since the supply pipe will be buried and will not be affected by the quality of the groundwater.

### 3.11.1.3. Impact on the stability of the grounds

The hydroelectric facility will be well anchored in its environment and there should no ground instability at the site.

At the site of the construction of the extension of the plant, bank protection measures will be taken by installing rip raps to prevent erosion of the bank.

After works, reforestation of the affected areas at the hydropower plant level, will also help to improve the stability of the bank.

#### 3.11.1.4. Impact on the landscape

The architecture of the buildings may be reflected in order to insert it as well as possible into the landscape.

The roof of the plant will be made with tiled plates.

The façades of the building will be plastered in the warmed smooth and stone tone.

Joinery will be in natural stained wood to blend with the exterior siding.

The ancillary works (office, maintenance room, sanitary control room) will be made of concrete

#### 3.11.1.5. Impact on existing developments

Upstream and downstream structures will not be considered in this study.

#### 3.11.1.6. Impact on the biological environment

- Terrestrial ecosystem

- **Flora**

The small surface area of the project and the mundane aspect of almost all the parcels give the site under study a rather low heritage interest.

In order to maintain all the biodiversity, the banks present upstream and downstream of the development will be maintained through rockfill and no longer a concrete veil.

In addition, local species will be planted on a band dominating these rip raps.

**Wild life**: There are no effects of the hydropower plant on the wild life.

# Chapter IV

# Results and discussion

## 4.1. Introduction

This chapter gives some statistical formulae used for the determination of the main dimensions of the Pelton turbine runner. It has to be remembered that the turbine design is an iterative process depending on miscellaneous criterion such as cavitation limits, rotational speed and specific speed, etc...

Statistical formulae used to estimate the project cost are also presented.

## 4.2. Calculation of the DTM for the study region using COVADIS software.

**Figure IV.1** shows how the triangulation with linear interpolation method works using COVADIS software.

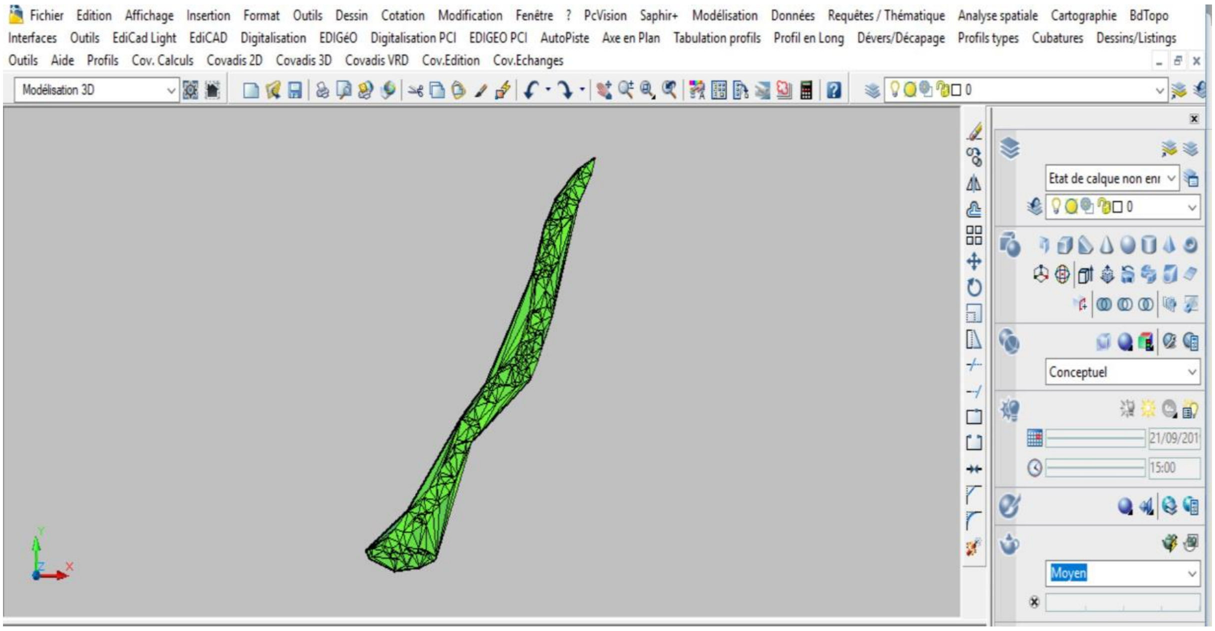


**Figure IV.1:** DTM of the present study region obtained using COVADIS software.

After calculating the DTM for the region studied, a plot of the pipeline above the DTM may be obtained. Table IV.1 shows the added value of the Z coordinate for the entire pipeline.  to be able to draw a good profile in length which makes it possible to have the technical problems that can you facing since you need to start realizing and to estimate the project cost

**Table IV.1:** Digital Terrain Model (DTM) results obtained for the region under study

| N° | Topographic point | X | Y | Z |
|---|---|---|---|---|
| 1 | P.1 | 727594.84 | 3966495.38 | 164.200 |
| 2 | P.10 | 727081.70 | 3965987.15 | 95.500 |
| 3 | P.100 | 725925.62 | 3963178.86 | 68.400 |
| 4 | P.11 | 726991.42 | 3965921.81 | 84.300 |
| 5 | P.12 | 726965.47 | 3965921.29 | 76.300 |
| 6 | P.13 | 727065.52 | 3965806.23 | 100.800 |
| 7 | P.139 | 725259.76 | 3962567.34 | 26.700 |
| 8 | P.14 | 727020.55 | 3965806.99 | 94.200 |
| 9 | P.140 | 725247.94 | 3962509.21 | 26.800 |
| 10 | P.15 | 726984.72 | 3965810.40 | 86.900 |
| 11 | P.16 | 726915.33 | 3965755.13 | 51.200 |
| 12 | P.17 | 727011.44 | 3965708.92 | 84.600 |
| 13 | P.18 | 727255.23 | 3965748.21 | 170.900 |
| 14 | P.19 | 727229.91 | 3965705.41 | 173.700 |
| 15 | P.2 | 727410.93 | 3966357.80 | 128.000 |
| 16 | P.20 | 726765.85 | 3965767.31 | 39.300 |
| 17 | P.21 | 726752.68 | 3965734.86 | 42.100 |
| 18 | P.22 | 726801.42 | 3965738.26 | 45.200 |
| 19 | P.23 | 726796.91 | 3965647.57 | 55.500 |
| 20 | P.24 | 726852.85 | 3965665.55 | 60.400 |
| 21 | P.25 | 726931.42 | 3965630.16 | 76.200 |
| 22 | P.26 | 726946.08 | 3965612.79 | 80.500 |
| 23 | P.27 | 727018.29 | 3965547.82 | 107.600 |
| 24 | P.28 | 727101.14 | 3965503.36 | 143.500 |
| 25 | P.29 | 727141.46 | 3965509.74 | 161.600 |
| 26 | P.3 | 727527.96 | 3966216.58 | 171.500 |
| 27 | P.30 | 726889.10 | 3965458.35 | 66.300 |
| 28 | P.31 | 726661.62 | 3965518.86 | 29.200 |
| 29 | P.32 | 726680.35 | 3965493.58 | 27.600 |
| 30 | P.33 | 726706.66 | 3965457.80 | 28.500 |
| 31 | P.34 | 726718.99 | 3965430.32 | 31.000 |
| 32 | P.35 | 726665.20 | 3965434.65 | 28.500 |
| 33 | P.36 | 726610.58 | 3965431.59 | 26.200 |
| 34 | P.37 | 726825.26 | 3965354.41 | 54.600 |
| 35 | P.38 | 726643.93 | 3965357.25 | 40.700 |

**Table IV.1:** Digital Terrain Model (DTM) results obtained for the region under study (continued)

| N° | Topographic point | X | Y | Z |
|---|---|---|---|---|
| 36 | P.39 | 726554.84 | 3965349.28 | 30.600 |
| 37 | P.4 | 727285.17 | 3966309.27 | 105.500 |
| 38 | P.40 | 726912.13 | 3965308.89 | 95.700 |
| 39 | P.41 | 726893.17 | 3965310.91 | 85.400 |
| 40 | P.42 | 726649.89 | 3965264.20 | 54.100 |
| 41 | P.43 | 726682.24 | 3965137.54 | 72.000 |
| 42 | P.44 | 726641.63 | 3965117.85 | 66.900 |
| 43 | P.45 | 726687.35 | 3965085.60 | 77.600 |
| 44 | P.46 | 726487.06 | 3965100.48 | 21.800 |
| 45 | P.47 | 726757.80 | 3965056.78 | 81.900 |
| 46 | P.48 | 726614.26 | 3965015.53 | 35.200 |
| 47 | P.49 | 726580.22 | 3965017.18 | 33.700 |
| 48 | P.5 | 727320.45 | 3966253.26 | 121.900 |
| 49 | P.50 | 726545.27 | 3964935.88 | 50.000 |
| 50 | P.51 | 726498.78 | 3964622.17 | 78.000 |
| 51 | P.51 | 726635.69 | 3964870.97 | 89.000 |
| 52 | P.52 | 726549.66 | 3964605.13 | 90.000 |
| 53 | P.52 | 726753.83 | 3964850.29 | 124.600 |
| 54 | P.53 | 726639.43 | 3964586.05 | 115.600 |
| 55 | P.53 | 726840.75 | 3964767.91 | 156.200 |
| 56 | P.54 | 726689.40 | 3964596.88 | 126.100 |
| 57 | P.54 | 726686.66 | 3964677.46 | 119.600 |
| 58 | P.55 | 726458.62 | 3964534.18 | 78.600 |
| 59 | P.55 | 726723.78 | 3964641.00 | 130.400 |
| 60 | P.56 | 726411.00 | 3964529.52 | 68.700 |
| 61 | P.56 | 726556.44 | 3964697.28 | 86.000 |
| 62 | P.57 | 726342.76 | 3964540.56 | 57.300 |
| 63 | P.57 | 726547.25 | 3964741.23 | 81.000 |
| 64 | P.58 | 726324.55 | 3964571.26 | 52.700 |
| 65 | P.58 | 726484.47 | 3964781.20 | 66.200 |
| 66 | P.59 | 726357.23 | 3964433.05 | 64.200 |
| 67 | P.59 | 726422.65 | 3964749.88 | 60.400 |
| 68 | P.6 | 727324.43 | 3966139.77 | 137.400 |
| 69 | P.60 | 726382.04 | 3964429.50 | 74.600 |
| 70 | P.61 | 726514.35 | 3964485.75 | 98.900 |

