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Common Type of Turbines in Power Plant: A Review

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Abstract – *Most conventional power plants require a turbine as conversion system from various working fluid like water, gas, steam and wind into mechanical energy that will be used to generate electricity. In future, the forecast energy usage is higher and thus, to compensate this, the power plant needs high efficiency of turbine to extract maximum quantity of energy from the working fluid. Therefore, various improvements on turbine technology has been done and studied. There are four common type of turbine which is hydraulic turbine, gas turbine, wind turbine and steam turbine that will reviewed in this paper. Each turbine was differentiating based on their working fluid and different type of turbine has their own efficiency. There is some parameter that affects the turbine efficiency like the turbine component, the characteristic of working fluid, materials used, cooling invention and many more. There is also some future development in progress to enhance the turbine efficiency and thus increase the amount of electricity produce. The aims for this review paper is to find out the common type of turbine used in power plant as different power plant needs different type of turbine. About 46 published studies (1939-2016) are reviewed in this paper. By reviewing others research studies worldwide, this review paper can be taken as a guideline in future regarding to common type of turbines used in power plant.*

Keywords: Turbine Types, Power Plant, classification of turbines, turbine components

1.0 INTRODUCTION

Turbines are energy producing devices they extract energy from the fluid (as water, steam, or air) and transfer most of that energy to some form of mechanical energy output, typically in the form of a rotating shaft.[1] The purpose of turbine technology is to extract the maximum quantity of energy from the working fluid, to convert it into useful work with maximum efficiency, by means of a plant having maximum reliability, minimum cost, minimum supervision and minimum starting time.[2] By any means, turbine converts potential energy of fuel to mechanical energy. Turbines have been used for centuries to convert available mechanical energy from rivers and wind into useful mechanical work, usually through a rotating shaft. Turbines can be classified by many ways such as based on fluid, in the basis of principle operation and direction of flow. For example, when the working fluid is water, the turbomachines are called hydraulic turbines or hydro turbines. When the working fluid is air, and energy is extracted from the wind, the machine is properly called a wind turbine. In coal or nuclear power plants, the working fluid is usually steam; hence, the turbomachines that convert energy from the steam into mechanical energy of a rotating shaft are called steam turbines. A more generic name for turbines that employ a compressible gas as the working fluid is gas turbine [1].

2.0 TYPE OF TURBINES

Based on the driving fluid such as gas, steam, water and steam, these turbines are reviewed accordingly.

2.1 Gas Turbine

Gas Turbine is turbine that used gas and it is widely used in power generation due to its capability to produce high efficiency, low pollution and low operational cost [3]. A gas turbine can be defined as a combustion engine that converts natural gas or other liquid fuels to form a mechanical energy [4]. Other than power generation, it also can be used in several different modes in critical industries such as oil and gas, process plants, aviation, as well domestic and smaller related industries [5]. For this review paper, the main focus is for the gas turbine power plant.

The basic operation of gas turbine power plant is simple. There are three major component related which are compressor, combustor and turbine. Figure 1 shows the three components were being attached together and this configuration are called as gas generator [5]. The fresh atmospheric air will flow through compressors which are functionally to compress air to high pressure. Then, this high pressure air will added with energy that produce from spraying fuel into the air and igniting it so the combustor will start the combustion and generates a high-temperature flow. This high pressure and temperature air will then enter the turbine and convert the heat into mechanical energy where the gases are expanded through a turbine [5] and rotating the shaft that is used to drive the compressor and other devices such as an electric generator that may be coupled to the shaft. The left over energy will then exits in exhaust gases in high pressure or high velocity manner [6]. Conventional Gas turbine generator used in industry is shown in Figure 1.

Figure 1: Gas turbine generator [7]

2.1.1 Gas Turbine Cycle

2.1.1.1 Brayton Cycle

In gas turbine power plant, the fundamental thermodynamic cycle used is Brayton Cycle or Joule cycle [8]. The basic Brayton cycle consist of three components which are a compressor, a turbine, and a combustion chamber [9]. Usually, gas turbine can be classified based on the working substance path whether open cycle or closed cycle as shown in Figure 2. In closed-cycle, it is capable to complement the conventional coal-fired power plant and internal combustion gas turbine power plants [10]. Moreover, the driving force for closed-cycle is gas or fluid. While, open-cycle uses gas only as a driving force and this cycle produces higher efficiency due to higher firing temperature.

