Sudan University of Science and Technology

College of Engineering

Mechanical Engineering

Power Department

Preliminarily Design of Pumped Storage Plant

تخزين الطاقة الكهربائية بواسطة المضخات المائية

A project Submitted in Partial Fulfillment for the Requirements of the Degree of B.Eng (Honor) In Mechanical Engineering

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الاستهلال

قال تعالى:

(ذَٰلِكَ فَضْلُ اللَّهِ يُؤْتِيهِ مَنْ يَشَاءُ ۚ وَاللَّهُ ذُو الْفَضْلِ الْعَظِيمِ)

[سورة الجمعة 4]

(إِنَّ اللَّهَ وَمَلَائِكَتَهُ يُصَلُّونَ عَلَى النَّبِيِّ ۚ يَا أَيُّهَا الَّذِينَ آمَنُوا صَلُّوا
عَلَيْهِ وَسَلِّمُوا تَسْلِيمًا)

[سورة الأحزاب 56]

DeDication

We like to dedicate our project to those who gave our life it's meaning and it's taste.........

OUR FAMILIES

ELMUTHANA

MOHAMMED

MOHAMMED

AKNOWLAGEMENT

Firstly we thanks our

GOD

That helps and gives us the Trust to finish this project

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To any Person

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Lastly sincere thanks to our

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Friends

ABSTRACT

Pumped storage reservoirs are not really means of generating electric power. They are a way of storing energy so that we can release it quickly when we need it. Demand of electrical power change throughout the day.

If the power station does not generate more power immediately, there will be power cut around the country - traffic lights will go out, causing accidents, and all sorts of other trouble will occur. The problem is that most of our power is generated by the fossil fuel power station, which take half an hour or so to crank them up to full power. Nuclear power station takes much longer.

We need something that can go from nothing to full power immediately, and keep us supplied for around half an hour until the other power station catch up. Pumped storage reservoirs are the answer we have chosen. Water is pumped up to the top reservoir, when demand for power across the country is low. When there is a sudden demand for power the head gates (huge taps) are opened, and water rushes down the penstock to drive the turbine, which drive the power full generators.

المستخلص

خزانات التخزين عن طريق المضخات هي ليست محطة لتوليد الكهرباء ؛ بل هي محطة لتخزين الطاقة الكهربائية و تعمل بسرعة عند الاحتياج اليها.الطلب على الطاقة الكهربائية يتغير أثناء اليوم .

المحطة الكهربائية اذا لم تنتج طاقة اضافية فورية و تمدنا بالطاقة اللازمة لمدة نصف ساعة او اكثر حتى يتم تشغيل محطة اخرى؛والمشكلة ان محطات التوليد الحرارية و النووية تحتاج الى زمن طويل حتى تعمل .

لذلك نحتاج الى شيء يعمل بسرعة و يمدنا بالطاقة لمدة نصف ساعة او اكثر حتى يتم تشغيل محطة اخرى ؛ نظم التخزين عن طريق المضخات هي الاجابة التي سوف نختارها. يتم ضخ الماء لأعلى الخزان عندما يكون استهلاك الكهرباء منخفضا. وفي لحظات الذروة في الطلب يتم فتح البوابات لترك الماء ينساب عبر القنوات لأسفل ويتم توليد الكهرباء بواسطة حركة التوربينات.

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Chapter One

Introduction

1.1. Introduction

Both the historical and the present-day civilization of mankind are closely interwoven with energy, and there is no reason to doubt but that in the future our existence will be more and more dependent upon the energy. Electrical energy occupies the top position in the energy hierarchy. It finds innumerable uses in home, industry, agriculture and even in transport.

Beside its use for domestic, commercial and industrial purposes it is required for increasing defense and agricultural production. In agriculture it's used for pumping water for irrigation and for improving the methods of production and numerous other operations. Electrical energy is convenient from of energy because it can be generated by centrally in bulk and transmitted economically over long distance and is almost pollution free at the consumer level. Further, it can be adopted conveniently in the domestic, industrial and agriculture fields.

The process of modernization , increase in productivity in industry and agriculture and improvement in the quality of life of the people depend so much upon the supply of electrical energy that the annual per capital consumption of electrical energy has emerged these day as an accepted yardstick to measure the property of a nation. Some of the advanced and developed nations of North America and Europe have a very high annual per capita consumption of electrical energy, say from 8 to 11 thousand KWH while the most of Africa, Asia and Latin America it is low to be considered.

1.2. Problem Statement

Change of demand of electrical power through the day make instability in power station control during peak and of peak periods. And we need to the something can handle that. We will prove Pumped storage can do that.

1.3. Project Importance

This project is necessary to balancing the electric demand between peak load and OF peak. And it can use for irrigation when the demand of electricity stable.

1.4. Project Objectives

This study is aiming to active some specific objectives that can be summarized as follows:

a. To study in details the theoretical bases of hydro electric power plants generally and pumped storage plant specially.

b. To design a hydroelectric power plant to generate electric power during peak load demand and up pump water during the low load period up to the head water bond "reservoir".

The plant utilizes on the surplus energy during the low load to pump water from the river water into the elevated reservoir through a water turbine to generate electric power during peak load demand.

c. To minimize the cost of the pumping water in to the elevated reservoir wind will be used during the windily month.
d. To try to show the economical benefits of the project.
e. To give detailed results of design of hydroelectric power plant units.

f. To discuss the final obtained results and give according to the final results - some suggestions and recommendations.

1.5. Project Scope

The project scope is about hydroelectric power and we focus on pumped storage hydroelectricity.

Chapter Two

Literature Review

2.1. Identifications of the Project & Previous Studies

2.1.1. Basic Feature

Pumped Storage power Plants are special type of power plants which work as ordinary conventional hydro-power stations for part of the time. The specialty of these power plants lies in the fact that when such plants are not producing power, Its can be used as pumping stations which pump water from the tailrace side to the high level reservoir. At such time these power station utilize power available from elsewhere to run the pumping unit. The working of the power station can be distinguished as the generating phase when the turbines and generators are producing electrical power and the pumping phase when the pumps and motors are in operation. During the generating phase, therefore water flows from the high level into the power house and thence to the tailrace side; in the pumping phase it is *vice versa*. This basic arrangement is schematically shown in Figure (2.1). [3]

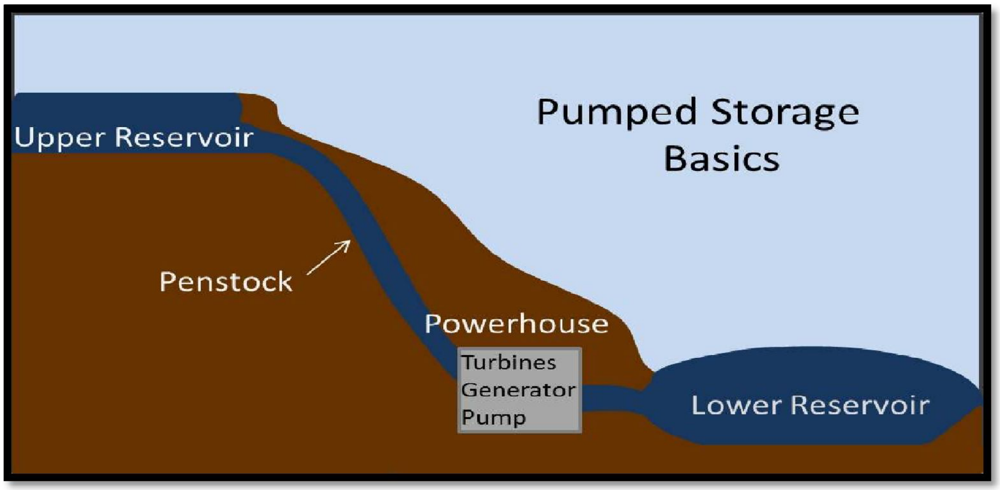


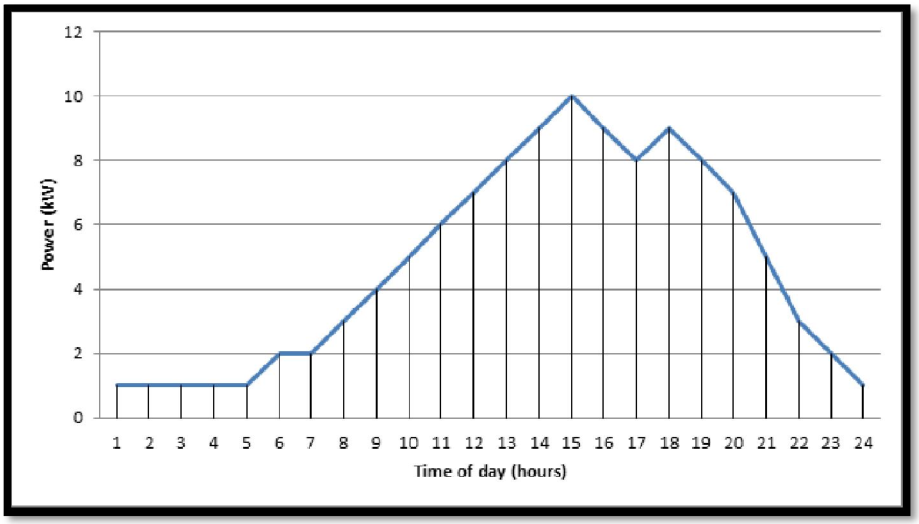
Figure (2.1) General arrangement of pumped storage power plant.

The fundamental arrangement consists in having two pools, one at high level and the other at a low level with a power house occupying the intermediate position.

The water passages are from the higher level pool to the power house and from the power house to the lower pool, which carry water in either direction depending upon the generating or the pumping phase.

On the face of it, it may appear as an altogether expensive and wasteful arrangement with greatly reduced plant efficiency (see under heading efficiency of power plants). A little consideration, however, will makes it clear that is a very ingenious method of conserving ,it limited water resource on one hand, and balancing the load on the distribution system, on the other hand Figure (2.2) shows a hypothetical daily load curve.

At least theoretically, the same water is recycled again and again. Hence such an arrangement can be conceived with even a limited amount of water the pumped storage plants thus serve much the same function as accumulators in mechanicals systems. It may also be called as peaking station. Its operation is necessarily intermittent with generations during system peak hours and pumping during off - peak hours. [9]



Figure(2.2) Hypothetical load curve.

2.1.2. Historical Development

The history of pumped storage plant can be traced as far back as 1890, in which year the first hydro-electric plant making use of pumped storage started functioning at Zurich in Switzerland. Till the year 1925, according to Freeman, about 30 pumped storage plants are functioning in various countries of Europe. However, all such plants were small units and the idea had not found a large scale acceptance. In the meanwhile, the concept of reversible pumped turbines was also developed and in 1931 the first reversible pump-turbine was installed at Baldeneyesee in Germany. The end of Second World War brought about a large scale industrial expansion allover the world which in turn increased the power requirements steeply. Along with these, large scale power grids also became possible due to higher transmission voltages and need of only peaking stations became more acute. All these circumstances favored a general acceptance of pumped storage plants as a part of the system. Tennessee Valley Authority took a lead in USA by installing at

Hiawassee Dam a big reversible pump-turbine unit of Francis type in 1955. The first major reversible diagonal turbine (Deriaz) was installed at Niagrra around the same time. In Europe, in 1961, Ffestiniog (Great Britain) with a total capacity of 360 MW and Provindenza (Italy) with a head of 284 m, were the major landmarks in the progress of pumped storage plants. In USA, Taum Sauk employed 230 MW capacity units using a head of 250m in 1963 although only two units were installed. In the last ten to twelve years, the capacity and head for pumped storage plants is continuously increasing. To- date, Ohira Plant in Japan (under construction) with a head of 513m and Ludington in USA with a capacity of 2053 MW hold the record for single stage high head plant and large capacity plant respectively Experience from advanced countries like USA or Japan tends to indicate that in a well-developed and balanced distribution system including nuclear power, thermal power and hydro-power, pumped storage can be used profitably up to as much as 20 percent of the total hydro-power potential. The optimum magnitude of pumped storage is between 10 percent to 30 percent of the total capacity of the system.

In India, there is no exclusive pumped-storage plant constructed so far, although some existing hydel plants are operating as pumped-storage plants for a small period of time. A 400 MW P-S plant is at design stage at Kadamparai in Tamil Nadu (India). This will be built with 'the existing upper Aliyar Reservoir as the lower pool, the higher pool being constructed on Kadamparai Ar River. There will be four 100 MW reversible units in an underground power house. [3].