**Table IV.1:** Digital Terrain Model (DTM) results obtained for the region under study (continued)

| N° | Topographic point | X | Y | Z |
|---|---|---|---|---|
| 71 | P.62 | 726635.77 | 3964495.96 | 132.000 |
| 72 | P.63 | 726679.76 | 3964499.95 | 139.000 |
| 73 | P.64 | 726575.79 | 3964275.26 | 117.400 |
| 74 | P.65 | 726673.47 | 3964143.49 | 126.700 |
| 75 | P.66 | 726741.77 | 3964126.74 | 139.400 |
| 76 | P.67 | 726600.46 | 3963992.65 | 128.400 |
| 77 | P.68 | 726669.40 | 3963964.61 | 137.600 |
| 78 | P.69 | 726724.94 | 3963946.56 | 148.500 |
| 79 | P.7 | 727245.45 | 3966123.55 | 115.500 |
| 80 | P.70 | 726462.36 | 3963953.06 | 100.500 |
| 81 | P.71 | 726436.94 | 3963897.03 | 90.600 |
| 82 | P.72 | 726354.01 | 3963926.17 | 79.000 |
| 83 | P.73 | 726308.73 | 3963937.96 | 71.700 |
| 84 | P.74 | 726283.05 | 3963895.05 | 60.200 |
| 85 | P.75 | 726242.87 | 3963916.93 | 52.500 |
| 86 | P.76 | 726714.93 | 3963848.48 | 148.400 |
| 87 | P.77 | 726493.52 | 3963770.53 | 136.500 |
| 88 | P.78 | 726262.21 | 3963672.02 | 89.400 |
| 89 | P.78 | 726262.21 | 3963672.02 | 89.400 |
| 90 | P.79 | 726201.31 | 3963676.31 | 74.200 |
| 91 | P.79 | 726201.31 | 3963676.31 | 74.200 |
| 92 | P.8 | 727391.38 | 3965999.29 | 171.300 |
| 93 | P.80 | 726174.51 | 3963650.61 | 73.000 |
| 94 | P.81 | 726192.51 | 3963589.13 | 91.700 |
| 95 | P.82 | 726378.08 | 3963596.53 | 125.800 |
| 96 | P.9 | 727134.44 | 3966037.53 | 95.100 |
| 97 | P.95 | 726337.72 | 3963166.25 | 118.400 |
| 98 | P.96 | 726184.46 | 3963189.25 | 93.600 |
| 99 | P.97 | 726089.22 | 3963179.41 | 91.800 |
| 100 | P.98 | 726055.29 | 3963191.43 | 88.700 |

## 4.3. Profile map

The profile map obtained is shown in figure IV.2

## 4.4. Piezometric profile

A Piezometric profile is shown in figure IV.3 for the maximum flow rate of $Q_{max}$= 744.7m$^3$/h.

## 4.5. Calculation of linear friction of pipe line

Figure IV.4 shows the procedure for calculating the head loss for a circular pipe using the Colebrook-White formula

## 4.6. Estimation the net head

Table IV.2 shows the calculation of the net head available

## 4.7. Estimation of power output

Power output calculations are given in table IV.3

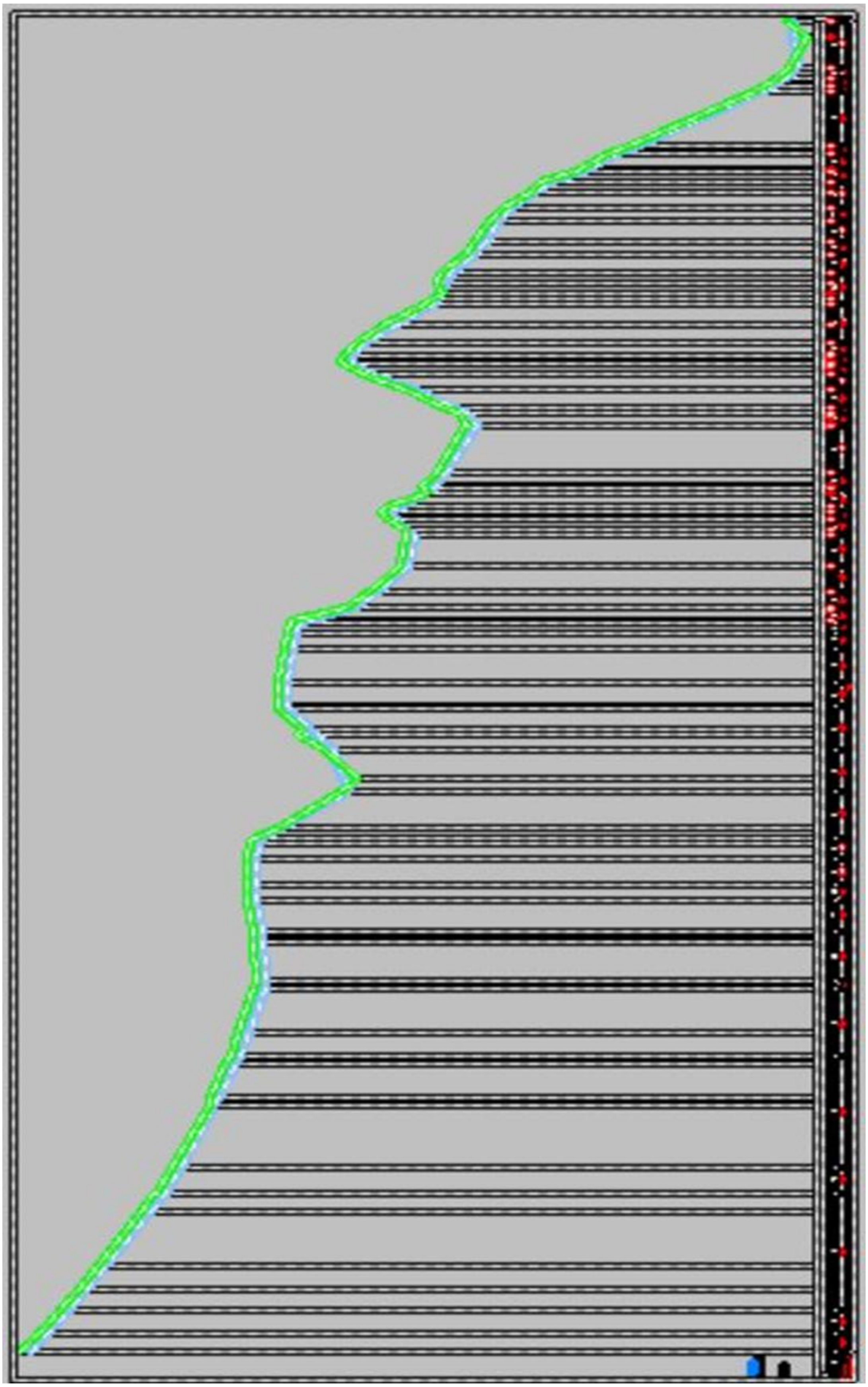


**Figure IV.2:** Profile map obtained using COVADIS software

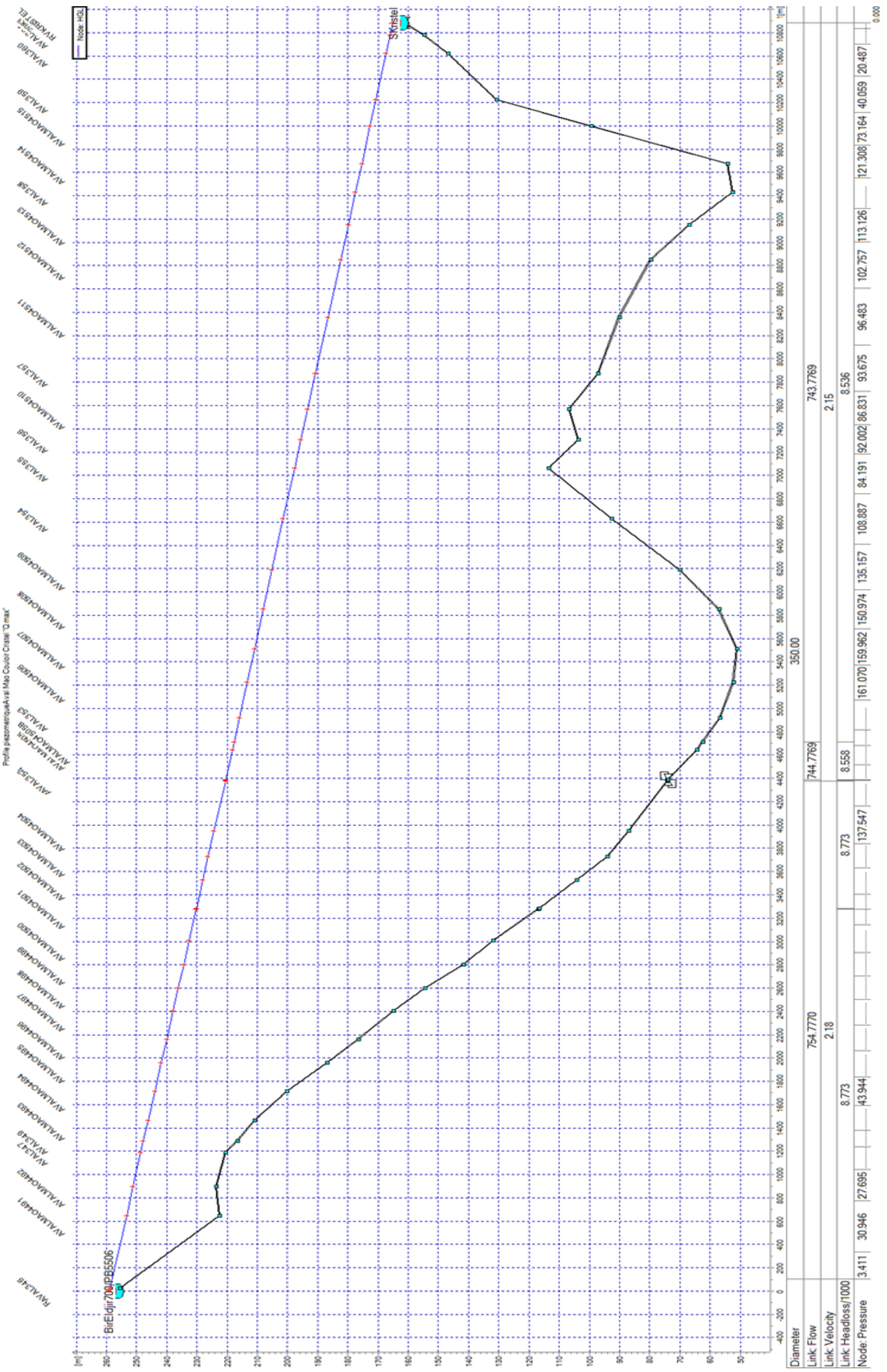
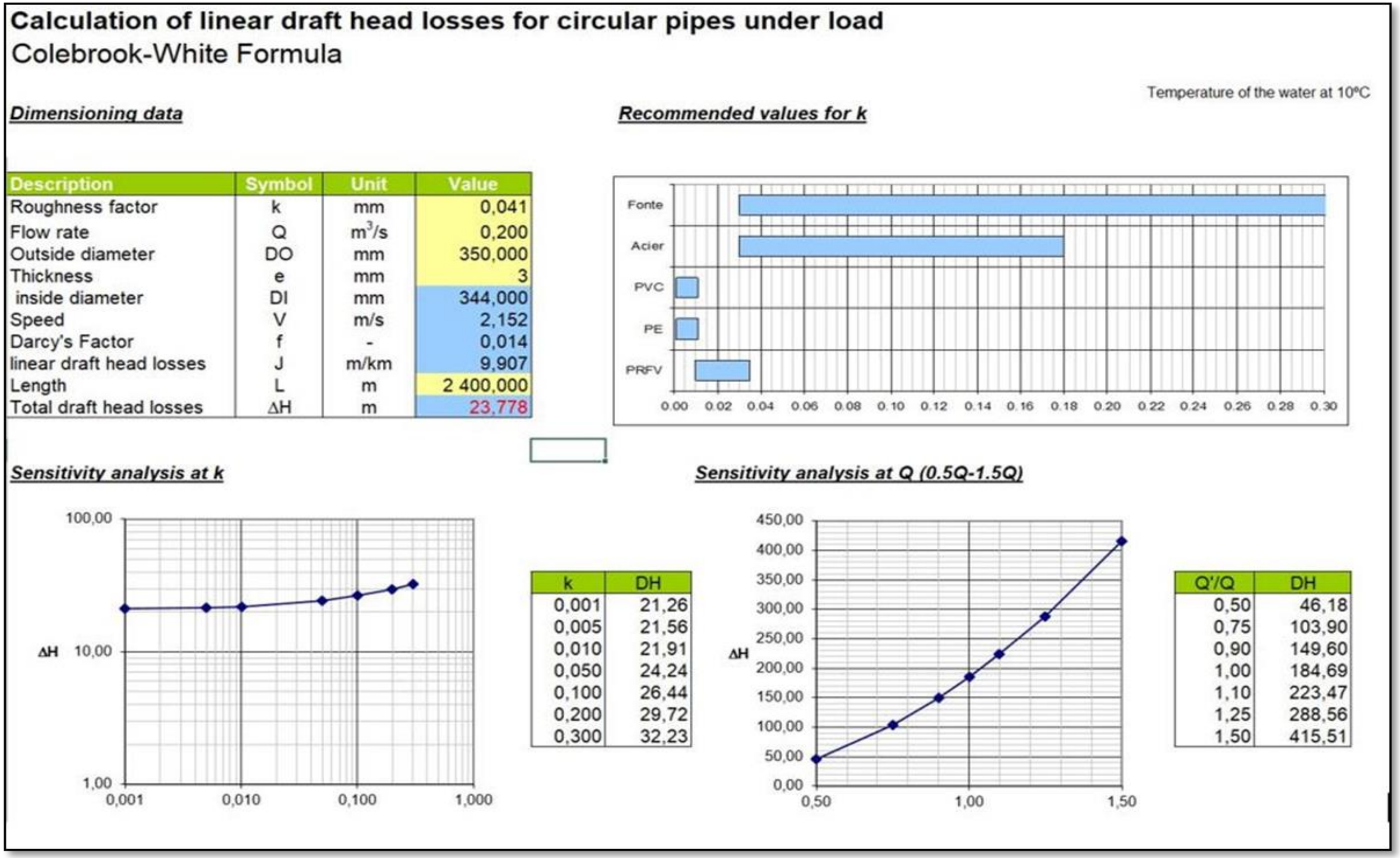