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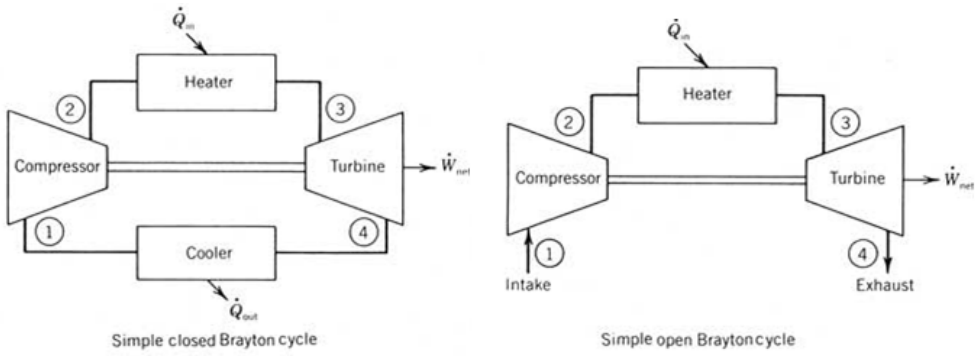

Figure 1: Open and closed Brayton Cycle

2.1.1.1.1 Closed Brayton Cycle

Closed-cycle gas turbine can be characterized by working fluid and heat source like fossils, nuclear, biomass and others [10]. The exhaust gas from turbine was recirculated and does not release to the atmosphere. The basic principle of closed cycle can be explained based on Figure 3(a) that illustrate the T-S diagram. The working fluid is compressed in the compressor from point 1 to 2. Then it enters the recuperator that is functionally to regenerate the heat content of the exhaust gas that coming out from the turbine at point 2–3. After regeneration, the fluid passes through the heat source which could either be a nuclear reactor core, an intermediate heat exchanger (IHX) or a gas heater (point 3–4). In the heat source, the fluid achieves the highest temperature within the cycle. This is followed by an expansion in the turbine (point 4–5). The turbine provides the work for the compressor and generator. The turbine exhaust is then used to preheat the fluid coming out of the compressor in the recuperator (point 5–6). Finally, heat is rejected from the cycle in the cooler, where the fluid is cooled to the initial conditions.

2.1.1.1.2 Open Brayton Cycle

The concept for open cycle is very simple where the driving force used is only air. The fresh air is drawn into the compressor and is supplied to combustion chamber or heater with highest cycle pressure. The high pressure and temperature airflow will enter the turbine and this high temperature air is obtained from an absorption of heat from fuel within the heater. The airflow will then expand and produce mechanical energy to run the compressor that located on the same turbine shaft [5]. Then, the airflow is exhausted to the atmosphere at the turbine outlet [9]. This cycle required the continuous replacement of driving force in order to run the gas turbine. The T-S diagram of open-cycle gas turbine.

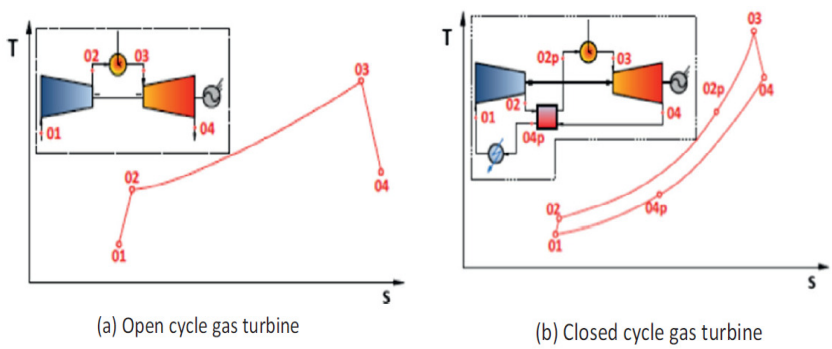

Figure 2: Open and Closed of cycle gas turbine [10]

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2.1.2 Advantage and Disadvantage

Closed-cycle gas turbine is one of the considerable interests of power plant because the capability to produce high thermal efficiency in order to compensate the high energy demand that are increasing day by day. A lot of advantages of this turbine have been listed in Table 2. However, all power plants has their own limitation as no ideal system is realistic in this world. Thus, the limitation or disadvantages of gas turbine also has been listed in table below.