2.1.3. Advantages Of Pumped Storage Plants

The pumped storage plants have the following advantages:

1. As compared to other peaking units, pumped storage plants have relatively low capital cost and are thus an economical source of peaking capacity.
2. The pumped storage plant is as rugged and dependable as conventional hydel power station and can pick up load rapidly in a matter of few minutes
3. Such power stations are readily adaptable to automation as well as remote control.
4. All hydel power is entirely free from effects of environmental pollution. The pumped storage plants are thus a valuable part of the power system in curbing air and water pollution.
5. Pumped storage plants allow a great deal of flexibility in the operational, schedules of the system.
6. The power required for pumping is available at a cheaper rate (Slack hours' rate), while the power produced by the plant can be sold at a prime rate (Peak hour' rate). The relatively low hydraulic efficiency is partly compensated due to this fact.
7. The pump storage plant allows the entire thermal or nuclear power generation to take up the base load. Thus, the load factor of these units improves giving rice to over all greater system efficiency. [10]

2.1.4. Types Of Pumped Storage Plants

Various arrangements are possible for the higher and lower reservoir. These can be enumerated s follows:

1. Both the reservoirs on a single river, in a tandem chain manner. The lower reservoir will be situated a few kilometers downstream from the upper reservoir. This arrangement is planned, for instance, on Takasc River in Japan for a pumped storage plant which is to take care of the peak loads of Tokyo city.
2. Two reservoirs on two separate rivers close to each other and flowing at different elevations. Shintoyone pumped storage plant in Japan is an example of this type. Here the lower reservoir is on Tenryu river while the higher reservoir is on Ohnyu, river which is a tributary of Tenryu river.
3. Higher reservoir an artificially constructed pool with the help of dykes all around, on a high level plateau or on a leveled hill- top and the lower reservoir on a natural river. This is the most common type of plant and instances of such a plant are Revin (France), Vianden etc. In many cases, the lower reservoir caters to conventional hydro-development as a valley dam plant.
4. The lower reservoir is a natural lake while the higher reservoir is artificial. The example of this kind is Ludington plant on Lake Michigan, USA. Use of sea as a natural lower reservoir is being visualised now and some schemes such as Atashika in Japan are under preparation. Another way of describing P-S plants is to classify them as pure or mixed operation. A pure pumped storage plant is a closed cycle plant with the volume of water flowing to the lower reservoir being equal to the volume pumped to the higher

reservoir in one cycle of operations. In such a system, same water is circulated again and again and thus except for make-up quantity of water for seepage and evaporation losses, the plant does not need any fresh water flow. Ffestiniog, Vianden etc., are example of this type. [10]

In mixed plants, the pumped storage feature is incorporated in a normal hydel scheme. In such plants, the total generation in one cycle is greater than the total pumping during that period. At Oroville dam (USA) for instance, three pump turbines provide the pumped storage feature, while the rest of the turbines are conventional Francis turbines.

In mixed type of plant, the higher reservoir has to be necessarily on a natural stream so as to provide greater Flow during generation.

Yet another classification of the P-S plants is on the basis of cycle of operations. Some plants are operated on a daily cycle or pumping and generation. Some are planned on a weekly cycle where the pumping is confmed to slack weekend periods only. A few pumped storage plants have been built even on a seasonal cycle where pumping is done during seasons of lean demand and generation during higher demand season. Many of the initial plants built in Europe were for seasonal operations. Examples of Lunersee (Austria) or Hewfurt II (Germany) belong to this type. In recent years, however, the daily cycle plants are predominant. The upper reservoir capacity depends naturally on these characteristics F or instance in Germany, Hausem plant and Herdecke plant have approximately equal capacities. But Hausem, working on a seasonal cycle has storage capacity of 108m cu m were as for Herdecke , working on a daily cycle, the corresponding figure is only 1.5m cu m.

The most important basis of the pumped storage plants is, however, the relative arrangements of the turbines and pumps. In the initial years, there were four different units namely pump, motor, generator and turbine. Pump and motor coupled together were completely independent of turbine and generator coupled together. This gave a complete independence of operation. But the space needed was more and the arrangement involved greater costs. This may be termed as a 'four-unit installation.'

This arrangement was quickly replaced by a three-unit system, namely, a pump, a turbine and a generator which can also function as a motor. Both the pump, called as storage pump, and the turbine were directly coupled to the generator/motor unit. When the turbine runs, the unit operates as a generator and when the pump is operated the same unit operates as a motor. We might refer this as a 'three-unit installation.' It is possible to have either a horizontal setting or a vertical setting under this arrangement. Figure (2.3) shows a typical horizontal setting. In vertical settings, the pump is situated at the lowest and the generator/motor unit at the top with the turbine occupying the intermediate position. Figure (2.4) shows a vertical setting. It is obvious that the vertical setting is more compact but needs a greater height of the power house structure.

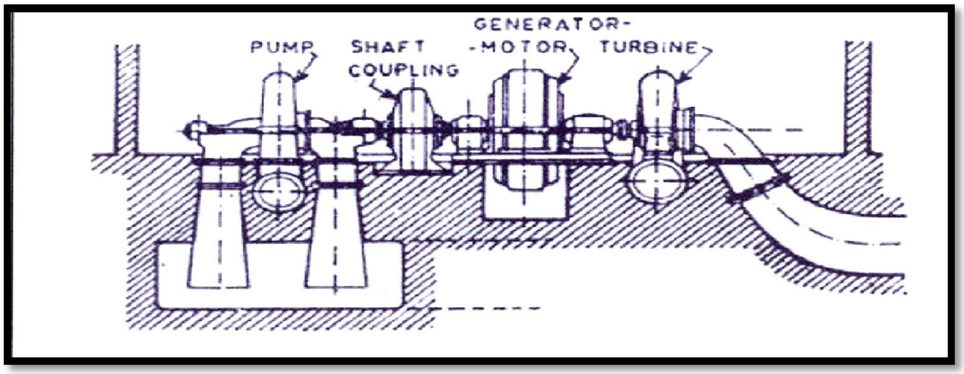


Figure (2.3) Horizontal setting of machines.

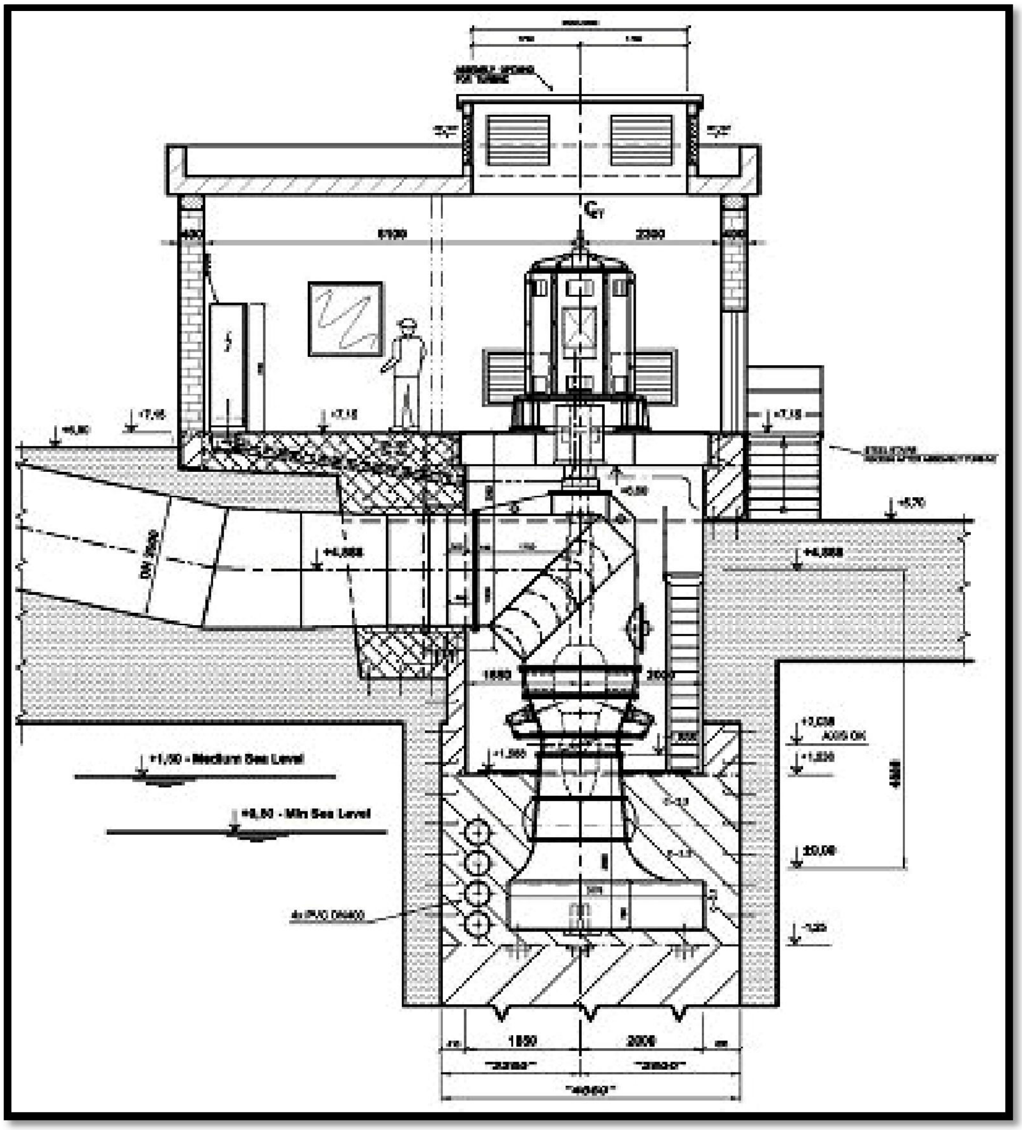


Figure (2.4) Vertical setting of machines.

The modern trend is to use only a 'two-unit installation,' namely, a generator which can operate as a motor coupled to a turbine which in turn also operates as a pump when rotating in reverse direction. This arrangement is popularly called as reversible pump-turbine installation. In countries like USA and Japan almost all new pumped storage plants invariably use reversible pump-turbines.

Relative Merits of Two-Units and Three-Unit Arrangements:

1. Reversible pump turbine (i.e. tow-unit arrangement) is compact and need much less space as compared to the three-unit installation. Further the cost of one additional unit is saved. Thus, the initial costs are considerably less in reversible unit installation.
2. In case of three-unit installation multi stage center fugal pump can be used, if necessary. Thus, for a very high head plant were reversible pump turbines cannot be used, three unit arrangement is possible. For example, at Reisseck-Kreusek (Austria), the pumping head is more than 1000m. Here separate 8-stage multi storage pumps are used, each pump of 56 MW capacity. The turbines are Pelton turbines.

In the reversible pump turbine installations, there is generally a single-stage arrangement and hence the head which can be used by such a machine is limited. For Cruachen P-S plant in UK reversible francis pump turbines are used. The operating head is 364m and in 1964, when the project is under construction, this was felt as a unique and daring step. In the last 10-12 years, further research has made it possible to use single-stage Francis reversible Machines for head over 500m. Ohira and Numappara plants in Japan use such high heads with reversible machines.

It is also noteworthy that with the world's first multi stage reversible pump turbine project at La-Coche (France) under construction, the monopole of three unit installation for heads over 500m while also be soon over. The La-Coche units are 85 MW, 5- stage pump turbines operating at a head of 930m.

3. In case of three-unit installations, the pump and the turbine, being separate units, can be designed optimally so as to operate at their

maximum efficiency point. In case of reversible machines if the machine is designed as a turbine, it's efficiency as a pump suffers to small extend.

4. From the operation point of view three-unit system is simpler. In generating and pumping modes, the direction of rotation is generally kept identical; so switching from pumping mode to generating mode or vice versa consists in coupling or decoupling the pump with a generator, which takes a much shorter time. The generator motor is not required to be brought to standstill or to change it's direction of rotation.This operation can be completed within tow to three minutes. In reversible machines, as the operating mode changes, the direction of rotation also changes and consequently the changeover from one mode to other involves a longer time.

A recent development to overcome this shortcoming is isogyre pump turbine which is reversible machine with the same direction of rotation in both the pumping and generating mode.

A typical example of isogyre pump turbine installation is at Handeck III plant (Switzerland) where one high head isogyre unit of 42 MW capacity operates against a head of 460m of l000 RPM.

5. As higher and higher heads are utilize, the cavitation become a major problem. As explaining subsequently, it becomes necessary to keep the pump below the tail water level in order to avoid cavitation. In three unit arrangement, since multi stage pumps are used, the head per stage is not very high, hence the cavitation problem is not as sever as reversible high head pump

turbine. In case of tow-unit installation, thus, there is an additional constraint in design.

All such this advantages are more than offset by the material savings in tow-unit arrangements which, therefore, are in ascendancy. [3]

2.1.5. Three-unit Arrangement

In three-unit arrangement, the turbine and generator are permanently locked together and the pump can be coupled during the pumping phase. As a matter of fact in certain plants, the pump is also never decoupled but stays coupled and keeps rotating empty during the generating mode. Occasionally, a single shaft arrangement as in Waldeck II is also used.

Where a pump needs decoupling, power-operated mechanical gear coupling or friction clutch coupling or combined torque converter and mechanical gear coupling are used.

For vertical setting, generally, the generator is at the top and pump is at the bottom. Such an arrangement provides more favorable working condition for the pump against cavitation damage. Waldeck II in Germany, uses an arrangement.

A high head pumped storage scheme necessarily has to use low-specific speed pumps with high head, low discharge characteristics. In order to increase the discharge capacity, the pump impeller may have double-suction inlets. The normal value of specific speed Ns per stage .

$$\mathrm{Ns} = \frac{\mathrm{N}\sqrt{\mathrm{Q}}}{\mathrm{H}^{\frac{3}{4}}} \tag{2 .1}$$

Where:

Ns = specific speed

N = speed by RPM

Q = flow rate m^3/s

H = high m

Such that (Ns × $\sqrt{H}$) is between 400 to 650.

Typical instance of a high head unit is San Fiarana P-S Plant (Italy) where two six -stage storage pumps are installed against a total head of 1438m. These are 105 MW pumps. Waldeck-II plant has a single-stage two storage pumps for a head of 319m with a power rating of 234MW running at 375rpm.