**Figure IV.3:** Piezometric profile for maximum flow rate Qmax = 744.7m³/h




**FigureIV.4:** Calculation of head losses

**Table IV.2**. Available energy

**Height available**

| | | |
|---|---|---|
| **Fluide** | Water 20ºC | |
| **Density** | 998 | kg/m3 |
| **Viscosity** | 0,001002 | Pa·s |
| **Δ Head** | 94 | m |

| Section | Pipe material | Roughness abs. [mm] | Length [m] | Q [m3/h] | Q [l/s] | Di [mm] | v [m/s] | ΔP [mm/m] | Loss in singular pieces % hm | ΔP Section [m] | Height available [m] |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 2.4 Km far from Rv-belgaide | Cast iron | 0,04 | 2 400 | **745** | 207 | 350 | 2,15 | 9,441 | 10% | 24,9 | |
| | | | | Manometric height available with draft head losses (m) | | | | | | | 69,1 |

| Re [-] | fs [-] | f1 [-] | f2 [-] | f3 [-] |
|---|---|---|---|---|
| 749 521 | 0,011 | 0,014 | 0,014 | 0,014 |

**Table IV.3:** Quantity of the electric energy produced

| Site | Height available (m) | Flow rate max (m3/h) | flow rate max (m3/s) | Gravity (m/s2) | hydraulic power (kW) | Efficiency of the turbine x generator x transformer | Electric power available (kW) | Availability of the system | Net energy obtained per year (kWh) |
|---|---|---|---|---|---|---|---|---|---|
| 2.4 Km far from the Rv-Belgaid | 69 | 744 | 0,21 | 9,81 | 140 | 97% | 136 | 100% | 1 188 678 |

**Hydraulic Power:** $\rho$*Q*g*H=1000*0,21*9,81*69,1=140[KW]

**Electric power :** P* 0,97= 136 [kW]

**Net Energy per Year:** P* 24*365*100= 1191521 [kWh]

## 4.8. Design

In order to design of the micro hydro power, there is a need to fix the position of the power house where the proposed power station is to be situated. The power house was proposed to be located in an area 2.4 km away from the Belgaid reservoir. The next task in the process was to calculate the head difference between the turbine and the available head of the reservoir. Using the GPS technology the head of the reservoir was calculated and was found to be 94m. The length of the penstock required is 2.4 km. The water flow rate is **Q=0,21m$^3$/s**

The output power of the power plant is given by the equation:

Output Power, P = Q×H × $\eta$ ×g (4, 1)

Where,

Q = Flow rate

H = Head

$\eta$ = Overall plant efficiency

g = Acceleration due to gravity

Thus we can the output power, P, for the entire system is equal to 135.23 kW.

For the entire system we take the efficiency $\eta$ = 95% as it includes the turbine efficiency, penstock efficiency and gear efficiency.

### 4.8.1. Penstock

The penstock is one of the most important part in a hydroelectric power station. It is a gate or intake structure that controls water flow, or an enclosed pipe that delivers water to hydro turbines and sewerage systems. It is a term that has been inherited from the earlier technology of mill ponds and watermills. The design of the penstock includes determining the diameter, thickness and the material to be used. And for our case the penstock is already existed to supply drinking water to the agglomeration. And it has own geometric characteristic. The cast iron penstock that has been selected has the following dimensions:

| | |
|---|---|
| Length | 2.4 Km |
| Thickness | 0.005m |
| Radius | 0.175m |

### 4.8.2. Nozzle

Nozzles are devices designed to control the flow velocity of the fluid passing through it. They are used in hydro power plants to produce impulse reaction in the turbine.

Velocity of water through the nozzle, $V_n$ is given by,

$$V_n = C_V \times \sqrt{2 \times g \times H_n} \qquad Where \quad C_v = 0.97 \qquad (4.2)$$

$$V_n = 35.715\, m/s$$

Thus the cross sectional area $A_n$ is given by,

$$A_n \times V_n = A_p \times V_p \qquad (4.3)$$

$$A_n = 0.005788m$$

Therefore the radius of the nozzle is given by,

$$r_n = \sqrt{\frac{A}{\pi}} = r_n = 0.0429\text{m} \quad (4.4)$$

**4.8.3. Turbine**

Turbines convert the energy from falling water into rotational shaft power. They can be classified according to their type of action as either impulse or reaction turbines.

The selection of the right type of turbine, for given site conditions, is one of the most important factors influencing efficiency and cost.

In the present study, the Pelton turbine was selected due to several important factors: Site characteristics, head and flow available. Figure IV.5 is used to select the water turbine type according to flow rate and head available.

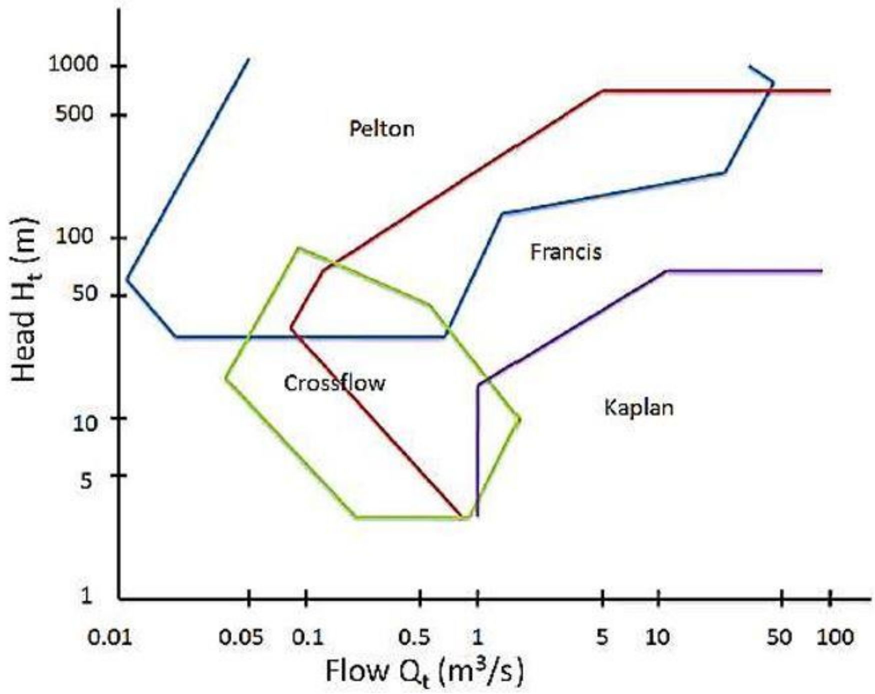



**Figure IV.5:** Guide to turbine type operating ranges

The maximum theoretical efficiency of the Pelton wheel becomes

$$\eta_{max} = E_{max}/(\text{kinetic energy of the jet}$$

$$= (v_1^2/4g)(1\text{-}k\cos\theta)/(v_1^2/2g)$$

$$\eta_{max} = (1\text{-}k\cos\theta)/2.$$

In the ideal case, assuming no friction, there is no reduction of the relative velocity over the vane and, therefore, k=1. Also, if θ = 180°, the maximum efficiency becomes 100 per cent. In practice, however, friction exists and the value of *k* is in the region of 0.8 to 0.85. Also, the vane angle is usually 165°, to avoid the interference between the incoming and oncoming jets. Thus, the ratio of the wheel velocity to the jet velocity becomes, in practice, somewhat smaller than the theoretical value. Figure IV.6 below shows the variation of the Pelton wheel efficiency with the speed ratio. It will be seen that, for the maximum efficiency, this ratio is about 0.46 [65].