Table 1: Advantages and disadvantages of gas turbine

Advantages	Disadvantages
1. Higher thermal efficiency 2. Reduced size 3. No contamination 4. Improved heat transmission 5. Improved part load η 6. Lesser fluid friction 7. No loss of working medium 8. Greater output 9. Inexpensive fuel	1. Complexity 2. Large amount of cooling water is required. This limits its use of stationary installation or marine use. 3. Dependent system 4. The wt of the system pre kW developed is high comparatively, thus it is not economical for moving vehicles 5. Requires the use of a very large air heater.

2.2 STEAM TURBINE

Figure 3: Steam Turbine

A steam turbine is a mechanical device that converts thermal energy in pressurized steam into useful mechanical work. The steam turbine derives much of its better thermodynamic efficiency because of the use of multiple stages in the expansion of the steam. This results in a 32closer approach to the ideal reversible process. Steam turbines are made in a variety of sizes ranging from small 0.75 kW units used as mechanical drives for pumps, compressors and other shaft driven equipment, to 150 MW turbines used to generate electricity. Steam turbines are widely used for marine applications for vessel propulsion systems. In recent times gas turbines, as developed for aerospace applications, are being used more and more in the field of power generation once dominated by steam turbines. [11, 12]

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2.2.1 Principle

The steam energy is converted mechanical work by expansion through the turbine. The expansion takes place through a series of fixed blades (nozzles) and moving blades each row of fixed blades and moving blades is called a stage. The moving blades rotate on the central turbine rotor and the fixed blades are concentrically arranged within the circular turbine casing which is substantially designed to withstand the steam pressure. [11, 12]

2.2.2 Parts of Steam Turbines

a) **Nozzle**: The nozzle expands steam of comparatively low velocity and high static pressure within considerable increase in velocity. The nozzle is so positioned as to direct the flow of steam into the rotor passage.

b) **Diffuser**: It is a mechanical device that is designed to control the characteristics of steam at the entrance to a thermodynamic open system. Diffusers are used to slow the steam's velocity and to enhance its mixing into the surrounding steam. In contrast, a nozzle is often intended to increase the discharge velocity and to direct the flow in one particular direction.

c) **Blades or Buckets**: The blades or buckets form the rotor flow passage and serves to change the direction and hence the momentum of the steam received in the stationary nozzles.

d) **Guide blades**: Often a turbine is arranged with a series of rotor flow passages. Intervening between the blades comprising the rotor passages are rows of stationary guide blades. The purpose of this guide is to reverse the direction of steam leaving the preceding moving blade row so that general direction of steam leaving the preceding moving blade rows is similar. If guide blades were not provided, opposing force would be exerted on the rotor which would largely negate each other.

e) **Casing Shell or Cylinder**: The turbine enclosure is generally called the casing although the other two names are in common use. The nozzle and guide are fixed on casing, which in addition to confining the steam serves as support for the bearings. Sometimes the word cylinder is restricted as a cylindrical form attached to inside of the casing to which the guides are fixed.

f) **Shaft, Rotor, and Spindle**: These terms are applied to the rotating assembly which carries the blades.

g) **Disc or Wheel**: The moving blades are attached to the disc which in turn is keyed to the shaft.

h) **Diaphragm**: The diaphragm which is fixed to the cylinder or casing contains the nozzle and serves to confine the steam flow to nozzle passage.

i) **Packing**: Packing in the form of carbon rings minimizes the leaking in the annular space between the diaphragm and shaft.

j) **Thrust Bearings**: Usually a combination of Kingsbury and collar types absorbs the axial forces.

k) **Exhaust Hood**: The exhaust hood is the portion of the casing which collects and delivers the exhaust steam to exhaust pipe or condenser.

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l) **Steam Chest**: The steam chest is the supply chamber from which steam is admitted to the nozzles.

m) **Governor**: The governing system may be designated to control steam flow so as to maintain constant speed with load fluctuations to maintain constant pressure with variation of demand for processed steam or both.

n) **Throttle Or Stop Valves**: The throttle and stop valves are located in the steam supply line to the turbine. The stop valve is hydraulically operated quick opening and shutting valves designed to be either fully opened or shut. On small turbines the stop valves may be manually operated but in any case is intended for emergency use or when fully shut down. The throttle valve is used in smaller turbines in addition to stop valve as a means of regulating steam flow during the starting or stopping the operation. [11, 12]