In a tree-unit installation, special arrangement has to be foreseen for the starting of the pump. Such pumps are first run to synchronous speed and then coupled to already rotating turbine generator unit. In such cases pump are speeded up from the rest position with the help of small turbine mounte on the pump shaft which runs the empty pump to synchronous speed before coupling. Alternatively, pony motor also can be used for the same. Where change overtime is not a critical factor as in case of seasonal plants, the machine can be stopped, the pump coupled and the machine speeded up by the maim turbine. The pump starts operating after the turbine is dewatered. The turbine, however, stays coupled during the pumping phase but run empty. [3]

2.1.6. Reversible Pump -Turbines

Any reaction turbine can, technically speaking, work as a pump if the direction of rotation is reversed. Thus, the propeller and Kaplan turbines, the diagonal flow Deriaz runners and the versatile Francis turbines, all can be used as reversible machines. The salient design features of reversible pump-turbines are not markedly different from those of conventional turbines.It may, however, be pointed out that the head range, for which a particular type of turbine is suitable, is approximately as below:

Propeller and Kaplan turbines	< 20 m
Deriaz turbines	< 150 m
Francis turbines	< 500 m [7]

Large capacity units are usually Francis type reversible pump-turbines. Largest unit capacity of a Francis reversible machine is 400 MW at Raccoon Mountain, USA. The largest wheel diameter is 8 m at Ludington, *USA,* for units of rating 343 M W each.

For low head run-of-river development, propeller} Kaplan turbines are suitable. Specially devised bulb units are only a variety of propeller units. For tidal plants, such reversible type bulb units have been used as at Rance in France.

The operating characteristics of the reversible machine are different when it runs as a turbine and as a pump. If the rotational speed is kept constant during both the modes, the discharge during the pumping phase is less than the discharge during the turbine operation. The maximum efficiency of the pump-turbine as a pump occurs at a different speed as compared to its running as a turbine. In order to obtain good efficiencies at the same head, some plants have gone in for different speeds in the two phases. At Hiwassee plant, for instance, the operating speeds are as below:

As a turbine	106 rpm
As a pump	136 rpm

Many designs, however, from the viewpoint of simplicity, keep the same rotational speed during both the phases. In such a case maximum efficiency occurs at different heads. Thus; for Raccoon Mountain, *USA,* the maximum efficiency as a turbine occurs at a head of 305 m while for the pumping operation the optimum head is 296 m, utilizing a discharge of 115.6 *m/s.* It is a 400 MW size unit, one of the biggest in the world.

The reversible pump-turbine, as mentioned earlier, suffers from the disadvantage that in order to change from one operating mode to the other, the machine rotation has to be reversed.

There are two exceptions to the above statement. Isogyre pump turbines mentioned earlier and Deriaz runners where the inclination of the blades can be reversed without stopping the machine. Various methods for starting the machine in a pumping mode are as follows:

1. Using a pony motor or a turbine as in case of separate storage pumps.

In such a case the machine is required to be brought to a halt, then dewatered using compressed air and then accelerated again by the pony motor to reach the synchronous speed. The capacity of the pony motor is about 5 percent to 10 percent of the main wheel and it is installed on the main shaft. This method is quite time consuming and may take as much as 10 minutes, as in the case of Taum Sauk in USA.

2. A synchronous starting i.e. using the main electrical machine as an induction motor fed from the system. In such a case the machine circuit gets complicated and an auto transformer becomes necessary.

3. Synchronous starting is done by connecting the machine back to back with an idle generating set which is then run up to speed. This is feasible only when a spare generating set is available. For Rodund II, a 270 MW P-S plant in Austria, the reversible pump turbines need a total time of 250 seconds for a changeover from full turbine load to full pump load.[2]

2.1.7. Problems of Operation

The main problem of high head pump is of cavitation.

Cavitation is a phenomenon which manifests in the flow when the

pressures are nearing vapor pressure. In such a condition minute bubbles of vapor and gases are formed in the flow. When the bubbles are carried along with the flow in high pressure zones, they collapse, giving rise to transient high pressures and vibration and consequent damage to the internal surface of the flow boundary. Thoma has suggested a cavitation parameter, δ for turbines and pumps such that:

$$\delta = \frac{h_b - h_s}{h} \tag{2-2}$$

where h_b, h_s and h denoted the barometric head, the suction head (or the height of the pump above tail water level) and the total effective head on the pump respectively. According to Thoma, for a cavitation free running b has to be greater than a critical value, δ_{crit}, or

$$\delta_{crit} = \frac{h_b - h_s}{h} \qquad (2\text{-}3)$$

δ_{crit} is function of the specific speed of the pump. For high values of head h, h_s come out to be negative and hence it becomes necessary to provide the pump with negative suction head. In other words, the power house location has to be so fixed that the pump operates under submerged conditions. The magnitude of this submergence depends upon the specific speed and the net head. Figure (2.5) can be used as a general guide in this respect. As shall be seen from it, sometimes the submergence is very high. For example, for Waldeck II, the submergence is 52.5 m. For such a ergencehigh degree of subm, the power house has to be located in underground rock caverns. As a result many of pumped storage plants have underground power house with a good deal of tunneling for the water passages. Other special problems of reversible machines arise due to reversing of rotation as well as flow direction, frequent starts and stops and transient loading of the runner as a result of elaborate starting procedure. The reversing of direction of flow gives rice to runner tracking due to fatigue.

The trash racks, which are designed for turbine below, vibrate violently during pumping operation unless special care is taken in their design. The flow during the pumping mode tends to lift the machine axially thus causing tensile stresses in bearings. The guide vanes are particularly susceptible to pump flow. Unless a special locking device is provided they vibrate and get damaged during pumping phase. Most of the pump turbine has to make special provisions in order to avoid this.[3]

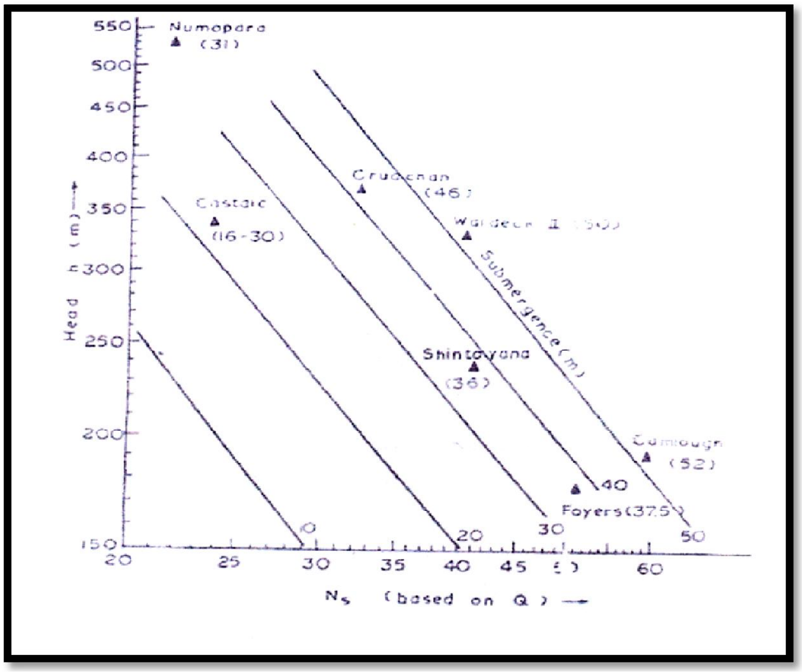


Figure (2.5) Depth of Submergence.

2.1.8. Topography

For an economic operation, an important criterion is a ratio of the length, L, between the two pools along the water passage to the head difference, h, between them. The less the value of this ratio L/h, more economic is prospect of the plant.

Another important factor regarding to suitability of the topography is that the site must be suitable for an underground power house and the extensive tunneling work that is so often necessary. [3]

2.1.9. Reservoirs and Water Conveyance

In mixed pumped storage plants, the reservoir capacity is determined by other considerations but in pure pumped storage plants, the reservoirs must have a capacity such that:

1. The upper reservoir is capable of holding all the water pumped up during the pumping period in addition to its dead storage.
2. The lower reservoir is capable of receiving and holding all the water that flows into it during the turbine operation in addition to its dead storage.
3. The lower reservoir also must have capacity to store the water that is expected to be lost through seepage and evaporation.

As mentioned earlier, the upper reservoir is many times on a hill-top and, hence, as small in size as is permissible. The storage capacity to be provided would, of course, depend upon the operation schedule of the power plant. The upper reservoir capacity is usually between six hours to twelve hours of pumping capacity. At Revin, for instance, the reservoir has a capacity to store seven and a half hours' pump discharge. Special operating conditions may need larger capacities. At Cruachan plant, twenty hours' storage is envisaged.

The upper reservoir, whenever built by an around earthen dyke, needs extensive treatment to avoid seepage losses. This is usually achieved by a layer or multiple layers of asphaltic concrete topped with a sealing layer of mastic.

The height of the dykes would depend upon the total storage needed as well as a minimum depth of water over the intake so as to avoid vortices at intake. At Ludington, the height of dykes is up to 52 m whereas at Revin, the height of the dykes ranges only from 10m to 20 m.

The design and construction of the dykes is similar to that of embankment dams. The only special feature which merits attention is the relatively rapid draw-down in the upper pool during generation phase. This draw-down is of the order of 12 m for the upper reservoir and 16 m for the lower reservoir for the Revin P-S plant. The embankments must be stable for the condition of frequent draw-downs and fillings in a short time.

The design considerations of the lower reservoir which is in a natural valley are not so stringent. The water is conveyed between the two pools through a system of penstocks and tunnels. If the conveyance system is long, intermediate surge tanks may have to be provided. But considering the two- way flow, it is clear that the permissible frictional losses have to be less than those in the conventional plants. As a result, the optimum size of a penstock in a pumped storage plant always comes out to be greater than that in an ordinary hydro-power plant.

In case of head race tunnels, the economic diameter normally works out such that the flow velocities at maximum flow are between 4.5m/s *to* 6.5 *mls.* For instance, Rodund II plant (Austria) provides a tunnel internal diameter of 4.15 m corresponding to a flow velocity of 6-7 m/s. The tunnel needs internal steel plate lining to resist erosion.

The intake at the upper reservoir is generally gate-controlled. These gates operate from an intake tower located in the reservoir. The minimum draw-down level in the reservoir must provide enough submergence depth over the intake so as to suppress the vortex formation at the intake. At Cabin Creek Plant (300 MW, USA) the minimum level is about 9 m above the top level of the intake. Further the level difference between the minimum and maximum levels is 27.5 m. [3]

Water Losses From Reservoir:

1. Evaporation loss.
2. Absorption loss.
3. Percolation loss. [11]

2.1.10. Power House

The power house of the P-S plant is situated between the *two* reservoirs. Due to requirements of submergence, the storage pumps or the pump-turbines are to be installed below the lowest tail water. Following table shows briefly, for a few well-known P-S plants, the submerge depth below the lowest tail water level.

Ronkhausen (2 X 76.5 MW)	16 m
Foyers (2 x *150* MW)	37.5 m
Cruachan (4 X 110 MW)	45.7 m
Waldeck II (2 x220MW)	52.6 m

Because of this requirement, virtually no P-S power house is above ground.

The usual construction is in one of the following three methods:

1. Installing the power house in an underground rock cavern with the flow passages and other utilities being provided through tunnels. Many plants have such underground power houses. Cruachan (UK), Coo- Troi-Ponts (France) Vianden (hj) and

Waldek II are examples of this kind. The cavern type underground house is usually egg-shaped with spans as wide -as 33.5m, as in Waldeck II. It can be theoretically shown that the egg-shaped or the elliptical rock caverns are the most efficient for rock-load.

2. Where the topography permits the power house is built in an open pit.
3. The power house can also be located in a shaft structure. This concept was first developed for Ronkhausen, and is now employed for plants such as Vianden (tenth machine), Rodund II (Austria) and Foyers (Scotland). The main feature of the power house is compactness.[3]

2.1.11. Efficiency Of P-S Plants

It is customary to state that for every 3KW input, you may expect 2KW output in pumped storage plants. The normally attainable overall plant efficiency is around 70%. It could be worked out as below, for closed cycle operation:

$$\eta_o = \frac{En_g}{En_p} \tag{2-4}$$

Where:

En_g= energy generated during the same cycle.

$En_{p=}$ Energy consumed during the same cycle

Now if Q is discharge and H is gross head , Then:

$$E_g = \frac{\omega \times Q(H-h_f)}{75} \times 0.376 \times \eta_t \qquad (2\text{-}5)$$

Where η_t = overall efficiency of generation

H = head m

Q = flow rate m^3/s

(including turbine , generator and transformer efficiency)

And

$$E_p = \frac{\omega \times Q(H-h_f)}{75} \times \frac{0.376}{\eta_p} \qquad (2\text{-}6)$$

Where η_p = overall efficiency of pumping operation

Then:

$$n\eta_o = \frac{\mathrm{Eg}}{\mathrm{Ep}} = \frac{(H-h_f)}{(H+h_f)} \times \eta_t \times \eta_p \qquad (2\text{-}7)$$

$$h_f = K\ H \qquad (2\text{-}8)$$

$$\eta_O = \frac{1-K}{1+K} \times \eta_t \times \eta_p \qquad (2\text{-}9)$$

Average values of η_t η_p and k are respectively 0.88, 0.85 and0.02 to 0.03. With these values, the overall efficiency comes out to be 72 percent.[3]

2.1.12. Electronics And Water Pumping Systems

Efficient pump selection depend on the accurate calculation of water system`s flow and pump head requirement . Digital electronics has created greater design accuracy that guarantees better pump selection . [11]

2.2. Main Components of the Plant

2.2.1. Prime Mover

The prime mover is hydraulic power plant converts the kinetic energy of water into mechanical energy and further into electrical energy.

The prime mover due to the action of water can be classified into Impulse turbine and reaction turbine.

In impulse type the pressure energy of water is covert to kinetic energy by nozzle and from high velocity of jet water and driving the wheel.