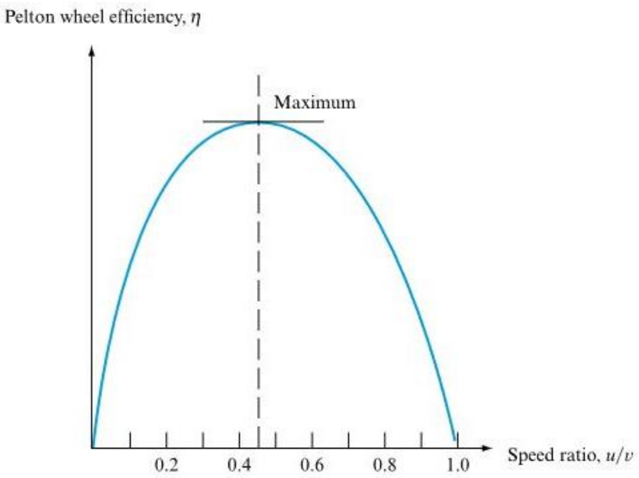
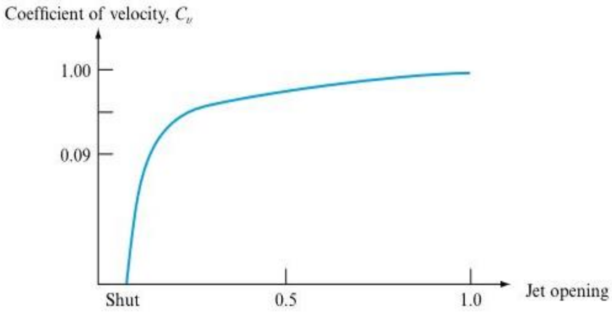



**Figure IV.6:** Pelton wheel efficiency a function of speed ratio [65].

Since a Pelton wheel is usually employed to drive an electrical generator, it is required that its speed of rotation is constant, regardless of the load. Thus, *u* must be constant, but for maximum efficiency it is also important that the speed ratio is maintained constant as well. Since the jet velocity depends only upon the total head *H*, which for a given installation is also constant, provided there is no reduction of head at the nozzle. This means that a throttling process using a valve in the penstock is not suitable, since a valve reduces flow by reducing head and dissipating energy. It follows, then, that any alteration of the load on the turbine must be accompanied by a corresponding alteration of the load on the turbine must be accompanied by a corresponding alteration of the water power, but with *u/v* remaining constant. Since $P = p.g.Q.H$, it follow that this requirement can only be achieved by alteration in *Q* such that *H* is unchanged.

$$\boldsymbol{Q = Av = AC_V}\sqrt{(2gH)}. \qquad (4.5)$$

Therefore, to vary *Q*, the area of the jet must be changed. This is achieved by means of the needle (spear) shown in figure IV.7, which does not alter *H*. Small changes in efficiency result because the nozzle loss represented by the value of $C_v$ will be changed and, also, jet windage as well as bearing losses will change slightly. Figure IV.7 below shows the typical variation of $C_v$ with the jet opening. [65]




**FigureIV.7:** Variation of $C_v$ with the jet opening.

The turbine is the main part of a hydropower plant. It is known as the heart of the hydropower plant. It is the part which delivers the machine to produce electrical energy. In the present study an impulse Pelton turbine is used. Normally Pelton wheels are used in high head areas. The design of the turbine includes diameter of turbine, speed of turbine and number of buckets.

4.8.4. Power Input to the turbine Pi

The calculate of power input is given by

$$P_i = Q \times h \times g \qquad (4.6)$$

$$P_i = 142.35kW$$

**4.8.5. Power output of turbine, Po.**

It is given by:

$$P_o = Q \times h \times g \times \eta \qquad (4.7)$$

$$P_o = 135.23kW$$

**4.8.6. Jet ratio of the turbine**

$D_T / d_n = 14 \qquad (4.8)$

Where:

$D_T$ = Diameter of the turbine (m)
$d_n$ = Diameter of the nozzle (m)

$$D_T = 1.201\ m$$

### 4.8.7. Velocity of the turbine

$$\mu = \emptyset * \sqrt{2.g.\mathrm{H}} \qquad (4.9)$$

Where,

φ = Speed ratio (0.46)

$u = 16.937\ m/s$

### 4.8.8. Speed of the turbine, $N_t$

$$N_T = \frac{u*60}{\pi*D_T}\ (rpm) \qquad (4.10)$$

$$N_T = \frac{16.94 * 60}{3.14 \times 1.20} = 269{,}74 = 270\ rpm$$

### 4.8.9. Width of the buckets, $W_b$

$$W_b = 5 \times d_n \qquad (4.11)$$

$$W_b = 5 \times 2 \times 0.0429 = 0.429\ m$$

### 4.8.10. Depth of buckets, $D_b$

$$D_b = 0.8 \times d_n \qquad (4.12)$$

$$D_b = 0.8 \times 0.0858 = 0.0686\ \mathrm{m}.$$

### 4.8.11. Number of buckets, n

Using the formula bellow to calculate the number of buckets

$$n = 15 + \frac{D_T}{2*d_n} \qquad (4.13)$$

$$n = 15 + \frac{1.201}{2 \times 0.0858} = 22$$

### 4.8.12. Specific speed, Ns

$$N_s = \frac{N_T \times P_o^{1/2}}{H^{5/4}} \qquad (4.14)$$

$$N_s = \frac{270 \times 185^{1/2}}{94^{5/4}} = 15.31\ rpm$$

As the value of $N_s$ is greater than 15, using the selection chart shown in figure IV.8, we can conclude that Pelton wheel can be selected as the turbine for the project.

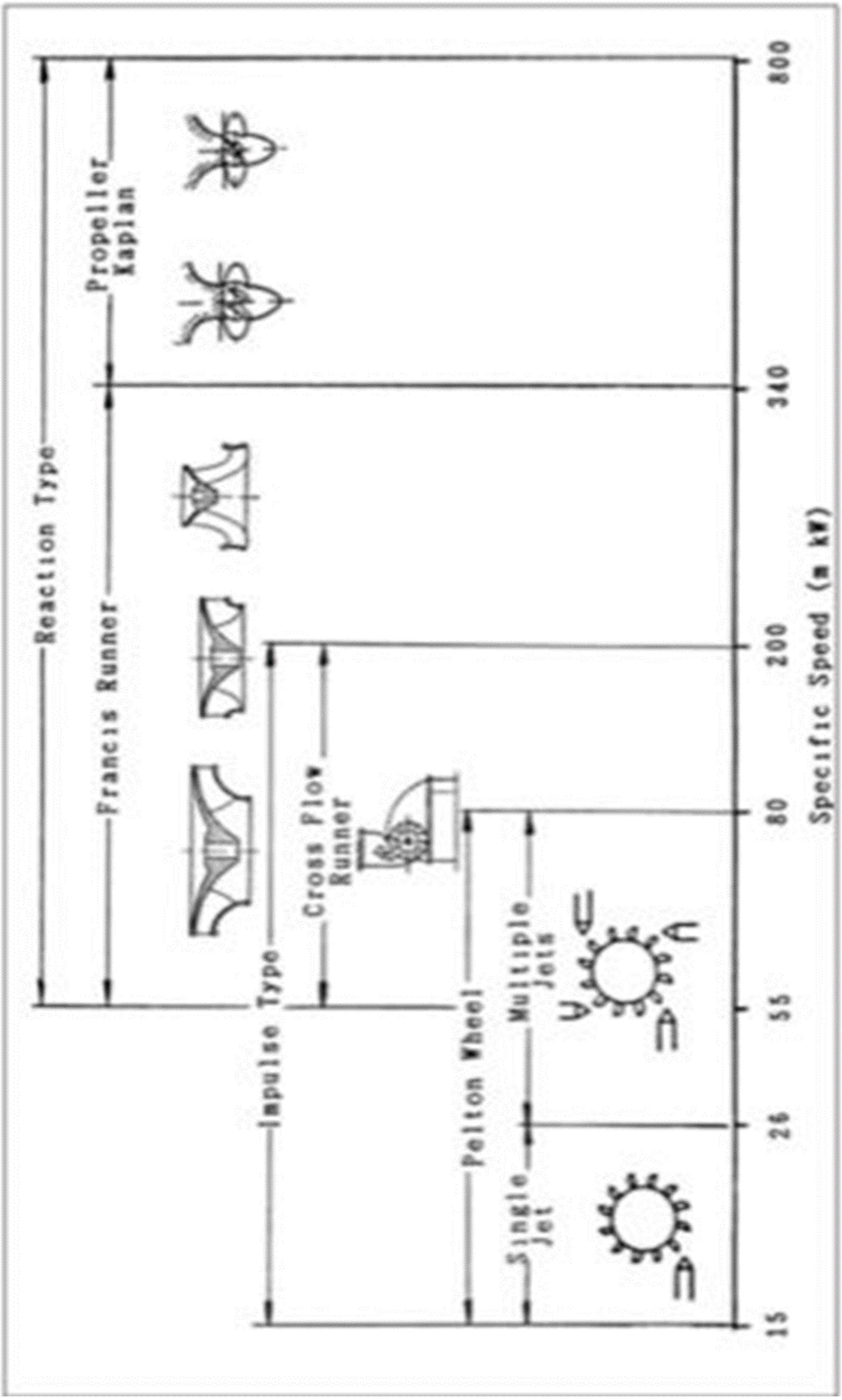



**Figure IV.8:** Specific speed, Vs, applicable to turbine type

**Table IV.4**: Dimensions of the Pelton wheel components

| Parameters | Dimension |
|---|---|
| Flow rate | 0.21 $m^3/s$ |
| Net Head | 69.1m |
| Velocity of water through the nozzle | 35.715 m/s |
| the radius of the nozzle | 0.042m |
| Power output of turbine Po | $135.23kW$ |
| Speed of the turbine | $270\ rpm$ |
| Width of the buckets | $0.42\ m$ |
| Number of buckets n | 22 |

## 4.9. Alternator

### 4.9.1. Apparent power of the alternator

The input power of the alternator corresponds to the mechanical power developed by the turbine which is of the order of 136 kW. The apparent power of the alternator is calculated as follows:

$$s = P\ /\ Cos(\varphi) \qquad (4.15)$$

With Cos(φ) = 0.8, we have S = 136 / 0.8 = 170 kW

### 4.9.2. Number of poles

The number of an alternator is imposed by the speed of the rotor and the frequency of the current to be produced.