2.2.3 Thermodynamic Cycle of Steam Turbine:

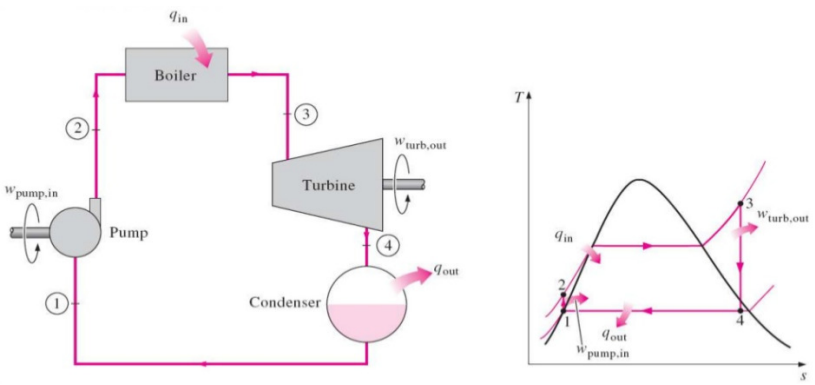

Figure 4: Rankine Cycle

Steam based power plants operate on the Rankine cycle. The processes are:

1 ---> 2 : Isentropic compression (Pump)
2 ---> 3 : Constant pressure heat addition (Boiler)
3 ---> 4 : Isentropic expansion (Turbine)
4 ---> 1 : Constant pressure heat rejection (Condenser)

Basically, the Rankine cycle utilizes a steam boiler to produce high pressure, high temperature steam. The steam, leaving the boiler at temperatures and pressures as high as 1000 F (540 C) and 4500 psig (300 bar), is routed through a steam turbine where it is expanded to produce shaft work that drives an electric generator.

<u>Neglecting the pump work input</u>,
The efficiency of an ideal Rankine cycle:

Efficiency, η = net work from the turbine / heat supplied in the boiler
η = (h3 - h4) / (h3 - h2)

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In order to increase the efficiency of the overall process, the expansion of the steam is generally performed in stages. After passing through a high pressure turbine stage, the steam is returned to the steam generator to be reheated. After the final expansion stage, the steam is routed to a condenser, where it is returned fully to liquid form and pumped back to the steam generator. By using this method of power production, electric facilities are able to approach 40% efficiency.

Specific Steam Consumption (SSC): This is the required steam consumption rate (kg/s) per unit power (energy) generation (kJ). [13]

2.2.4 Type of Steam Turbines

The necessity to keep down the production costs lead to standardization of the types of steam turbines, such as back pressure, condensing, extraction back pressure and extraction condensing, injection condensing

- Condensing turbines
- Back pressure turbines
- Multiple extraction turbines
- Injection condensing turbines for combined cycle plant
- Reheat condensing turbines for utility type

Most of the industrial steam turbines are high speed turbines for the power output range of 1-30MW with speed reduction by turbo gears which in turn means smaller sizes and higher efficiency for the turbine for the output of 30MW and above the turbine speed is 3000rpm [11, 14].

2.2.5 Classification of Steam Turbines

Steam turbines may be classified into different categories depending on their construction, the process by which heat drop is achieved, the initial and final conditions of steam used and their industrial usage as follows:

a) Number of pressure stages:
Single – stage turbines with one or more velocity stages usually of small power capacities, mostly used for driving centrifugal compressors, blowers and other similar machinery.
Multistage - impulse and Reaction turbines, made in a wide range of power capacities varying from small to large.

b) Direction of steam flow:
There are steam turbines based two direction of steam flow. First one is axial turbines, in which the steam flows in a direction parallel to the axis of the turbine. Secondly, radial turbines, in which the steam flows in a direction perpendicular to the axis of the turbine. One or more low pressure stages in such turbines are made axial.

c) Number of cylinders:
Single cylinder turbines
Multi cylinder (2, 3 and 4 cylinders) turbines, which can have single shaft, i.e. rotors mounted of the same shaft, or multiaxial, having separate rotor shaft and have their cylinders placed parallel to each other.