In the reaction turbine the water pressure combined with the velocity work in the runner and due to the combination and water passage the power will developed. [7]

2.2.2. Classification of Hydraulic Turbines

The hydraulic turbines are classified as follows :

1. According to the head and quantity of water available.
2. According to the name of the originator.
3. According to the action of water on moving blades.

4. According to the direction of flow of water in the runner.
5. According to the disposition of the turbine shaft.
6. According to the specific speed $N_{s.}$[1]

1. According to the head and quantity of water available :

a) Impulse turbine ... requires high head and small quantity of flow.
b) Reaction turbine ... requires low head and high rate of flow.

Actually there are two types of reaction turbines, one for medium head and medium flow and the other for low head and large flow.

2. According to the name of the originator :

a) Pelton turbine ... named after Lester Allen Pelton of California (U.S.A.). It is an impulse type of turbine and is used for high head and low discharge.
b) Francis turbine ... named after James Bichens Francis. It is a reaction type of turbine from medium high to medium low heads and medium small to medium large quantities of water.
c) Kalpan turbine ... named after Dr. Victor Kaplan. It is a reaction type of turbine for low heads and large quanties of flow.

3. According to action of water on the moving blades of the:

1. Impulse turbines (Pelton).

2. Reaction turbines(Francis).

4. According to direction of flow of water in the runner :

a) Tangential flow turbines (Pelton turbine).
b) Radial flow turbine (no more used)
c) Axial flow turbine (Kaplan turbine)
d) Mixed (radial and axial) flow turbine (Francis turbine).

In tangential flow turbine of Pelton type the water strikes the runner tangential to the path of rotation.

In axial flow turbine water flows parallel to the axis of the turbine shaft. Kaplan turbine is an axial flow turbine. In Kaplan turbine the runner blades are adjustable and can be rotated about pivots fixed to the boss of the runner. If the runner blades of the axial flow turbines are fixed, these are called “propeller turbines”.

In mixed flow turbines the water enters the blades radially and comes out axially, parallel to the turbine shaft. Modern Francis turbines have mixed flow runners.

5. According to the disposition of the turbine shaft :

Turbine shaft may be either vertical or horizontal. In modern practice, Pelton turbines usually have horizontal shafts whereas the rest, especially the large units, have vertical shafts. [1]

6- According to specific speed N_s:

Specific speed refers to the speed of a geometrically similar turbine (i.e a turbine identical in shape, blade angles and gate opening etc) which would develop unit power when working under a unit head. The turbine specific speed is prescribed by the relation:

Specific speed is a characteristic index which serves to identify the types of hydraulic turbine.

Pelton wheel	**Francis turbine**	**Kaplan turbine:**
N_s=9-17 for a slow runner =17-25 for a normal runner =25-30 for a fast runner =40 for a double jet.	N_s=50-100 for a slow runner =100-150 for a normal runner =150-250 for a fast runner	N_s=250-850.

2.2.3. Pelton Wheel Turbine

This is special type of tangential flow impulse turbine generally mounted on horizontal shaft; a number of buckets are mounted round the periphery as same in figure (2.6).

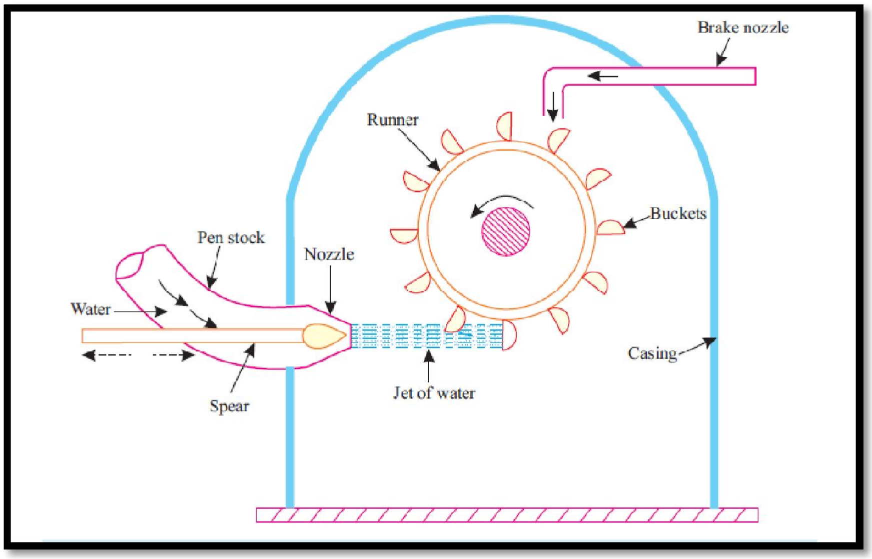


Figure (2.6) Single jet horizontal shaft Pelton turbine.

It consists of a rotor equipped with elliptical shape bucket and nozzle. The hydraulic efficiency of Pelton wheel lies between 85- 90%, Now a day's Pelton wheel are used for very high heads up to 2000m. [8]

2.2.4. Francis Turbine

It a reaction type turbine and is suitable for low and medium head power plants show in Figure (2.7). On this type the water enters into a casing with relatively low velocity passes through guide around circumference and flow through the runner and finally discharges into a draft tube sealed below the tail water limit. The water passage from head race to tail race is completely filled with water which acts upon the whole circumference of the runner. There are mainly to types of Francis turbines known as open flume type and close. In open flume type the turbine is immersed under water of the head race in concrete chamber and the discharged into the tail race through draft tube.

In the closed type the water is led to the turbine through the pen stock whose end is connected to the spiral casing of the turbine. The open type is used for the plants of 10m head where as closed type is preferred above 30m head.

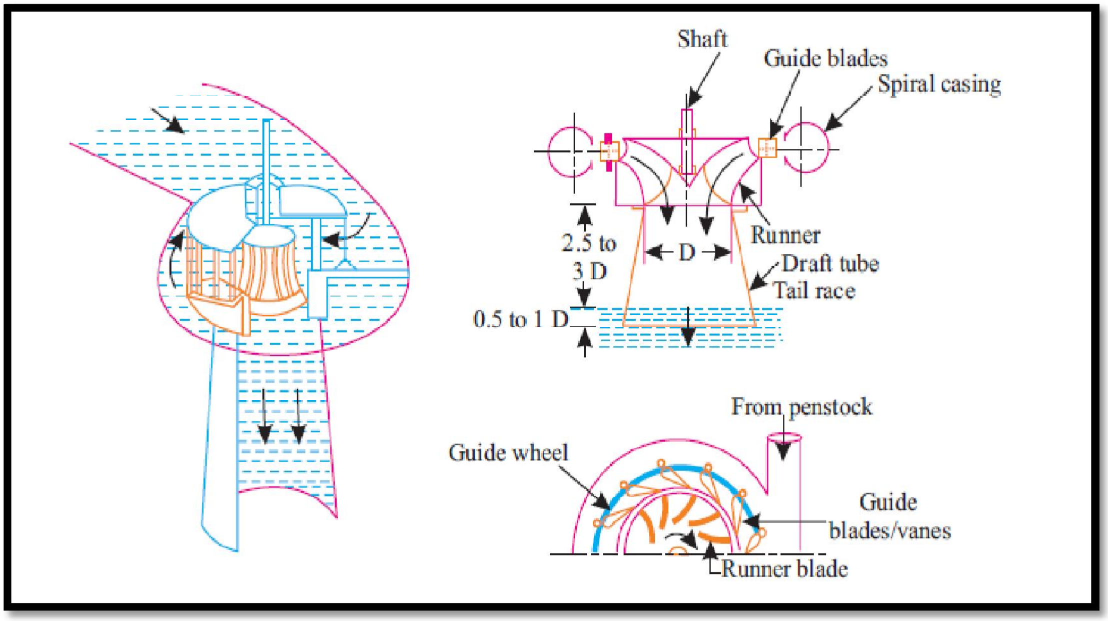


Figure (2.7) Francis Turbine.

The guide race vanes are provided around the runner to regulate the water flowing through the turbine.

The majority of the Francis turbine is in ward radial flow type and it’s preferred for medium heads. The advantages of inward over out ward are:

1. The formations of eddy and pressure loss are reducing by the gradually convergent.
2. The runaway speed of the turbine is automatically checked as the centrifugal force acts out wards while the flow is in wards.
3. The regulations by the guide vanes are better.
4. The frictions losses are less.
5. This type can be used for high heads without increasing the speed of the turbine.

Recent development of Francis Turbines:

The last decade has seen considerable developments in the design of Francis turbine and the modem trend is to go in for large sizes of machines with high speeds so as to economies in the cost of plant and civil work. [8]

2.2.4.1. Francis versus Pelton

The Francis turbine is used for all available heads on the other hand. Pelton Wheel are used for very high heads only (200- 2000m).

The Francis turbine is preferred over Pelton for:

1. 1The variation in operating head is easily on Francis.
2. The size of runner, generator, power house for Francis IS small.
3. The ration of Maximum and Minimum operating head can be even tow incase of Francis turbine.
4. The efficiency of Pelton decrease faster with wear. [1]

2.2.5. Kaplan Turbine

It is also are action type turbines and has gates and governing mechanism similar to that of Francis turbine. The different between Kaplan turbine and Francis turbine is that in the former runner the water strikes the turbine plates axially where as the later receives water radially. Water flows radially in wards through regulating gates all rounds the sides changing directions in the runner to axial flow and casing a reaction force which drive the turbine a Kaplan is shown in Figure (2.8).

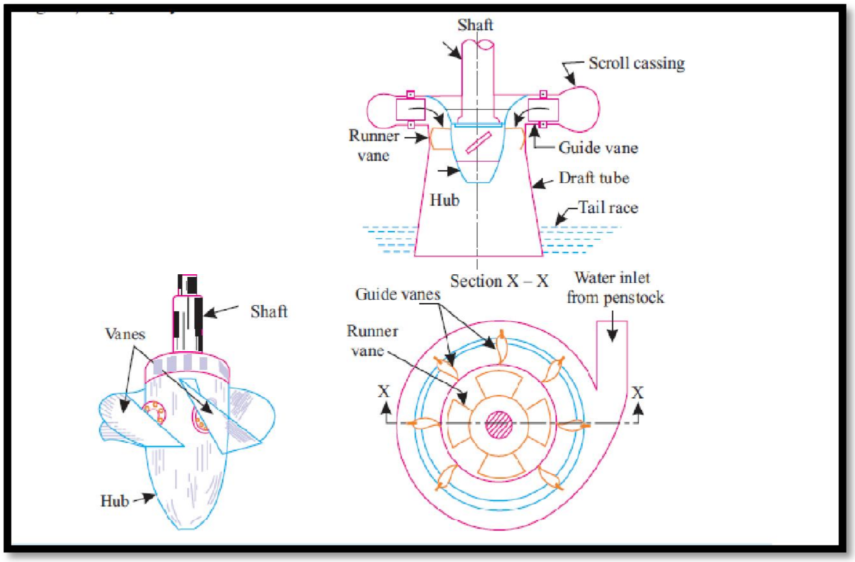


Figure (2.8) Kaplan turbine.

This type of turbine is suitable for low head and large flow plants. In this type of turbine the drawback of considerable loss at low loads due to rotary motion of water in Francis turbine is over come and uniform efficiency at all loads is maintained. Kaplan turbine gives high speed than ordinary Francis turbines. The characteristics feature of Kaplan turbine is that the gate opening and blade angle and adjusted simultaneously by the governing mechanism. Its efficiency about 90% at all loads. [8]

2.2.5.1. Kaplan versus Francis Turbine

The Kaplan turbine is preferred over Francis turbine for:

1. More compact and small size.
2. It is part-load efficiency is considerably high.
3. The friction losses are small.[1]

2.2.6. Selection of Turbine

The major problem confronting the engineering is to select the type of turbine which will give maximum economy. The hydraulic prime mover is always selected to match the specific conditions under which it has to operate at maximum possible efficiency. [7]

The following factors have the bearing on the selection of the right type of hydraulic turbine which will be discussed a partly:

1. Rotational speed:

In all modem hydraulic power plants, the turbines are directly coupled to the generator to reduce the transmission losses. This arrangement of coupling narrows down the range of the speed to be used for the prime mover. The generator generate the power at constant voltage and frequency, and therefore, the generator has to operate at it is synchronous speed. The synchronous speed of generator is given by:

$$N_{sync} = \frac{60\,f}{P} \qquad (2\text{-}10)$$

where:

f = Frequency ,P = Number of pairs of poles used

For the direct coupled turbines, the turbine has to run at synchronous speed only there is less flexibility in the value of synchronous speed. As more or less fixed (50 or 60 cycle per second). It is always preferable to use high synchronous speed for generator because the number of poles required would be reduced with an increase in the synchronous speed, and the generator size gets reduced. Therefore The value of specific speed adopted for The turbine should be such that it will give synchronous speed of The generator.

2. Specific Speed.

The specific speed can be calculated using the equation of:

$$\frac{N\sqrt{P}}{H^{\frac{5}{4}}} = \frac{n\sqrt{p}}{h^{\frac{5}{4}}} \qquad (2\text{-}11)$$

Where:

H= head in m

P = power output.

N = speed by RPM

In modem power plants, it is common practice to select a. high speed runner because it more economical as the size of The turbo-generator as well as that of power house will be smaller.

High specific speed is essential when the available head is low and power output is high because otherwise the rotational speed will be very low and it will increase the cost of turbo- generator and the power house as the sizes of turbine, generator and power house required at low speed will be large. On the other hand, there is no need of choosing high specific speed runner when the available head is sufficiently large because even with low specific speed, high rotational speed can be attained. Now it has been shown with the above discussion that if the speed and the power under given head are fixed the type of the runner required is also fixed.