Each time a pair of poles move in front of a conductor, the induced voltage thus describes a complete cycle. We deduce that the frequency is given by riding.

$$f = \frac{PN}{120} \qquad (4.16)$$

$f = \frac{P \times N}{120} \Rightarrow \quad P = \frac{f \times 120}{N} = \frac{50 \times 120}{270} = \quad 22$ P = 22 poles or p = p / 2 = 11 pole pairs

**Table IV.5** Summary of the alternator data

| Three-phase asynchronous generator with salient poles | |
|---|---|
| Power | 136 kW |
| Voltage | 3 (phase): 480 V |
| Frequency | 50 Hz |
| Power factor | 0.8 |
| Rated speed | 272 rpm |
| Overspeed (speed of runaway) | 1.8 X 270 rpm |
| Excitement | self-excited, self-regulating |

## 4.10. Cost estimate of the electromechanical components

The most recent research involved a study of 81 hydropower projects in 32 countries around the world in order to determine a trend relating electromechanical costs to power output of the project. The electromechanical costs include costs of turbines, valves, cooling and drainage systems, cranes, workshops, generators, transformers, control equipment and auxiliary systems. The following formula was generated in addition to a number of graphs and curves for the different turbine types [66]

### 4.10.1. Electromechanical equipment costs

Recently, Giovanna &al [67] proposed a new methodology to estimate the cost of electro-mechanical equipment; this methodology decomposes the cost of electro-mechanical equipment into three terms:

$$C_{EM} = a \times H_m^b + c \times Q_{l/s}^d + e \times P_{KW}^f + g \qquad (4.17)$$

Where a, b, c, d, e, f and g are correlation constants and depend on the type of turbine. The developed correlations to estimate the cost of Pelton, Kaplan and Francis turbines are presented in Table IV.6.

**Table IV.6:** Summary cost equations for electromechanical equipment developed by Giovanna

| Turbine | Equation used for calculating electromechanical equipment cost |
|---|---|
| Pelton | $C_{EM} = 1358677.67 \times H_m^{0.014} + 8489.85 \times Q_{l/s}^{0.515} + 3382.1 \times P_{KW}^{0.416} - 1479160.63$ |
| Francis | $C_{EM} = 190.37 \times H_m^{1.27963} + 1441610.56 \times Q_{l/s}^{0.03064} + 9.62402 \times P_{KW}^{1.28487} - 162157.28$ |
| Kaplan | $C_{EM} = 139318.16 \times H_m^{0.02156} + 0.06372 Q_{l/s}^{1.45636} + 155227.37 \times P_{kW}^{0.11053} - 302038.27$ |

**Table IV.7:** Hourly consumption according to SONALGAZ tariffs

| Unit Cost of kWh | Hours | Electric power output | Power 100% available | Cost |
|---|---|---|---|---|
| **DZ/kWh** | | kWh | kWh | DZD |
| **0,8533** | 01:00 | 136 | 136 | 116 DZD |
| **0,8533** | 02:00 | 136 | 136 | 116 DZD |
| **0,8533** | 03:00 | 136 | 136 | 116 DZD |
| **0,8533** | 04:00 | 136 | 136 | 116 DZD |
| **0,8533** | 05:00 | 136 | 136 | 116 DZD |
| **0,8533** | 06:00 | 136 | 136 | 116 DZD |
| **1,6147** | 07:00 | 136 | 136 | 220 DZD |
| **1,6147** | 08:00 | 136 | 136 | 220 DZD |
| **1,6147** | 09:00 | 136 | 136 | 220 DZD |
| **1,6147** | 10:00 | 136 | 136 | 220 DZD |
| **1,6147** | 11:00 | 136 | 136 | 220 DZD |
| **1,6147** | 12:00 | 136 | 136 | 220 DZD |
| **1,6147** | 13:00 | 136 | 136 | 220 DZD |
| **1,6147** | 14:00 | 136 | 136 | 220 DZD |
| **1,6147** | 15:00 | 136 | 136 | 220 DZD |
| **1,6147** | 16:00 | 136 | 136 | 220 DZD |
| **7,2668** | 17:00 | 136 | 136 | 988 DZD |
| **7,2668** | 18:00 | 136 | 136 | 988 DZD |
| **7,2668** | 19:00 | 136 | 136 | 988 DZD |
| **7,2668** | 20:00 | 136 | 136 | 988 DZD |
| **7,2668** | 21:00 | 136 | 136 | 988 DZD |
| **1,6147** | 22:00 | 136 | 136 | 220 DZD |
| **0,8533** | 23:00 | 136 | 136 | 116 DZD |
| **0,8533** | 00:00 | 136 | 136 | 116 DZD |
| | | | | |
| | DAY | | 3 264 | 8 285 DZD |
| | YEAR | | 1191360 KWH | 3 024 173 DZD |

### 4.10.2. Total investment cost

In the present study, Pelton turbine so by using the corresponding equation we find

$$C_{EM} = 1358677.67 \times H_m^{0.014} + 8489.85 \times Q_{l/s}^{0.515} + 3382.1 \times P_{KW}^{0.416} - 1479160.63 \quad (€)$$

$$C_{EM} = 1358677.67 \times 69.1_m^{0.014} + 8489.85 \times 210_{l/s}^{0.515} + 3382.1 \times 136_{KW}^{0.416} - 1479160.63$$

$$C_{EM}(€) = 121930.05\ €$$

**Table IV.8:** Investment Cost

| Cost with EURO (€) | Convert from € to DZD | Acquisition Cost [DA] |
|---|---|---|
| **121930.05 €** | **1 DZD = 0,0068965 EUR**<br>**1 EUR = 145 DZD**<br>Last updated: 2019-07-20 | **17679857,25 DZD** |

| | **Rush hours dial 2** | **Full hours (day) dial 3** | **hollow hours (night) dial 1** | | |
|---|---|---|---|---|---|
| | 17:00h-21:00h | 06:00h-17:00h<br>21:00h-22:30h | 22:30h-6:00h | | |
| **Tariff** | **E Active tip** | **E Active full / day** | **E Active night / hollow** | **E Active total** | **Annual amount** |
| | E1 | E2 | E3 | E | |
| Hourly cost DA / KWH | 7,27 | 1,61 | 0,85 | | |
| Energy KWH | 136 | 136 | 136 | | |
| Hourly rate | 5 | 11 | 8 | | |
| Annual power KWH | 248200 | 546040 | 397120 | 1191360 | |
| Annual purchase cost | 1804414 | 879124.4 | 337552 | | 3021090.4 |

Maximum sale price 95%: **2870035.88** [DA]

## 4.11. Economic study

**Table IV.9:** Overall cost of hydroelectric facility installation

| | **DESIGNATION** | **AMOUNT [DA]** |
|---|---|---|
| **1** | Amount of acquisition of the turbine | 17 679 857.25 |
| **2** | Freight charges 10% | 1 767 985.725 |
| **3** | Customs clearance fee 40% | 7 071 942.9 |
| **4** | On-site transportation costs | 100 000 |
| **5** | Operating and maintenance costs 3% | 530 395.717 |
| **6** | Cost of civil engineering | 5 400 000.00 |
| **7** | Cost hydraulic equipment, | 6 428 000.00 |
| | **General Amount Tax free** | **38 978 181.59** |
| | Taxes (TVA) 19 % | 7 405 854.5 |
| | **Total Amount** | **46 384 036.09** |

### 4.11.1. Depreciation of the installation

**Table IV.10:** Depreciation

| Charges and amortization | **AMOUNT (DZD)** |
|---|---|
| Amount of acquisition of the hydroelectric power station DA | **46 384 036.09** [Da] |
| Annual power recovered | 1191360.0 [KWH] |
| Annual cost of electricity purchase according SONELGAZ tariff | 3021090.4 [Da] |
| Sale price to SONELGAZ | **2870035.88** [Da] |
| Amortization (purchase price / selling price) year | 16 years |

## 4.12. Experimental study

In this section the characteristics of both the tested impulse turbine and the reaction turbine are presented.

### 4.12.1. Impulse Turbine

Tests are conducted by increasing the break setting in order to reduce the turbine speed by a chosen increment. Almost ten readings are obtained for each measured parameter: brake power, efficiency and power. For each pump speed, the flow rate is kept constant while varying the brake setting. Hence the effect of turbine speed may be highlighted. Characteristics are obtained for three different pump speeds for varying flow rate. The latter is varied using the four feeding nozzles mounted around the turbine.

**A. Characteristics of the Impulse turbine for a pump speed of 3400 rpm:**

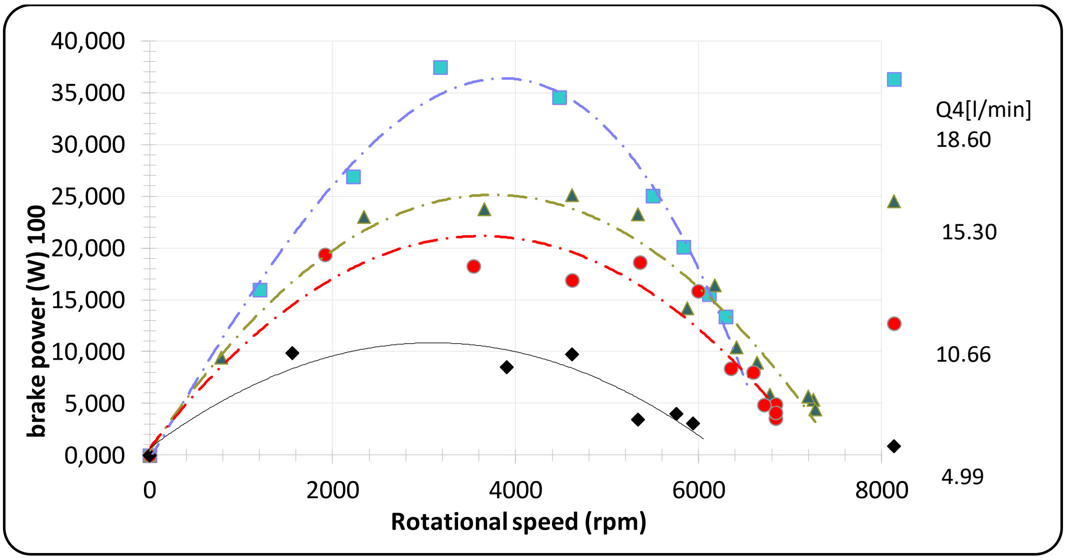



**Figure IV .9.** Brake power versus turbine speed for varying flow rate at a pump speed of 3400 rpm.

Figure IV.9 shows the relationship between brake power and turbine speed for varying flow rate and for a constant pump speed of 3400 rpm and for varying flow rate. As can be seen, for a constant flow rate, brake power increases with turbine speed till reaches a maximum value then decreases. Also brake power decreases with decreasing flow rate. Maximum brake power is reached for a turbine speed of around 3600 rpm for all flow rates.