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d) Method of governing:
Turbines with nozzle governing and turbines with bypass governing in which steam besides being fed to the first stage is also directly led to one, two or even three intermediate stages of the turbine.

e) Action of steam:
There are four type of turbine that designed based on action of steam which are impulse turbines, axial reaction turbines, and radial reaction turbines without any stationary guide blades and radial reaction turbines having stationary guide blades.

f) Heat drop process
Condensing turbines with exhaust steam let into condenser with regenerators, condensing turbines with one or two intermediate stage extractions at specific pressures for industrial and heating purposes.
Back pressure turbines, the exhaust steam from which is utilized for industrial and heating purposes.
Back – pressure turbines with steam extraction from intermediate stages at specific pressures.
Low – pressure (Exhaust pressure) turbines in which the exhaust steam from reciprocating steam engines, power hammers, presses, etc. is utilized for power generation.
Mixed – pressure with two or three pressure extractions with supply of exhaust steam to its intermediate stages.

g) Steam condition at inlet:
Low – pressure turbines using at pressures 2.2 to 2 atm
Medium – pressure turbines using steam at pressure up to 4.0 atm.
High – pressure turbines using steam at above40 atm.
Very high pressure turbines using steam up to 40 atm and higher pressure and temperature. [11, 15, 16].

2.2.6 Advantages and Disadvantages of Steam Turbines

Table 2: Advantages and disadvantages of steam turbine

Advantages	Disadvantages
Thermal Efficiency of a Steam Turbine is higher than that of a Reciprocating Engine.	Steam turbines have a few drawbacks, although approximately 80 percent of the world's electricity is reliant on steam turbines.
The Steam Turbine develops power at a uniform rate and hence does not required Flywheel.	Not profitable smaller turbines
No internal lubrication is required for Steam Turbine as there is no rubbing parts inside.	Side Effect of low pressure steam turbine
No heavy foundation is required for Turbine because of the perfect balancing of the different parts.	Possibilities of complete mechanical failure

If the Steam Turbine is properly designed and constructed then it is the most durable Prime Mover.	Load change behaviour [17]
Much higher speed may be developed and a far greater range of speed is possible than in the case of Reciprocating Engine.	
There are some frictional losses in Reciprocating Engine as some arrangements are required for conversion of Reciprocating Motion into circular motion. But in Steam Turbine no friction losses are there.	
Steam Turbine are quite suitable for large Thermal Power Plant as they can be built in size from few Horse Power to over 200000 HP in signal unit. [17]	

2.3 Water Turbine

Water turbine is used to make electricity in hydroelectric power plants. The general idea of hydroelectric power is that you dam a river to harness its energy. You make it fall through a height (called a head) so it picks up speed (in other words, so its potential energy is converted to kinetic energy) instead of the river flowing freely downhill from its hill or mountain source toward the sea, then channel it through a pipe called a penstock past a turbine and generator. Hydroelectricity is effectively a three-step energy conversion from river's potential energy is turn into kinetic energy when water falls through a height, kinetic energy in the moving water is converted into mechanical energy by water turbine, the spinning water turbine drive a generator that change the mechanical energy into electrical energy [18].

2.3.1 Classification of Water Turbines

Turbine can be classified according to direction of flowing fluid, head at the inlet of turbine etc. [19]. Such as:

2.3.1.1 According to the type of energy at inlet:

The two distinct classes are reaction and impulse turbines. In general, the reaction turbines (e.g. Kaplan, Francis or Archimedes Screw) are used in locations that are not mountainous utilising relatively low heads and high flow rates (with the exception of Francis machines which are sometimes utilised in high head and relatively low flow rate applications). Impulse turbines (e.g. Pelton, Turgo or Cross-flow), on the other hand, were developed for medium to high head and low flow rate applications. [20]