3. Maximum efficiency:

The maximum efficiency, the turbine can develop deepened upon the type of the runner used. In case of impulse turbine, low specific speed is not conducive to efficiency, since the diameter of the wheel becomes relatively large in proportion to the power developed so that the bearing friction and wind age losses tend to become too large in percentage value. The value of specific speed for high efficiency is nearly 20.

The low specific speed of reaction turbine is also not conductive to efficiency. The large dimension of the wheel at low specific speed contributes disc friction loss. In addition to this the leakage loss is more as the leakage are through the clearance spaces becomes greater and they hydraulic friction through small bracket passages is larger .these factors tend to reduced the efficiency as small values of specific speed are approached.

The high specific speed reaction turbine is associated with larger discharge losses (v2/2g) as mentioned earlier. The friction and leakage losses are reduced with an increase in specific speed is to decrease the efficiency. Total losses (friction, leakage and disgorge) is minimum at medium specific speed .there for, it’s always preferable to select the reaction turbines of medium specific speed if they operate at constant load conditions.

The effect of specific speed on the maximum efficiency . Higher efficiencies have been attained with reaction turbines than with Pelton wheels the maximum recorded efficiency till now for reaction turbine is 93.7% about quite large units have shown efficiencies over 90%. The highest recorded value of efficiency for impulse turbine is 89% but the usually maximum is 82%.

The efficiency Pelton wheel is not dependent on its size- like reaction turbine for smaller powers.

4. Part Load efficiency:

Full load is defined as the load under which a turbine develops its maximum efficiency. Anything above that is known as over load and anything below that is known as part load.

The part load efficiency differs greatly for different specific

Speed and Type of Turbine:

In case of Pelton wheel only the jet diameter through which the water flow is reduced by the governing mechanism when the load on the turbine is reduced below full load. The velocity diagram at inlet and out let remain practically unaltered in shape at all loads except for very low and very high loads. Thus the absolute velocity at inlet does not change and the discharge loss remains same therefore, the part load efficiency curve is more flat in case of pelton turbine.

In case of reaction turbine, the water completely fills the bucket passage and a reduced rate of discharge (require at part load) requires appropriate reduction in the relative velocity at outlet. Thus the absolute velocity at out let and discharge losses are in evitable increased. Therefore, the efficiency decreases with decrease in load on the turbine.

The higher specific speed of the turbine the generator the discharge losses at the normal gate opening and hence greater the effect produced upon the efficiency .

The part load characteristic of Francis turbine may affect the choice of the type of wheel to be used. For a plant with variable load, the advantages of the higher specific speed wheel may be offset by lower part load efficiencies. If a constant speed is selected which is the best for full load, there will be sacrifice of efficiency at part load condition and this sacrifice will be greater as specific speed of turbine is higher. The high specific speeds Francis turbines is suitable for low head plants, but are unsuitable when required operating under part load condition.

The efficiency versus load curve remain constant for Kaplan turbine as The blade angle is adjusted according to The load on The turbine therefore, this turbine is more suitable than Pelton when The load on The turbine changes from minimum to maximum .

5. Head:

The choice of turbine is the function of power and speed desired as well as the head also. Head plays a predominating influence, therefore, the choice of the turbine depends upon the available head. The relationship between the tow is given by the equation :

$$\text{Specific Speed of The turbine} = \frac{6800}{H+907} + 84.5 \qquad (2\text{-}12)$$

(for Francis turbine)

The specific speed of Propeller turbine $= \frac{6800}{H+907} + 156$ (2-13)

Where : H = head in meters.

The Pelton wheel is preferred generally in the range of 200m to 2000m head. The example of high head plant is Reisseek plant in Austria where the head is 5800ft (l800m).

The reaction turbine is generally used for the head between 15m and 250m. The reaction turbine can be used with variable head as tends itself readily to the use of draft tube and it may be drowned without any losses of efficiency. The efficiency of reaction turbine is not much sensitive to the change of head as that of Pelton turbine. The percentage variation in head is usually greater in low head plant and this is the reason for not adopting.

The Pelton turbine for low head plants. The maximum head for The reaction turbine is limited to 330m because of possible danger of cavitations and difficulty of building casings, to with stand such high pressure by using high speed reaction turbine (high Ns), The runner size and overall cost of the power plants is reduced. However, the is some lost of efficiency at high specific speed. The present trend is to use runner at high specific speed. The present trend is to use runner at high specific speed sacrificing some efficiency.

The propeller turbine are used in The range of 5m to 30m head the maximum head utilize for Kaplan is 70m in Bort Rhuct power plant in France with rating of 31800Hp. Propeller turbines are commonly used upon 15m head but only when there are practically no load variation.

6. Types of Water Available:

The reaction turbines are not suitable for high head plant when the water carries undue amount of dirty and sand, because its runner cannot with stand the erosive action of the water. Its use is further restricted because the water ways are of very small suction area and easily become choked by floating debris and fluid frictional losses become relatively high.

The greater simplicity and accessibility of The parts requiring replacement due to normal wear and tear or due to the chemical action of water renders Pelton wheel more suitable when the supply is taken from stream carrying an appreciable amount of grit or silt in suspension or the water from chemical industries are discharged in the river and carried in prime movers.

7. Run away speed:

In selecting runner, consideration must be given to the relation between the characteristics of the turbine and generation. The speed of the turbine increases with increase in head.

The percentage change in head in low head plants is much more than in head plants, and therefore, the turbine speed shoots up when the acting head increases. Therefore, the generator must be designed to stand the full run away speed of turbine to which it is connected under maximum head conditions.

The reaction turbine will reach about 193% of its normal speed if the head on the turbine reaches 15% above normal. For fix blade propellers the maximum ruin a way speed is as high as 250% of its normal speed. Higher the runaway speed of the turbine, the greater will be the cost of the machines as they should designed to with stand up normal stresses which occur hardly for small period of the year.

Presently the operation of hydraulic turbine frequently involves the injection of air into the center of the water stream before or after the runner. The purpose of air injection is to reduce the dynamic forces during time of runaway operation. The air injection can result in an increase in runaway speed of up to 20%. In most cases air injection has beneficial effects but under normal operating conditions, the air while suppressing pressure pulsation and vibration can also reduce the power output by as much as 1 to 3%.

Cavitations:

The use of runner having higher specific speed greater than the recommended values may result in cavitations. This may be avoided by setting the runner at lower elevation from the tailrace.

If the cavitation occurs, the runner blade of 2.5 thick may be corroded with in a year’s operation. The usual method to repair is welding of corroded parts. The dense metals likes cast steel and stainless steel resist better to cavitation than porous material like cast iron. The save height of setting the runner above tailrace level varies with head and specific speed. Many time, the runner must be, located under tailrace level (high speed Kaplan or Francis turbine used in low head plant) to avoid therefore, cavitation. It is always desirable and economical to repair, once in a year, by welding the damages done by cavitation than to prevent cavitation.

8. Numbers of Units**:**

The average over all efficiency of large plant is .influenced by the numbers of units installed. A plant with two similar units would have better value of average efficiency than with one unit of double the size of single unit. The plant containing three or more units would have still better average efficiency through an improvement is not as marked as when one unit is replaced two. Multi unit's plants can meet large variation of load more economically as more units work at full load and only one unit's works under a variable load to take the fluctuating load.

The present trend is to use single units of big size instead of two or more units to reduce the capital cost and running expenses. The selection of number of unit to be installed left as a management and economic problem rather than a design problem. [7]

Over All Cost of The Plant: The plant should be designed for the minimum cost as cost is the prime consideration in designing a plant. The total cost consideration should include the capital cost and running cost. The design should generate the power with minimum cost. [2]

2.2.7. Penstocks

General Penstocks are the pipes that supply water from the head pond or the fore bay to the turbines. Water, after entering the intake structure is carried through the conveyance system which may be a canal flume, tunnel , pipe of any martial or a combination of these. The penstocks are the pressure conduit, and the high line or non pressure conduit are the canal and flumes. The design principle for the penstock are the same as for pressure vessels and tanks; however, because of the governor control and turbine gate operation, sudden pressures be considered while designing. When the distances between the fore bay and the power house are short, a separate penstock for each turbine is preferable, while for moderate heads a long distances, a single penstock to feed two or more turbine through a pipe special - termed as manifold provided at the turbine end. [3]

2.2.7.1. Classification of Penstocks

Penstocks may be classified on the bases of:

1. The material of fabrication.
2. The method of their support.
3. The rigidity of connections and support.

Wall thickness of Penstock:

The ASME code gives the formula for thickness as follows:

$$t = \frac{pR}{S\eta - (0.6\,P)} + 0.15 \qquad (2\text{-}14)$$

Where: t = wall thickness in cm.

P = pressure Kgf/cm^2.

R = internal radius in cm.

S = design stress Kgf/cm^2.

η = join efficiency factor.

And 0.15 cm is allowance of corrosion.

Handling stresses, however, should also be taken into a count as a criterion in determining the wall thickness of a penstock.

The main considerations which lead to the final choice are given below:

1. Economy. The design should strive for maximum economic solution. If the number of penstocks increases, the total weight of steel and the erection costs also increase. For instant, if a single penstock is used to feed 4 turbines of a power house instead of 4 different pipes, each for one turbine, the total saving in weight of the steel would be of the order of 25 to 30%. It is for this reason that the present trend is to use a bigger diameter-smaller number arrangements rather than small size-bigger number arrangement.

However, the saving in the penstocks costs would decreased due the increased number of accessories and specials needed in case of either first or the third alternative. In such a case, the penstock has to have a manifold at the end and also the inlet valves to control the discharge in each branch of the manifold. Thus from overall economic point of view we can that where the length of the penstocks is short, providing one pipe for each turbine may prove to be more economical. On the other hand, for long penstocks, a single pipe or next best to it, as few pipes as are possible, may be a better choice.

2. Operational Safeguards. From the view point of operational safeguards, a single penstock is often ruled out, as any damage to that penstock would necessitate a total shut-down of all the turbines.

3. Transportation Facilities. The penstocks are shop-welded in short suctions and then transported to the sites. The decision regarding the number of penstocks automatically would influence the dia. Of each penstock. It, therefore, has to be seen whether there are

adequate facilities for the transportation of a given size of a penstock. [3]

2.2.7.2. Economical Diameter of Penstocks

Once the number of penstocks is fixed, the discharge to be conveyed by each penstock is also fixed. The next step is to determine the size of the pipe to transport the required discharge.

We have there two variables, namely, the diameter of the penstock D and the velocity of flow V which is inversely proportional to D2. Thus, there are various combinations of V and D which would gives the same discharge. We have also to remember that the friction allosses in the penstock pipe given by h f = fl x Q 52 /12.1D also depend upon diameter and in turn determine the transmission efficiency on the penstock pipe. Thus, larger than diameter for a given discharge, smaller will be the head losses and greater will be
the net head available to the turbine, resulting in greater power development. On the other hand, greater size penstock would mean less velocity and greater velocity investment. We should choose, therefore, a size which would give us least annual costs. Thus, the problem is one of economic comparison of various alternatives and to choose an optimum size which results in maximum economy.

The methods used to determine the size /diameter of penstock are given below:

Empirical Formula:

The empirical formula is some over-simplified thump rule solutions based on available experience. These may not fit to conditions different than those from which they are deduced. Two popular formulas are due to

USBR (United States Bureau of Reclamation) and to G. Sarkaria respectively are as follows:

a. USBR Formula:

$$V = 0.125\sqrt{2gH} \qquad (2\text{-}15)$$

Where:

V = optimum velocity in m/s .

H = maximum working head in m .

The formula generally apply up to middle range of heads.

b. Sarkaria Formula :

$$D = 0.62\frac{P^{0.35}}{H^{0.65}} \qquad (2\text{-}16)$$

Where :

D = Penstock diameter in m.

P = hp transmitted by the pipe .

H = Max net head at the end of Penstock in m . [2]

2.2.8. Draft Tubes

The draft tubes are either straight conical draft tube with a circular suction or they are elbow-shaped tubes with gradually increasing area; the shape changing from circular at the runner suction to rectangular at the outlet suction. The draft tubes are needed for Francis and Kaplan turbines and fulfill a two-fold function.

1. They achieved the recovery of velocity head at runner outlet, which otherwise would have gone to waste as an exit loss.

2. They allow the turbine to be set at higher elevation without losing the advantages of the elevation difference.

This is achieved as a result of sub atmospheric pressure developing at runner outlet due to the draft tube. Looking to Figure. (2.9) and applying energy equation between typical points i and o

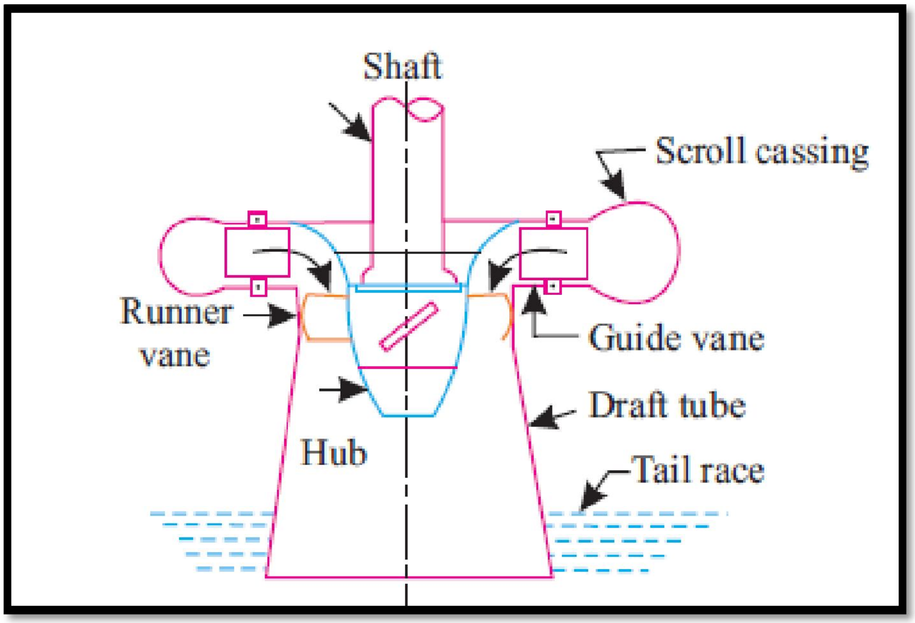


Figure (2.9) draft tube.

$$\frac{p_i}{w} + h_s + \frac{V_i^2}{2g} = \frac{V_o^2}{2g} + h_{i\text{-}o} \qquad (2\text{-}17)$$

or

$$\frac{p_i}{w} = - h_s - \frac{V_i^2 - V_o^2}{2g} + h_{i\text{-}o} \qquad (2\text{-}18)$$

Where $h_{i\text{-}o}$ is the loss of head between the points i and o .