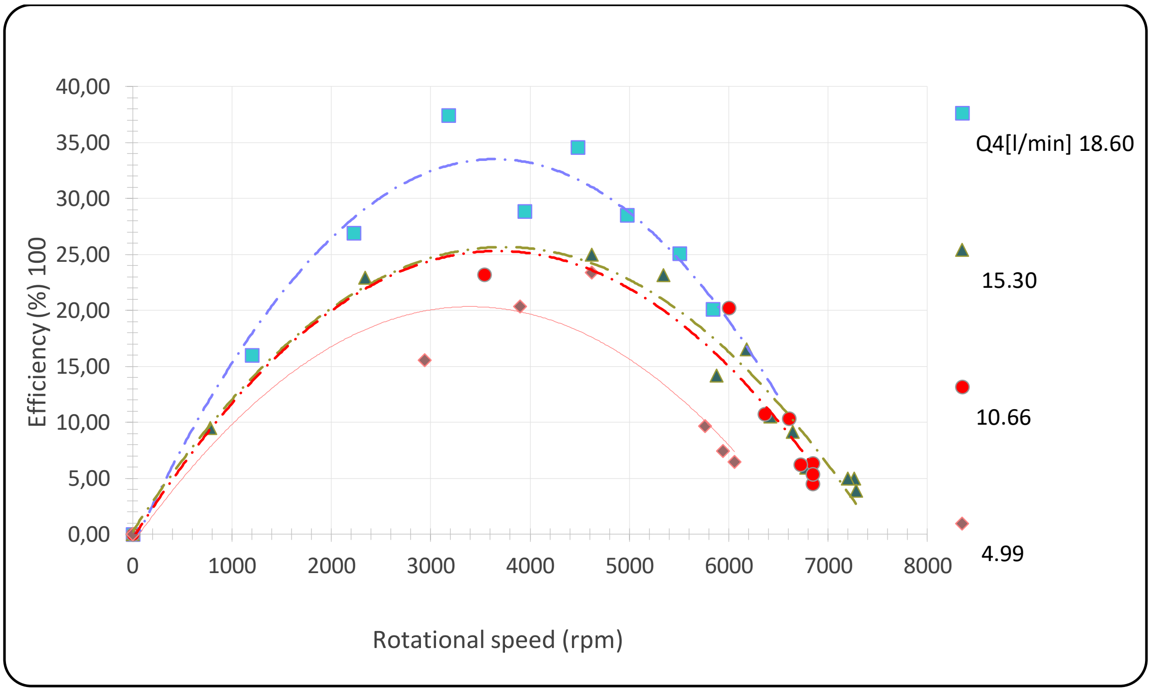



**Figure IV.10.** Turbine efficiency versus turbine speed for varying flow rate at a pump speed of 3400 rpm.

Figure IV.10 shows the variation of turbine efficiency with turbine speed for varying flow rate and for a constant pump speed of 3400 rpm and for varying flow rate. At constant flow rate, efficiency increases with turbine speed till reaches a maximum value then decreases. Efficiency decreases with decreasing flow rate. Maximum efficiency stands at around 35% with a flow rate of 18.6 L/min.

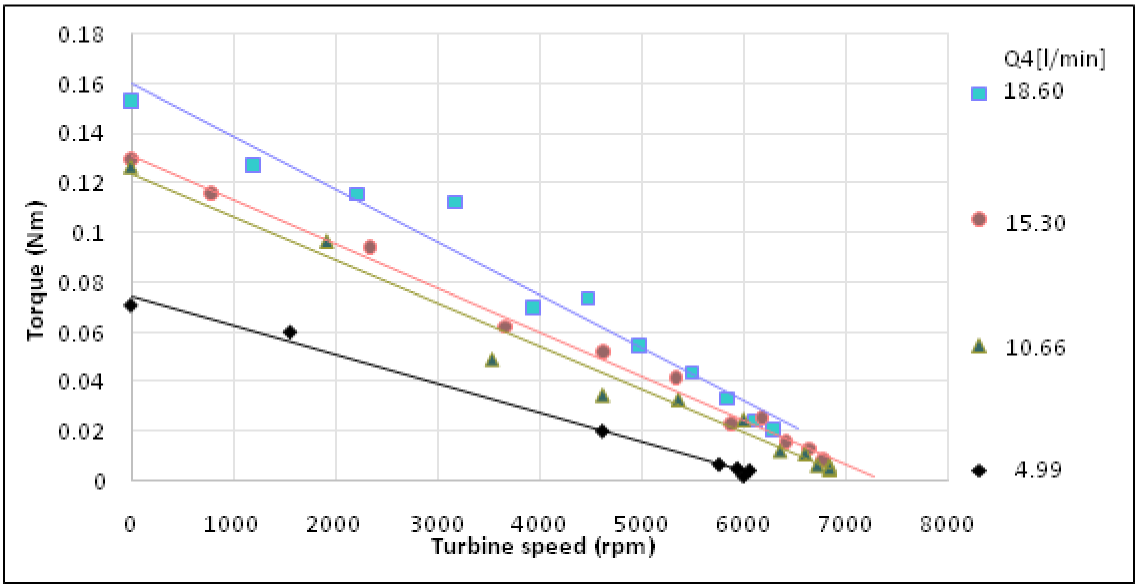



**Figure IV.11.** Torque versus turbine speed for varying flow rate at a pump speed of 3400 rpm.

Figure IV.11 shows the influence of turbine speed on the torque for varying flow rates. Torque decreases linearly with increasing turbine speed till it becomes nil for a turbine speed of around 7000 rpm. Torque also decreases with decreasing flow rate and all corresponding lines converge to the zero minimum torque.

## B. Characteristics of the Impulse turbine for pump speed of 3060 rpm.

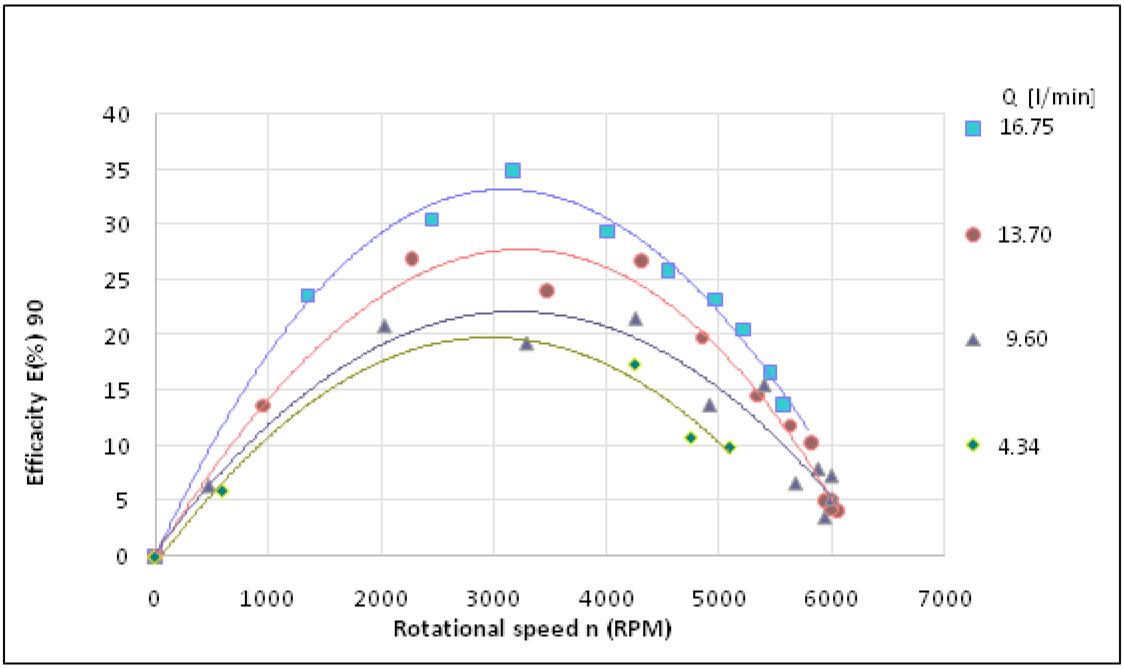



**Figure IV.12.** Turbine efficiency versus turbine speed for varying flow rate at a pump speed of 3060 rpm..

Figure IV.12 shows the effect of turbine speed on the efficiency for varying flow rate at pump speed of 3060 rpm. Efficiency increases with increasing turbine speed reaching a maximum then decreases. It also decreases with decreasing flow rate. A maximum efficiency value of around 34% is reached for maximum flow rate at a turbine speed of around 3100 rpm.

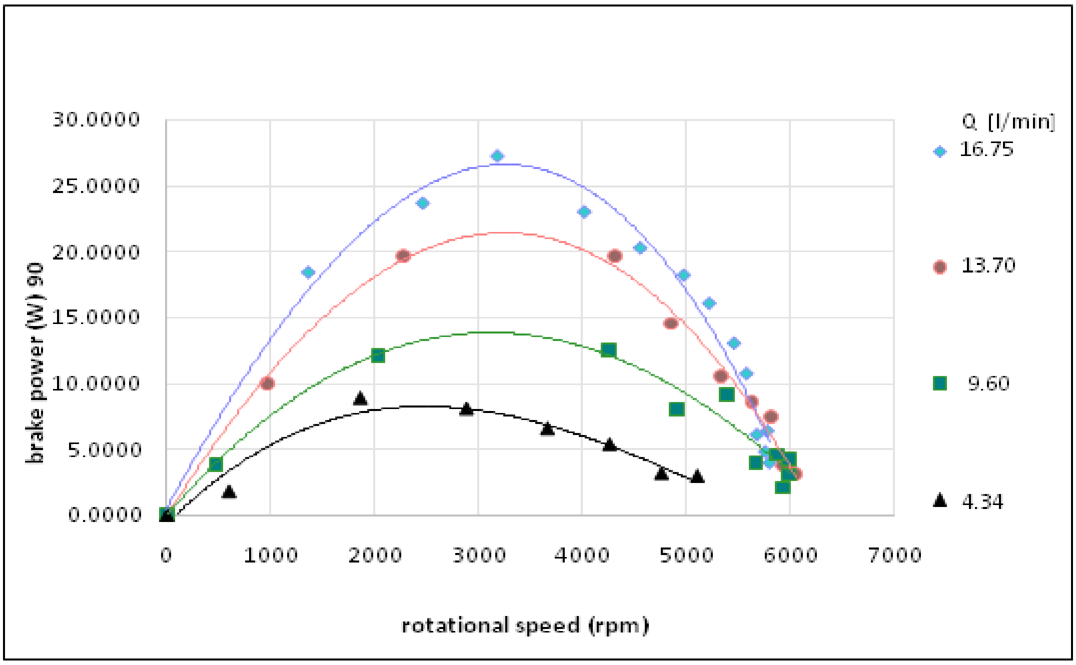



**Figure IV.13.** Brake power versus turbine speed for varying flow rate at a pump speed of 3060 rpm.

Figure IV.13 shows that maximum brake power of around 27 W is obtained for maximum flow rate at a turbine speed of around 3100 rpm.