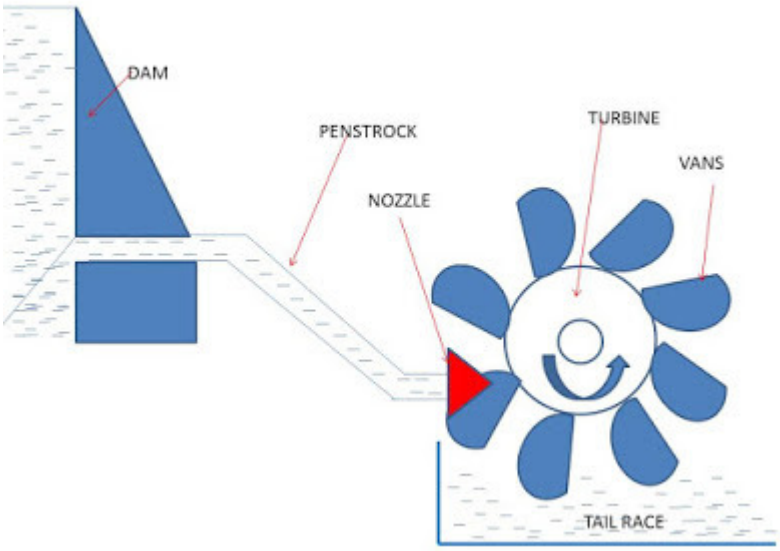

Figure 5: Water Turbine

2.3.1.1.1 Impulse Turbine

The impulse turbine generally uses the velocity of the water to move the runner and discharges to atmospheric pressure. The water stream hits each bucket on the runner. There is no suction on the down side of the turbine, and the water flows out the bottom of the turbine housing after hitting the runner. An impulse turbine is generally suitable for high head, low flow applications. [21]

- **Pelton**
  A pelton wheel has one or more free jets discharging water into an aerated space and impinging on the buckets of a runner. Draft tubes are not required for impulse turbine since the runner must be located above the maximum tailwater to permit operation at atmospheric pressure.

  A Turgo Wheel is a variation on the Pelton and is made exclusively by Gilkes in England. The Turgo runner is a cast wheel whose shape generally resembles a fan blade that is closed on the outer edges. The water stream is applied on one side, goes across the blades and exits on the other side.

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

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2.3.1.1.2 Reaction Turbine

A reaction turbine develops power from the combined action of pressure and moving water. The runner is placed directly in the water stream flowing over the blades rather than striking each individually. Reaction turbines are generally used for sites with lower head and higher flows than compared with the impulse turbines.

- **Propeller**
  A propeller turbine generally has a runner with three to six blades in which the water contacts all of the blades constantly. Picture a boat propeller running in a pipe. Through the pipe, the pressure is constant; if it isn't, the runner would be out of balance. The pitch of the blades may be fixed or adjustable. The major components besides the runner are a scroll case, wicket gates, and a draft tube. There are several different types of propeller turbines:

  a) BULB TURBINE
     The turbine and generator are a sealed unit placed directly in the water stream.

  b) STRAFLO
     The generator is attached directly to the perimeter of the turbine.

  c) TUBE TURBINE
     The penstock bends just before or after the runner, allowing a straight line connection to the generator.

  d) KAPLAN
     Both the blades and the wicket gates are adjustable, allowing for a wider range of operation.

- **Francis**
  A Francis turbine has a runner with fixed buckets (vanes), usually nine or more. Water is introduced just above the runner and all around it and then falls through, causing it to spin. Besides the runner, the other major components are the scroll case, wicket gates, and draft tube.

- **Kinetic**
  Kinetic energy turbines, also called free-flow turbines, generate electricity from the kinetic energy present in flowing water rather than the potential energy from the head. The systems may operate in rivers, man-made channels, tidal waters, or ocean currents. Kinetic systems utilize the water stream's natural pathway. They do not require the diversion of water through manmade channels, riverbeds, or pipes, although they might have applications in such conduits. Kinetic systems do not require large civil works; however, they can use existing structures such as bridges, tailraces and channels.

2.3.1.2 According to the direction of flow through runner:

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1. Tangential flow turbine:

   If the water flows along the tangent of the runner, the turbine is known as tangential flow turbine. Pelton wheel turbine is the example of tangential flow turbine.

2. Radial flow turbine:

   If the water flows in the radial direction through the runner, the turbine is called radial flow turbine. If the water flows from outward to inward, radially, the turbine is known as inward radial flow turbine and if oppose the turbine is known as outward radial flow turbine.

3. Axial flow turbine:

   If the water flows along the direction parallel to the axis of the runner, the turbine is known as axial flow turbine. Francis turbine is the example of axial flow turbine.

4. Mixed flow turbine:

   If the water flows through the runner in the radial direction but leaves in the direction parallel to the axis of rotation of the runner, the turbine is called mixed flow turbine.