If we define the draft tube efficiency η_d by ratio :

$$\eta_d = \frac{\frac{V_i^2 - V_o^2}{2g} + h_{i-o}}{\frac{V_i^2}{2g}} \qquad (2\text{-}19)$$

Where:

V= speed

g = gravity

Then equation above can be written as :

$$\frac{p_i}{w} = -h_s - \eta_d \frac{V_i^2}{2g} \qquad (2\text{-}20)$$

Draft tube efficiency is usually of the order of 85 to 90%. Since Pi is the pressure at the outlet of the runner, the turbine over pressure increases by the magnitude of its negative value. The maximum negative pressure allowed depends upon the cavitation characteristics of the runners.

The draft tube efficiency naturally affects the overall efficiency of the runner. The water which flows from the runner into the draft tube does not have a clear axial flow, but also has a vortex pattern and hence the losses are due to this swirling flow. [7] [1]

2.3. Wind Energy & Wind Pump

2.3.1. Importance of wind

Wind is air in motion, wind mill, wind pump, or wind turbines convert the kinetic energy of the wind into useful work.

Wind energy is movement force or (mechanical force) that push air to move from area to another that made difference of temperature from area to another that made difference in air density and then there is areas of high atmospheric pressure and areas of low atmospheric pressure.[10]

The reasons that make difference in temperature are:

1. Rotating of the earth around the sun.
2. Rotating of the earth around its axis.
3. Topography.
4. Rains.

From experience found that 0.15% of the solar energy that arrived to the earth surface go to move the air. In these days when the prices of the energy became expensive, many countries made programs to use wind in generation of energy.

It's believed that the annual wind energy available on the earth is about 13 x 10 12 KW Ih. This is equivalent to a total installed capacity of about 1000 mw or 1500 power station each of 1000 mw capacity. And this number me be became more in this last years.

While the power that could be tapped out from the rat’s sea of the wind me be comparable with hydropower, it should be remember that it's available in a highly altitude form. Therefore while dams are built to exploit and regulate hydropower there is no such parallel on the wind power scene.

Wind had been used as source of power in sailing ships for many centuries. The force that acts on ship sail later employed to run a wheel like a water wheel which already existed. The wind driven wheel first appeared in Persia in the seventh century AD by tenth century AD windmills where used for pumping water for irrigation and by thirteenth century AD for com grinding.

The com grinding mill was two- storage structure, the millstone was located in the upper story and the lower story consist of a sail rotor. It consists of six to twelve fabric sails, which rotated the mill by the action of wind. Shutters on the sail regulated the rotor speed. In 1592 AD the windmill was used to drive mechanical saw in Holland. A large Dutch mill of the eighteenth century, which a 30.5-m sails, spans developed about 7.5 kW at wind velocity of 32 km/h.

The energy of fowling water and wind was the only natural source of mechanical power before the advent of steam and internal combustion engines, therefore wind mills and water mills where the first prime movers which were used to do small jobs, such as com grinding and water pumping. It is generally believed that the windmill it is appearance much later than the water mill.

The water mills had to be located on the banks of stream. They fore they suffered from the disadvantages of limited location. In this respect windmills had greater freedom of location. If sufficient wind velocities where available over reasonable period, more important factors in choosing a site for the wind mill would be the transportation of com grinding and the site for water pumping.

In both water and wind turbine plants the working fluid and it is energy are freely available though they are no fuel costs involved, other expenditures in harnessing this form of energy not negligible. The capital cost of some wind power plants can be prohibitive. As other power plant the cost per unit of energy generated decrease as the size of the wind turbine increase. Compared to other well-established sources of energy, the wind energy at present appears to be in significant as far as the contribution to the total energy requirement is concerned. However, at a time when mocking is facing energy irises every source, however small, should be tapped. [10]

2.3.2. Wind Power Applications

In the past wind power was first used widely for com grinding and waters pumping. Then windmills where used to drive saw mills and oil extraction plant. Now wind energy is being used for large number of other application in areas where either electric supply is not available or fuel supplies are scarce.

A wind driving AC generator of sufficient large size is used the main supply lines in this application the main problem is to usefully wind energy at variable velocities. Therefore, to overcome this limitation windmill can be used to drive DC generator which generate electric power of varying voltage corresponding to the fluctuation wind velocities. This power can between used for heating electrolysis of water, battery charging etc... charged batteries and stored hydrogen and oxygen can then be used to supply energy as and when required. Hydrogen can also be used for the manufacture of the hydrochloric acids and methane gas.[15]

Wind energy has been utilized for storing compressed air. The compressed air is used either to drive an electric generator through an air turbine or for other industrial applications. Other application of wind energy, especially in rural areas are in the heating of water and rural products, refrigeration and drying of agricultural products.

The success of wind power utilization schemes depends on suitable applications, energy storing methods and the overall costs involved.[10]

2.3.3. Difficulties of Uses Wind Energy

Wind energy lie any type of renewable energy, that we cannot depend on it in continues manner, because in any place on the earth in same times there is available wind and in other time there is no wind, and to solve this problem of fluctuating energy due to changing in wind speed, important to have another program with the program of wind energy. This program is to build plants that save wind energy in shape of electrical energy or in pumping water in high place (storage) and use it again to generate electricity and this is same to our project. [10]

2.3.4. Selection Of Site For Wind Pump

The major considerations for selection of site for wind pump are:

1. High value of main wind velocity.
2. Nature of surrounding (building, rocks, forests).
3. Topography.
4. Altitude and distance from the sea.
5. Accessibility by rail or road, cause of construction of service road.
6. Quality of land for huge foundation.
7. Possibility of installing number of wind pump in the same area.
8. Availability of local labor and building material. [10]

2.3.5. Wind Pump

It is a devise that use to convert wind energy into pumping action.[4]

2.3.5.1. Elements Of Wind Pump

The main elements of wind pump are:

1. Rotor :

A high-speed rotor requires a number of blades to extract the energy from the wind stream, where as slow machines requires a relatively larger number of blades.

The rotor blades are subjected to high an alternating stress. There for the blades must be sufficient strength and be light.

The materials used in the blades like wood for small high - speed machines, small blades are cast plastic materials are now also making inroads into the manufacture. Also the blades must have high strength density ratio.

2. Motion Transmission:

It is consisting of crankshaft and pump link the main faction of the transmission is to convert rotary motion into reciprocating motion.

THE PUMP:

a) It consists of the following:
b) Piston with skin over
c) Stainless steel piston cylinder Pressure valve

3. Rotation Mechanism:

A horizontal axis wind Pump requires mechanism, which turn the rotor into the wind stream.

A fantail whose axis of rotation is normal to the axis of main rotor is also employed to turn the windmill into the wind stream.

4. Tower:

All windmills have to be mounted on stand or tower above the ground level. Tower high above 250 m has been employed for obtain high wind velocities and mounting large wind pump rotor. Increasing the tower high besides increasing capital cost also increase the maintenance cost.

The tower me constructed from wood, brick and concrete, but an angle iron steel tower of four sides pyramidal shape is commonly used. [4]

2.3.6. Available Sites For Wind Energy In Sudan

Sudan has good average wind velocities that the average wind velocity along the river NILE from Khartoum to Halfa is more than 5 m/s also this in Red Sea coat. In Gazeera and northern areas of Sudan the average year generating of wind energy between 500-600 kW/m2 [5]

2.3.7. Uses of Wind Energy In Sudan

Wind energy is used to push the sailing boats from many years ago. But the really use of wind energy in Sudan in 1950 that the government bout about 250 wind Pump (southerner type) to pump the water from depth between 150-400m. But this Pumps face many problems and it is stopped in 1965. Also there is some research in wind energy.[6]

Table (2.1) Show Wind Pumps in Sudan.[6]

AREA	NUMBER OF UNITES	TYPE
TOUTE ISLAND	2	CWD
SOUBA	4	CWD
GABA AWLYA	4	CWD
TOKAR	2	CWD
KAREEMA	2	CWD
ALBOTANA	2	KIJITO
SHAMBAT	2	CWD
TOTAL NUMBER	18	

Table (2.2) Show the average wind velocity and wind power for main stations in Sudan.[5]

Name of the station	Average Wind velocity in The year (m/s)	Average Wind power (W/m^2)
ABO HAMAD	4.67	65.8

ABU NEEAMA	3.83	14.6
ATBARAH	2.12	11.6
ALDAMAZEEN	2.6	11.4
ALFASHIR	2.21	7
ANEHOUD	2.32	8.1
ALOBAIED	3.35	27.3
ALGADARIEF	2.68	12.4
ALGENENAH	2.96	16.9
HALFA ALJADEEDAH	3.5	27.7
KAREEMA	4.3	53.4
KASSALA	1.8	3.8
KHARTOUM	4.12	45.2
KOSTI	2.37	8.6
PORT SUDAN	3.76	34.4
WADIE HALFA	4.22	48.6
WAD MADANE	3.22	28.2
DONGOLA	4.5	62.1

Table (2.3) Show the average wind velocity in Khartoum.[5]

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NO	DEC
2006	5	5	5	4	4	4.5	5	5.5	4.5	3.5	5	4.5
2007	5	4.5	5	4.5	4	4.5	5.5	5	4	4	4	4.5
2008	5	5.5	4.5	4.5	4	4.5	4.5	5.5	3.5	3	4	4
2009	4.5	4.5	5	4	5	4	5	4.5	4	3.5	4.5	4
2010	4.5	4	5	4.5	4	4.5	4.5	5	4	3.5	4	4.5
2011	4.5	4.5	5.5	5	4.5	4	5	4.5	4	3.5	4.5	4.5
2012	5	5	5.5	4	4	4.5	5	5	4	3	4	4.5
2013	4.5	5	4.5	3.5	3	3.5	4.5	4	4.5	4	4	4.5
2014	4.5	4.5	5	4.5	4	3	5	4.5	4	4	4.5	4
2015	5	4.5	5	5.5	4	4	4	5	4	3.5	5	5.5
2016	5.5	5	4.5	4	4	4.5	5	4.5	4	3.5	4	5.5

The numbers is wind velocity in m/s

Wind power density $= \frac{1}{2} \times \delta_a \times V^2$ (2-21)

Where :

δ_a = Air Density = 1.293 kg/m^3 .

V = The average velocity of wind at the high of 15.2 m from earth surface .

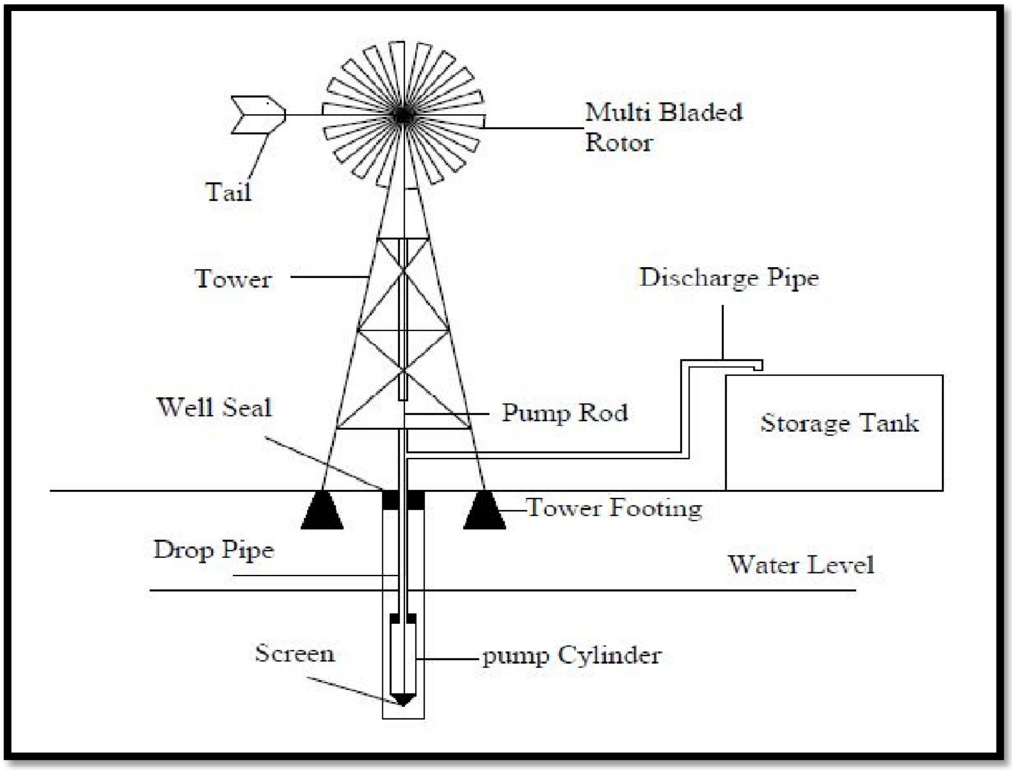


Figure (2.10) Wind Pump Elements.