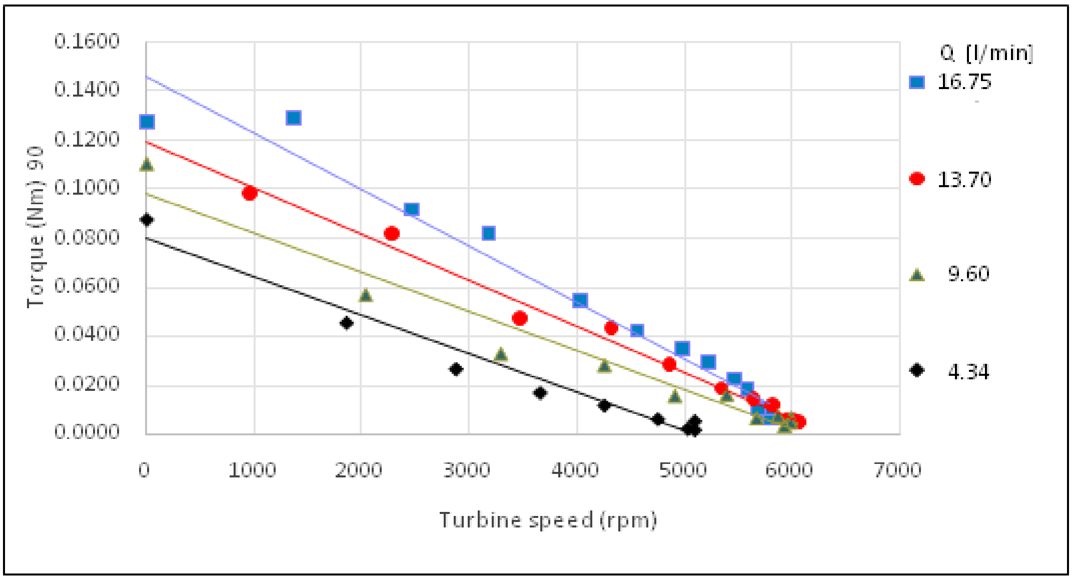



**Figure IV.14.** Torque versus turbine speed for varying flow rate at a pump speed of 3060 rpm.

Figure IV.14 shows that a maximum torque of around 0.147 Nm is reached at zero turbine speed. Torque becomes zero at a turbine speed of around 6000 rpm.

### C. Characteristics of the Impulse turbine for pump speed of 2720 rpm

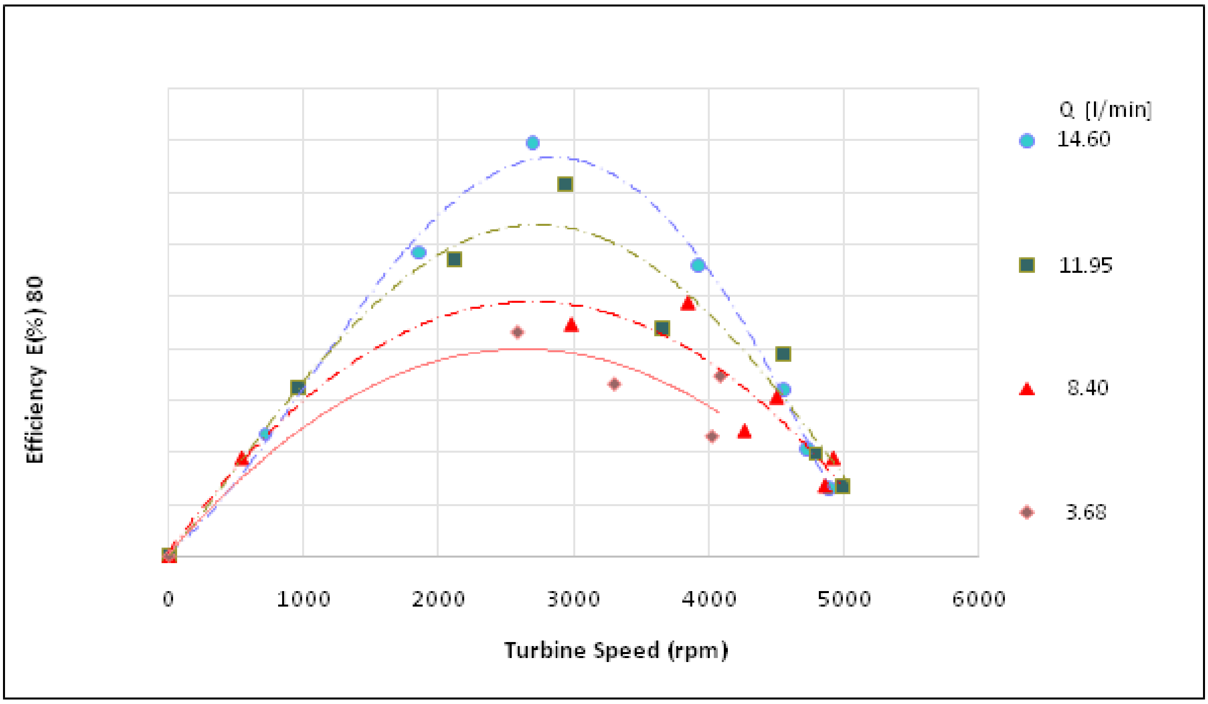



**Figure IV.15.** Turbine efficiency versus turbine speed for varying flow rate at a pump speed of 2720 rpm.

Figure IV.15 shows that at pump speed of 2720 rpm, maximum efficiency of around 35% is reached for the maximum flow rate at a turbine speed of about 2750 rpm. Efficiency decreases with decreasing flow rate.

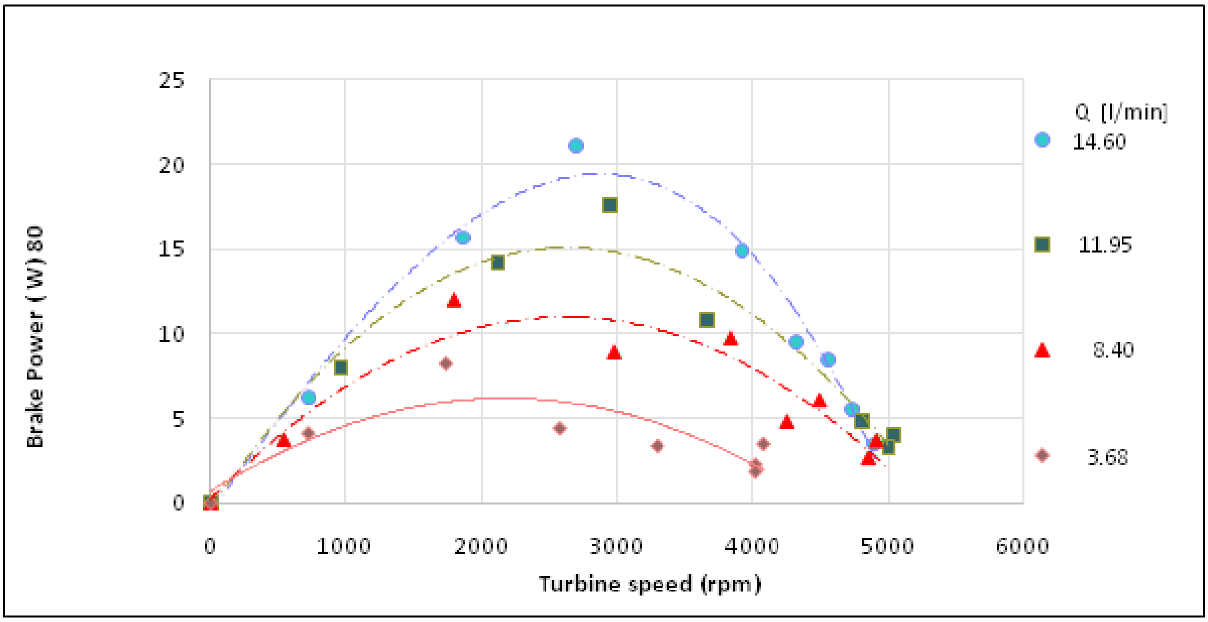



**Figure IV.16.** Brake power versus turbine speed for varying flow rate at a pump speed of 2720 rpm.

Figure IV.16 shows that brake power reaches a maximum value of around 20 W at maximum flow rate and for a turbine speed of 2800 rpm

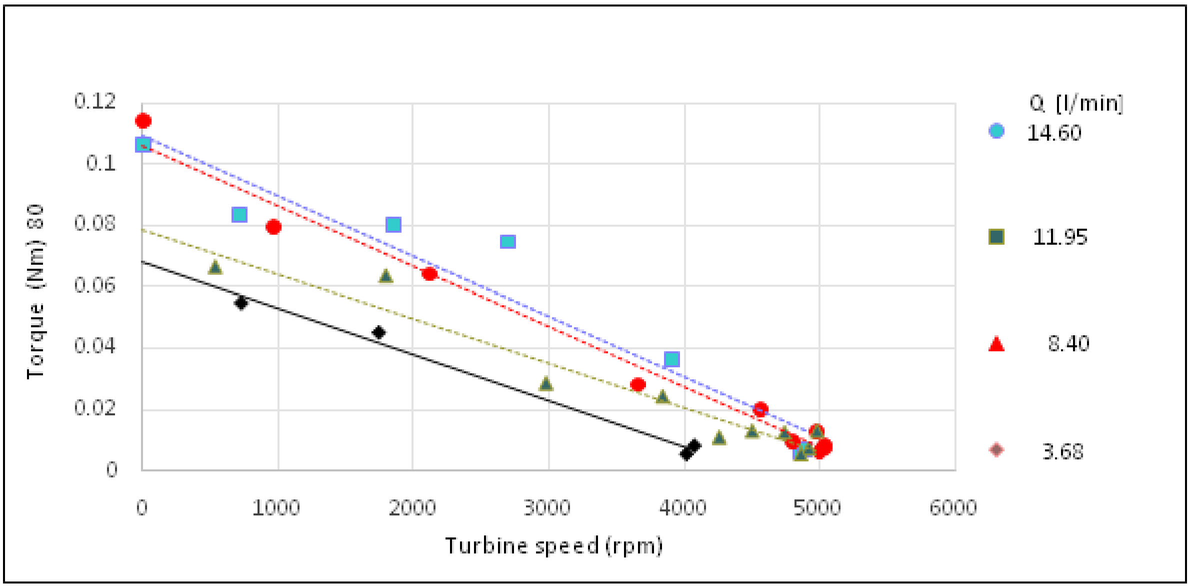



**Figure IV.17.** Torque versus turbine speed for varying flow rate at a pump speed of 2720 rpm.

Figure IV.17 shows that a maximum torque of around 0.1Nm is reached at zero turbine speed. Torque becomes zero at a turbine speed of around 5000 rpm.

### 4.12.2. General conclusion of impulse turbine testing

The experiment was carried out with great care. The testing results show that there is an increase in efficiency with increasing flow rate. Efficiency increases with turbine speed reaching a maximum value and then decreases. The value of the highest efficiency was 35% which was found with higher flow and higher pump speed.

Experimental results show that brake power increases with increasing flow rate. The value of the highest brake power was 34.9 W with a flow of 18.60 l/min.

Torque is shown to decrease with increasing turbine speed and increases with increasing flow rate.

### 4.12.3. Reaction Turbine

Reaction turbine characteristics are presented for varying flow rate. Results are given in tabular form by the data acquisition system at later presented in graphical form.