1) The Mechanical Power that developed from Wind:

$$P = \frac{1}{2} \square V^2 \qquad (2\text{-}22)$$

Where :

P = mechanical power.

□ = mass flow rate kg/s .

$$\square = \rho A V \qquad (2\text{-}23)$$

where :

ρ = air density watt/m^2 .

A = surface area that the blade of the fan move it m^2 .

2) Work done by the Pump:

$$\text{Work} = w\ Q\ (h_s + h_d) \qquad (2\text{-}24)$$

Where :

w= specific weight of water .

h_s = section head of pump .

h_d = delivery head of pump . [4]

Chapter Three

Methodology

3.1. Introduction

The classification of Pumped storage plant is on the basis of cycle operation. Some plants are operated on a daily cycle of pumping and generation. Some are planned on weekly cycle where the pumping is confined to slack weekend periods only. A few pumped storage plants have been even on seasonal cycle where Pumping is done during seasons of lean demand and generation during high demand seasons.

The project is like the last type that we pump the water during winter; in this season the demand the electricity is reduced, the generation during the summer season that there is higher demand of electricity. Many types of plants built in Europe for seasonal operation. Examples of this type are Lunerse (Austria) and Hewfurt II (Germany). But important point of view that this plant (our project) is work under emergency conditions when the peak demand is present.

The selection of 100 Mw capacity of our plant that refer to the available M watts in winter season, see below table for demand. Also we select 100 Mw due to the capacity of upper – reservoir.

.

Table (3.1) Peak load and Of peak for Sudan and Khartoum.[12]

	Peak load (MW)	OF Peak (MW)
Sudan	3000	800
Khartoum	1650	500

3.2. The Project Site

The site of the project is located on the Sabloka. The Sabloka area is located at 80 km north of Khartoum it is oval shaped. This area is accessible by means of transport bus or train. The total area of the oval shape is about 2755km^2.

This area is very significant due to their position from Khartoum and the industrial area of Garri, also it is not far from the main road of Khartoum-Shendi. The main feature in the Sabloka area is the River Nile which penetrates and divide it into two parts which make the area more suitable for our project and provide good availability of water.

On this area choose the area near the cataract on their east side, (as shown in fig (3-1) the shadow area) due to many reason such as: The availability of solid and flat type of rockets at which called (Rhyolite Lava Volcano) at which make the storage very easy also it has moderate area their diameter is 5-10 km and has a high of 140-150 m.

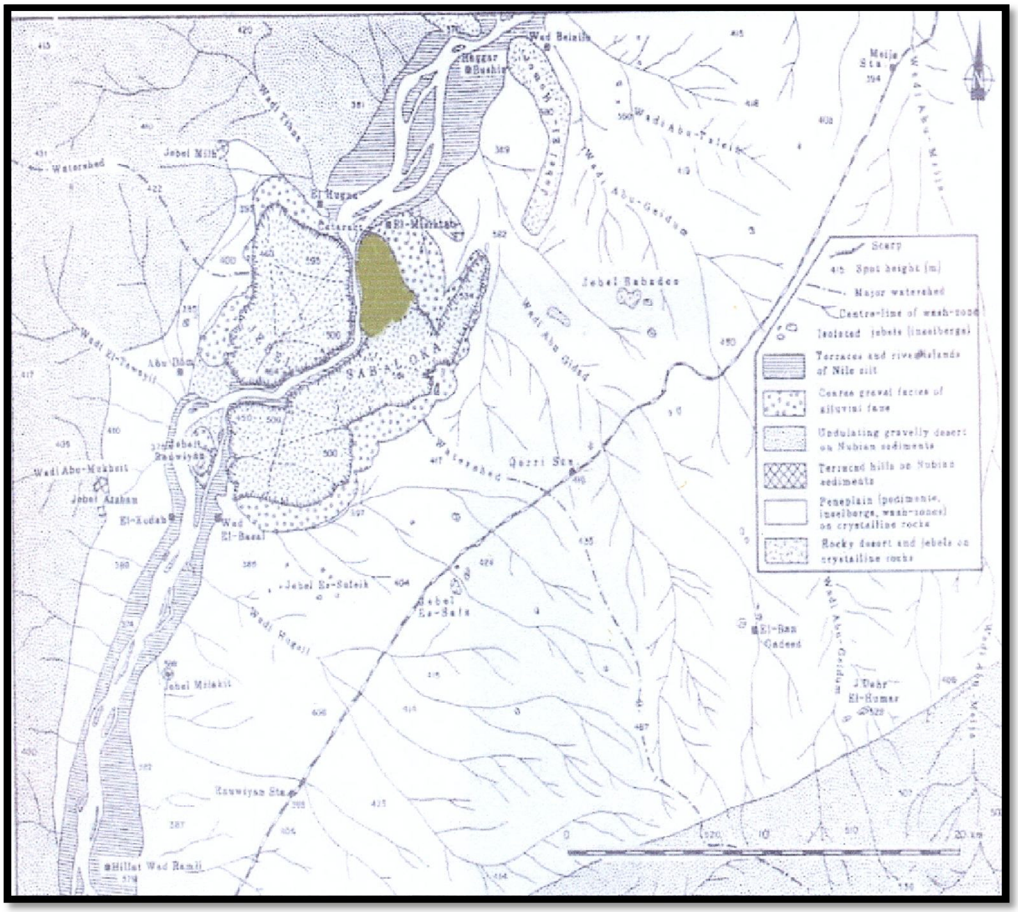


Figure (3.1) Geological map of the Sabaloka area.[13]

3.3. The Human Activity

The Sabaloka area is populated by Elhussania and Elgualian. Their main activity is agriculture, fishing. They live along the Nile while some of them breading sheep and goats. Also they grow some vegetables fruits, also they have some agricultural project like Alhugna. Their villages are Elmisktab, Elhugna and Hagar Alasal. Our project can improve these areas by increasing their agricultural capacity due to the provider of electricity. they can make some factories such as factory for fruits and vegetables canning.

3.4. Reservoir

In mixed type of plant (lower of the reservoir is a natural stream and the upper reservoir is hill top likes this project, and this is most common type of plant such as Reven plant (France).

The intake of upper reservoir is generally gated. Controlled this gate tower located at upper reservoir.

Figure (3-2) Shape of Reservoir of Pumped Storage Plant.

3.5. Surge Tank

The surge tank or surge tower is a structure which forms an essential part of the conveyance pressure conduit system whenever such systems are long. If the powerhouse is located within a short distance of the headwork, surge tanks are not necessary. Thus run- of-river plants and medium head schemes where the powerhouse is located at the toe of the dam, no surge tank is needed.

In this project we did not use surge tank because there is no pressure tunnel. That due to small distance between the upper reservoir and the power house.

It may be mentioned here that some of the resent plants in USSR however do not have surge tank. One such example is Nureksk station.

3.6 Penstock

The design of penstock should strive for maximum economic solution. If the number of penstocks increase , the total weigh of steel and erection costs also increase.

In our project used two penstocks for the two turbines and we did not use orrpen stock with y -branch, (that reduce the cost), because the single penstock is often avoided, as any damage to that pen stock would necessitate a total shut down of all the turbines.Also we install the penstock on the surface of mountain to reduce the cost of the plant.

$$The\ length\ of\ the\ penstocks = \sqrt{H + (slope)H} \qquad (3.1)$$

The velocity of water in the penstocks (V) is given is given by the equation:

$$V = 0.125\sqrt{2gH} \qquad (3.2)$$

The diameter of the penstocks (d) =

$$= \frac{0.62 \times P^{0.35}}{H^{0.65}} \qquad (3.3)$$

Where:

H= head of reservoir in m.

P =power

Friction losses:

$$h_f = \frac{4flV^2}{2gd} \qquad (3.4)$$

Where:

f = dracy factor $= 0.005\left(\frac{1}{12d} + 1\right)$ for a new and smooth pipes.

Where:

L = Length of penstocks

V = The velocity of water in the penstocks.

$g = 9.81\frac{m}{s^2}$

The thickness of the Penstocks:

$$\text{Thickness} = \frac{pR}{S\eta - (0.6P)} \qquad (3.5)$$

Where:

P = Pressure in kgf/cm^2

R = Internal radius in cm = 64 cm.

S = Design stress of the material in kgf/cm^2.

η = Joint efficiency factor.

and 0.15 cm the allowance for corrosion

Figure (3.3) Shape of Penstock.

3.7 Turbines

Used in this project two reversible pump-turbine (two unit' s arrangement) because they are compact and need less space as compared with three-unit installation. Further the cost of one addition unit is saved. Thus, the initial cost is considerably less in two reversible unit's installation.

Also we find some plants use this type of turbine like the largest unit capacity in the word of Francis reversible machine 400 Mw at Raccoon Mountain (USA).

Also we used vertical arrangement pump-reaction turbine for this reasons:

1. It's more compact and need less floor area for powerhouse
2. The design of hydraulic passage IS simpler in vertical arrangement
3. Heads above 25m, vertical arrangement gives cheaper solution

Equation of power of the turbine:

$$P = WQH \qquad (3.6)$$

Where:

P = Power generated in watt.

W= Specific weight of water N/m^3.

Q = Discharge of water m^3 /s.

H= The head 130 m.

The specific speed of the turbine is given by the equation:

$$N_S = \frac{K}{\sqrt{H}} = \frac{N\sqrt{P}}{H^{\frac{5}{4}}} \qquad (3.7)$$

Where :

N_S = Specific speed of the turbine

K = Constant (2500-3000) for reversible pump turbine, we choose 2750 .

N = Speed of the turbine in RPM.

The diameter of runner of the turbine is given by the equation:

$$Q = A\ V \qquad (3.8)$$

$$A = \frac{Q}{V} = \frac{39.21}{6.3} = 6.22\ m^2$$

Where:

A = Area of the runner

V = Velocity of penstocks entering the runner = (6.3 m/s) (See the calculation of penstocks)

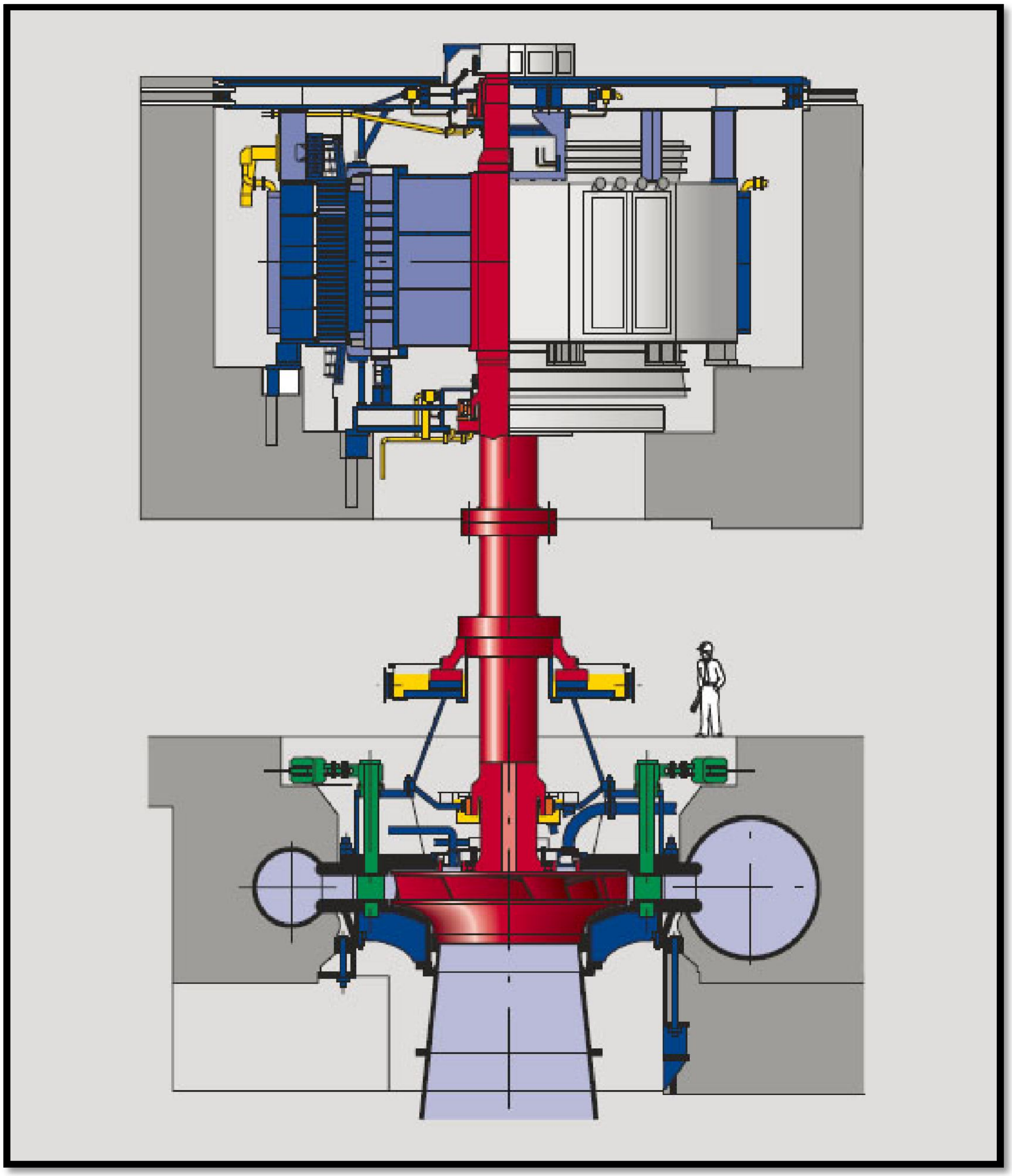


Figure (3-4) Reversible Pump Turbine Section.