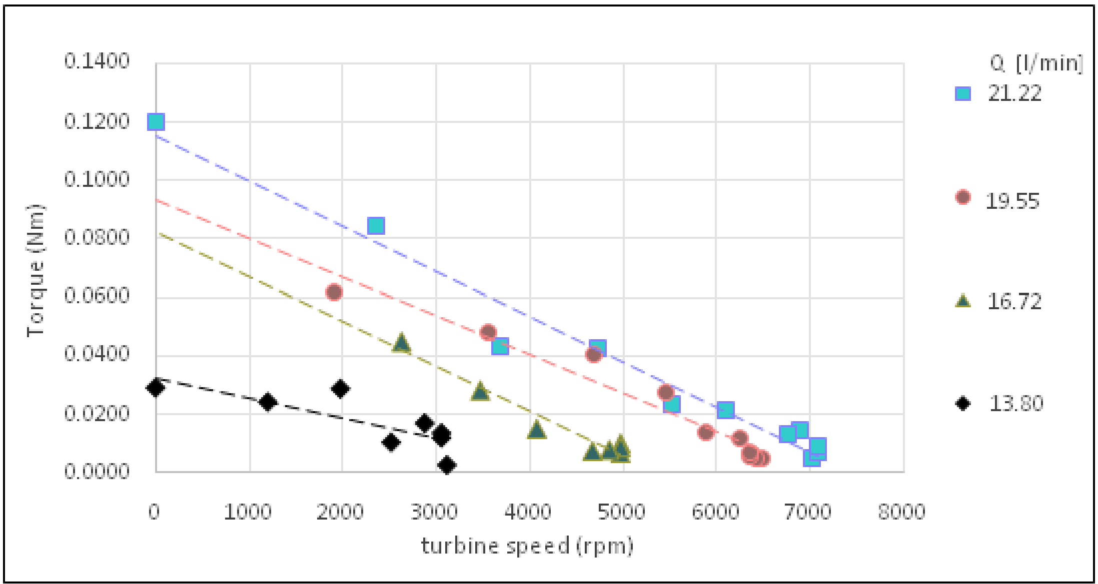



**Figure IV .18.** Torque versus turbine speed for varying flow rate

The variation of torque at different discharge shown in Fig.IV.18 indicates that torque experienced by the runner increases with increasing flow rate and decreases with turbine speed.

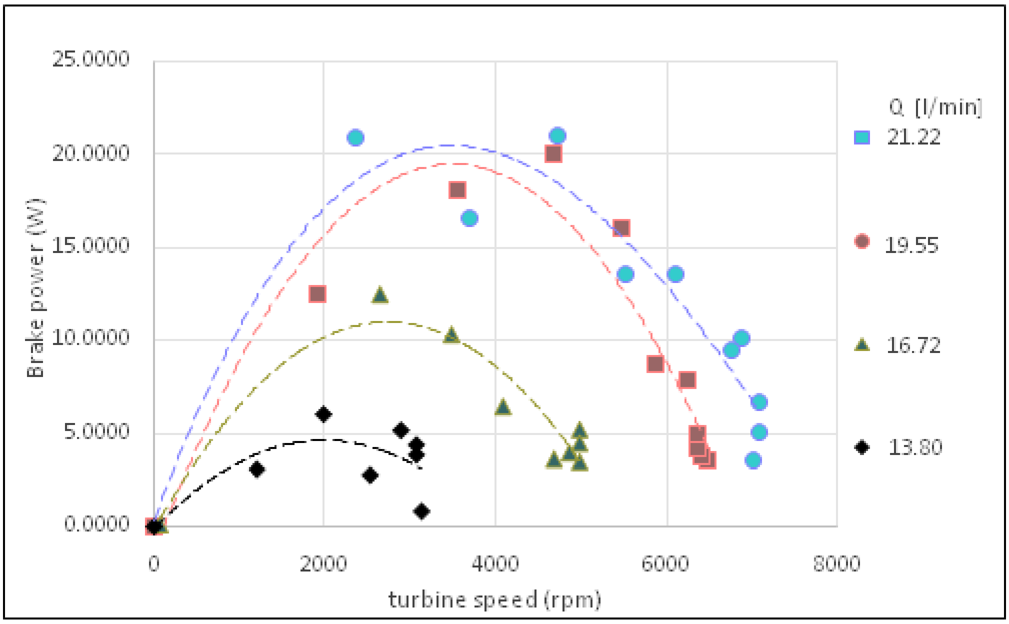



**Figure IV .19.** Brake power versus turbine speed for varying flow rate

Figure IV.19 shows that brake reaches a maximum value of around 20 W at maximum flow rate and for a turbine speed of 3500 rpm.

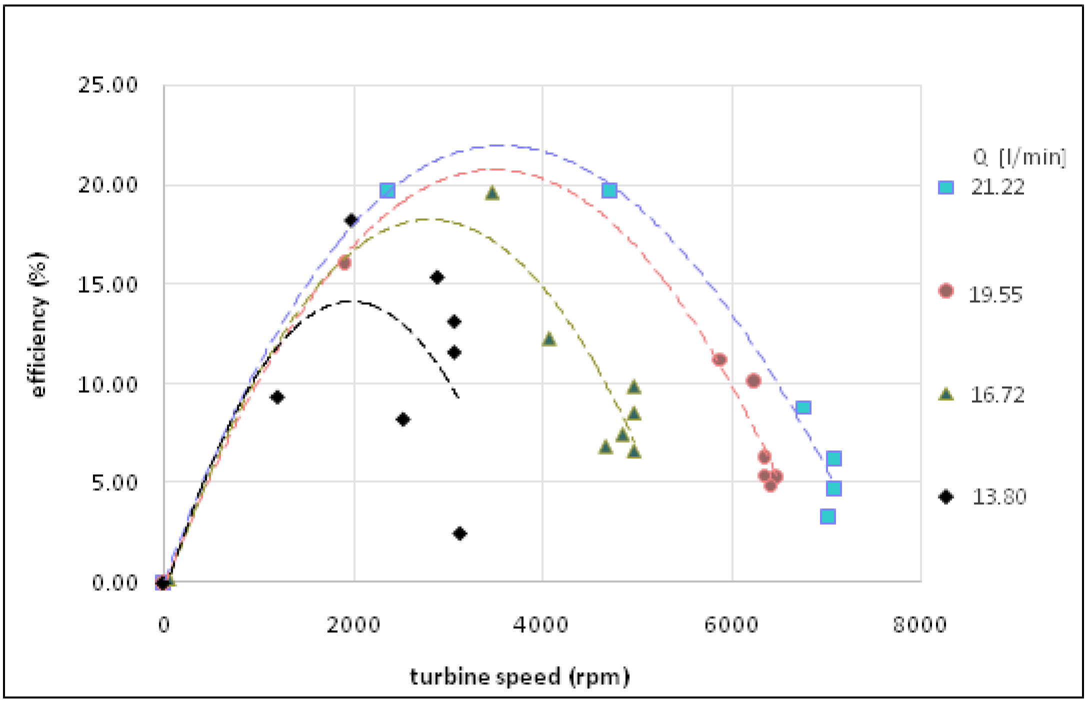



**Figure IV .20.** Turbine efficiency versus turbine speed for varying flow rate

Figure IV.20 shows efficiency increases with increasing turbine speed reaching a maximum value before decreasing again. Maximum efficiency is achieved at rated discharge of 21.22 l/min. It decreases with decreasing flow rate.

## 4.13. Conclusion

Comparisons of characteristic results of both impulse and reaction turbines have shown the following:

- Both efficiency and power output for both types of turbines show an increase with increasing flow rate. They also increase with increasing turbine speed reaching a maximum value before decreasing.
- It may be noted that for a given pump speed, maximum efficiency and brake power for the impulse turbine always occur at the same turbine speed at all flow rates. However in the case of the reaction turbine maximum efficiency and brake power occur at different turbine speeds for varying flow rates.

# Chapter V

# Conclusions and Recommendations

## CONCLUSIONS

Micro-hydro power continues to grow around the world, it is important to show the public how feasible micro hydro systems actually are in a suitable site. The only requirements for micro-hydro power are water sources, turbines, generators, proper design and installation, which not only helps each individual person but also helps the world and environment as a whole.

The choice of turbine will depend mainly on the pressure head available and the water flow rate. There are two basic modes of operation for hydro power turbines: Impulse and reaction. Impulse turbines are driven by a jet of water and they are suitable for high heads and low flow rates. Reaction turbines run filled with water and use both angular and linear momentum of the flowing water to run the rotor and they are used for medium and low heads and high flow rate.

The water and energy nexus is increasingly becoming a central concern at scientific, institutional and user levels. It is estimated that global demand for energy will increase by 30% by 2040, requiring a boost in global power production.

Hydropower has been increasingly seen as a two-fold solution to the provision of renewable energy and water storage.

The electricity market in Algeria is very important and electricity consumption has grown by almost 10% per year since 2009, bringing it to 59,000 GWh in 2016. The integration of renewable energies into the national energy mix constitutes a major challenge in the preservation of fossil resources, the diversification of electricity production ways and the contribution to sustainable development.

Today Algeria is at the dawn of a period of change tending to systematize the taking into account of the environmental impact of each project in areas as diverse as construction, energy consumption, waste production, or industrial activity.

Nuclear power and fossil fuels have led the world to a dead end, it is necessary to leave as soon as possible.

A new approach to business, knowledge, and know-how will be essential to respond effectively to these new challenges. This modest project is part of this logic.

The installation of the hydroelectric power plant at the 2.4Km level downstream of the Belgaid reservoir on the Kristel supply line allowed us to generate an estimated power of 1.191 521 kW / h, this recovered energy will allow us to relieve in electricity the towns of Ain Franine and

Kristel both situated at the Daira of Bir Eldjir. It must be also be born in mind that the study area in a tourist zone and it is subject to repetitive power cuts, which calls for supplementary electrical energy during peak hours.

Despite the low power recovered and estimated at 136 kW, our goal is to sensitize the public authorities, policymakers, politicians to opt for this renewable and inexhaustible energy coming from water which is in abundance in our region.

In order to make investment decisions for the development of small hydropower projects, both technical feasibility and financial viability are considered to be the foremost requirements. The cost of electro-mechanical equipment represents a high percentage of a small hydro-power plant budget (around 30 % and 40 % of the total sum). According to the present study, installation costs are manageable and because water supply system already exits and therefore the cost of hydroelectric plant must cover only the additional costs that it generates, because a large part of the equipment, especially the catchment, pipe, and tank, is used primarily to supply the drinking water supply and must be built.

A laboratory experimental study was conducted on two types of water turbines, namely the impulse turbine and the reaction one. Results of brake power, efficiency and torque were obtained for both types and for variable turbine speed and flow rate. Comparisons between characteristics of both types of turbines were made.

## Recommendations:

It is suggested that a micro hydro power prototype be built in the present study area in order to highlight the importance of such a renewable energy system.

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