3.8. Draft Tube

In straight conical draft tube, the increase of hs (head that draft tube makes it) beyond permissible limits and for most installation, increase the depth of excavation of tail channel. This makes it complete un suitable and un economical for use specially for medium fast and fast runners, where runner exit velocity is higher on one hand and hs is severally limited due to cavitation condition, hence in such all cause elbow draft tube is preferred.

The elbow draft tube has essential' advantages of having desired reduction of velocity without requiring exceeding the limit of hs.

Further the elbow draft tube enables to affect a change of section from circular to rectangular by introducing special transmission section at the bend of tube. If necessary, it is possible to introduce a tailgate at the out let of the elbow draft tube. These facilities complete department watering of the turbine for repairs.

This type of draft tube was first developed for Ronkhausen (INDIA), and now employed for the plants such as Rodund II(AUSTRIA) and Foyers (SCOTLAND).

We are study the elbow draft tube has h, L Where:

h = height of elbow draft tube m .
L = Length of elbow draft tube m .
D = Diameter of the runner m .

$$h = 2D$$

$$L = 5D$$

3.9. Staff Of The Plant

It very important point for the plant to organize the management and to have good planning of work, this help the plant to run smoothly and reduce the disturbance, that reduce the running cost.

When the staff of the plant has goods experience in the work and good training is present, this is an important factor for successful plant.

The stander division from (NEC) of the power plant is:

1. Plant manger
2. Efficiency and planning department
3. Operation department
4. Maintenance department

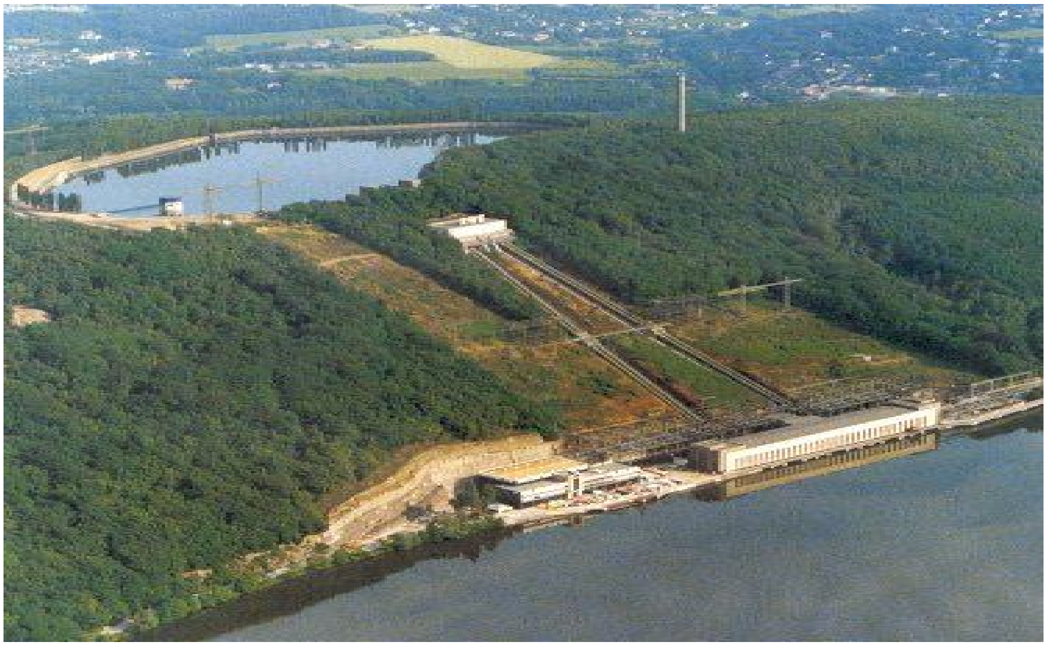


Figure (3.5) shape of pumped storage plant.

Chapter Four

Results and Discussion

4.1 Calculation Of Upper Reservoir

Area of The Reservoir = 6000 * 2000 = 12*$10^6 m^2$

The average depth = 5 m .

The volume of water in the reservoir = 12 * 10^6* 5 = 60 * $10^6 m^3$.

4.2 Calculation Of Pump-Turbine When Use As A Turbine

Capacity of the plant=50 MW * 2 Units

Form the equation of power of the turbine:

$$P = WQH \qquad (4.1)$$

Where:

P = Power generated in watt.

W= Specific weight of water N/m^3.

Q = Discharge of water m^3 /s.

H= the head 130 m.

$$Q = \frac{P}{WH} = \frac{50\times10^6}{9.81\times1000\times130} = 39.21 \ m^3/s$$

The specific speed of the turbine is given by the equation:

$$N_S = \frac{K}{\sqrt{H}} = \frac{N\sqrt{P}}{H^{\frac{5}{4}}} \qquad (4.2)$$

Where:

N_S = Specific speed of the turbine

K = Constant (2500-3000) for reversible pump turbine, we choose 2750 .

N = Speed of the turbine in RPM.

$$N_S = \frac{2750}{\sqrt{130}} = 241.2$$

$$N = \frac{N_S * H^{\frac{5}{4}}}{\sqrt{P}} = \frac{241.2 \times 130^{\frac{5}{4}}}{\sqrt{50 \times 1000 \times 1.36}} = 406 \text{ RPM}$$

The diameter of runner of the turbine is given by the equation;

$$Q = A\,V \qquad (4.3)$$

$$A = \frac{Q}{V} = \frac{39.21}{6.3} = 6.22\ m^2$$

Where:

A = Area of the runner

V = Velocity of penstocks entering the runner = (6.3 m/s) (See the calculation of penstocks)

$$A = \frac{\pi D^2}{4}$$

$$D = \sqrt{\frac{4A}{\pi}} = 2.8 \approx 3m$$

∴ The diameter of the runner of the pump turbine = 3m.

4.3 Draft Tube Calculations

We are study the elbow draft tube has h, L Where:

h = height of elbow draft tube m .

L = Length of elbow draft tube m .

D = Diameter of the runner m .

$h = 2D = 2 \times 3 = 6\ m$

L = 5 D = 5 × 3 = 15 m

4.4 The Penstocks Calculations

The head of the mountain = H = 130 m and the slope = 0.3997

$$\therefore The\ length\ of\ the\ penstocks = \sqrt{H + (slope)H} \qquad (4.5)$$

$$= \sqrt{130 + 0.3997 \times 130} = 140\ m\ .$$

The velocity of water in the penstocks (V) is given is given by the equation:

$$V = 0.125\sqrt{2gH} = \sqrt{2 \times 9.81 \times 130} = 6.3\ m/s \qquad (4.6)$$

The diameter of the penstocks (d) =

$$= \frac{0.62 \times P^{0.35}}{H^{0.65}} = \frac{0.62 \times (67051.1)^{0.35}}{130^{0.35}} = 1.28\ m.$$

Where:

P = $Powe$r in hp = 67051.1 hp.

H = $Head\ in\ m.$

The friction losses in the Penstocks $(\boldsymbol{h_f})$:

$$h_f = \frac{4flV^2}{2gd} \qquad (4.7)$$

Where:

f = $d$racy factor $= 0.005\left(\frac{1}{12d} + 1\right)$for a new and smooth pipes.

$$f = 0.005\left(1 + \frac{1}{12 \times 12.8}\right) = 0.0053$$

Where:

L = Length of penstocks

V = The velocity of water in the penstocks.

$g = 9.81 \dfrac{m}{s^2}$

$$h_f = \frac{4 \times 0.0053 \times 140 \times (6.3)^2}{2 \times 9.81 \times 1.28} = 4.7 \approx 5\, m.$$

$h = H - h_f = 130 - 5 = 125\, m.$

The thickness of the Penstocks:

$$\text{Thickness} = \frac{pR}{S\eta - (0.6P)} \qquad (4.8)$$

Where:

P = Pressure in kgf$/cm^2$

R = $Inte$rnal radius in cm = 64 cm.

S = $Design\ st$ress of the material in kgf$/cm^2$.

η = $Joint\ efficienc$y factor.

and 0.15 cm the allowance for corrosion.

$P = \rho \times H = 1000 \times 130 = 13 \times 10^4 kgf/m^2 = 13\, kgf/cm^2$

Suppose that the there is 30 ٪ increase in pressure due to transient condition.

$$P = 13 + (13 \times 0.03) = 16.9 \approx 17 kgf/cm^2$$

the design stress of the material (cast steel)=

1020 kg f/cm^2 and the efficiency of the joint may be 85 ٪

$$t = \frac{17 \times 64}{(1020 \times 0.85) - (0.6 \times 17)} + 0.15 = 1.42\ cm.$$

The checked of the penstock thickness:

$$f_t = \frac{pd}{2t} = \frac{17 \times 128}{2 \times 1.42} = 766.2\ kgf/cm^2 \qquad (4.9)$$

f_t=circumferential or hoop stress for the material.

∴the design is safety.

4.5 Calculation Of Pump-Turbine When Use As A Pump

$$P = WQH \qquad (4.10)$$

$H = h + h_f = 130 + 5 = 135\ m.$

$$Q = \frac{P}{WH} = \frac{50\times10^6}{1000\times9.81\times135} = 37.75\ m^3/s$$

∴the water discharged by the pump $= 37.75\ \boldsymbol{m^3/s}$

4.6 Overall Efficiency Of The Pump Storage Plant

$$\eta_o = \frac{H-h_f}{H+h_f}\times\eta_t\times\eta_p = \frac{130-5}{130+5}\times 0.88\times 0.85 = 0.69 \qquad (4.11)$$

Where :

$\eta_t =$ Over all efficiency of the generation (including turbine , generator and transformer) about 0.88.

$\eta_p =$ Overall efficiency of pumping operation about 0.85.

∴The over all efficiency of PS plants is 69 ٪ and its excellent , because the average value of the PS efficiency about 72 ٪ .

4.7 Wind-Pump Calculation

we study five wind mills each of them has a fan diameter of 20 m and have a tower of height 15.2 m. from the table (4-2) we found that the average velocity of the wind in ou site (that nea Khartoum), equal to 4.12 m/s and the wind power density of 45.2 watt/$\boldsymbol{m^2}$

The available wind power for one mill is :

$$P = \frac{\delta_a A V^3}{2} = \frac{\pi \delta_a d^2 V^3}{8} = \frac{\pi \times 45.2 \times 20^2 \times 4.12^3}{8} =$$

$$496535.1066\, Watt. \qquad (4.12)$$

Where :

$P = Available\ power\ in\ Watt$

$\delta_a = Wind\ power$ densitywatt/m^2

$d = Diameter\ of\ the\ fan\ m.$

V = The average velocitym/s.

The quantity of the water delivered by the wind pump :

We are stud reciprocating pump, the power drive the pump

$$P = Q\rho g\,(h_s + h_d) \qquad (4.13)$$

$$Q = \frac{P}{\rho g\,(h_s + h_d)} = \frac{496535.1066}{1000 \times 9.81 \times 130} = 0.38935\, m^3/s$$

$= 1211020.5\, m^3/year$

The quantity of the water delivered by the five units =

$60551352.45 m^3/year$.

If you compare this quantity with the capacity of the reservoir that give the ratio $= \frac{60551352.45}{60000000} = 1.009$

This ratio means that the wind-pump gives 100.009٪ of the reservoir capacity in the year.

4.8. Results Analysis

4.8.1 Flow rate and discharge time:

Flow rate is equal 39.21 m^3/s .and the volume of reservoir is $60*10^6$

Time for discharge = $60*10^6/39.21$= 1530221.882 sec = 425 hour

That mean the reservoir can use 425 hour before refilling.

4.8.2 Wind pump and electrical pump:

The wind pump can fill the reservoir in 1 year .and the reservoir can supply the 425.If we use the plant for 8 hour per day ,the reservoir can supply 53 day. That mean we don’t need to use electrical pump for 53day.then we can reduce the capacity of the main power station for this period.

Chapter Five

Conclusion and Recommendations

5.1. Conclusion

•We have make a heavy study to this project, by studding actual projects of pump storage plants installed in the world, which gives good results to our project.

•We have collect the data from many sources like ministry of electricity and Development Meteorological Authority – Computer Center.

•We have make study to install pump storage plant (in Sabaloka area) it is capacity 100 MW and consist of two reversible Francis pump-turbine each of them 50 MW capacity.

•The upper reservoir of the plant has capacity of 60x 10^6 m', that operate the plant 213 hour for full capacity generation.

•We have study installing of wind pumps to reduce the cost of pumping. Also to cover the losses of water due to: friction, evaporation and sewage.

•The estimated cost of the project is about 35 million dollars; this is same as Revine plant (France) and Marwai dam project.

5.2. Recommendations

WE HOPE THAT:

A- From the new incomers and researchers to scan our work.
B- To cover another sides of the project such as:
  1.1.1. Civil work (construction).
  1.1.2. Electric work.
C- To make another studies for other sites that suitable to apply this project.
D- Authorities to encourage and support this project to improve the scientific role in our country.
E- To make study to use the delivery water for irrigation.

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