2.3.1.3 According to head at the inlet of turbine:

a) High head turbine
b) Medium head turbine
c) Low head turbine

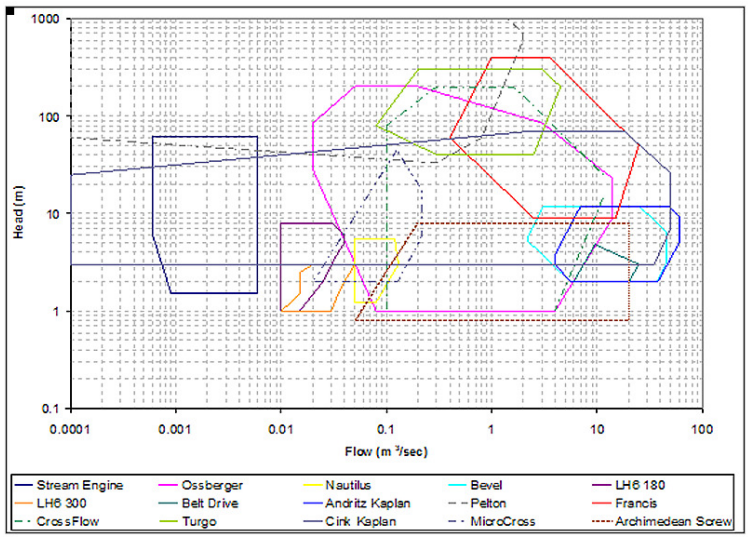

Figure 6: Performance envelope of water turbines. [22]

2.3.1.4 According to specific speed of turbine:

a) Low specific speed turbine
b) Medium specific speed turbine

c) High specific speed turbine

The indicative ranges of various turbines are presented in Fig. 7 but the borderlines of the particular regions may vary depending on the specific manufacturer.

2.3.2 Advantages and Disadvantages Water Turbines

Table 3: Advantages and Disadvantages Water Turbines

ADVANTAGES	DISADVANTAGES
Can cover up to 90% of the energy of water into electric energy	Negative impacts that a large-scale dam and reservoir hydro system has on the environment. (Impact of hydropower on the environment)
With this high efficiency the cost of hydroelectricity has dropped with evolving technologies, and is estimated to be about 40% less expensive than using fossil fuels.	very expensive to implement, so it takes a long amount of time before a hydropower system will begin to return profits on the original cost of the investment.[23]
Since hydro power is fueled by water, it has the advantage of being only used when needed, because it is easy to control the storage and allowable flow of water into a hydropower system.	
Hydro power has an advantage over wind power because water is more dense than air, so collecting the mechanical energy of wind requires a greater force of wind to rotate the turbine than it would for water in a hydropower system.[23]	

2.4 Wind Turbine

Most researchers and engineers have proposed wind turbines as an alternative to conventional energy supply systems in order to reduce greenhouse gas emissions. Large-scale wind turbines have become very popular in the market; they will play a very important role in the energy supply requirements in the near future [24]. Wind turbine helps to convert kinetic energy in wind into mechanical energy. Currently, various countries are installing large scale wind farms both on shore and offshore in order to meet their growing power demand. In 2014,China has installed capacity of around 114,609 MW of wind energy contributing 32.0% of the total wind power followed by USA, Germany, Spain and India which produce 65,879 MW , 39,165 MW, 22,987 MW and 22,465 respectively [25]

2.4.1 Mechanism

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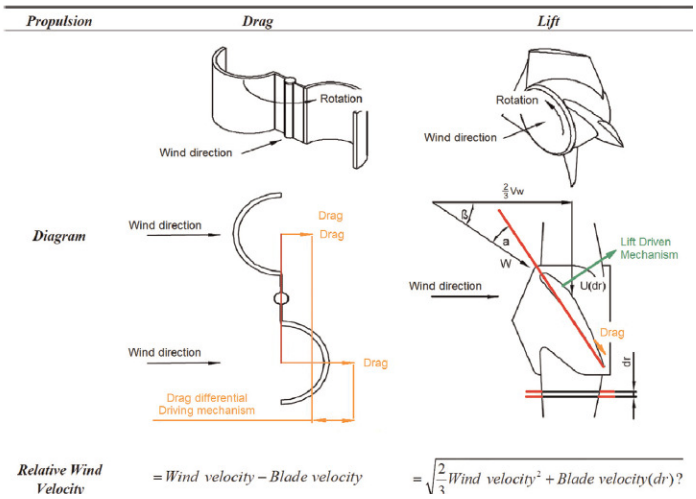

Figure 7 : Drag and lift operating mechanisms of wind turbines (Schubel and Crossley, 2012)

The basic principle of every wind turbine is to convert the kinetic energy of the wind into mechanical energy; most often in the form of torque. The first mechanism is based on aerodynamic drag. The second mechanism of operation is based on aerodynamic lift. In this embodiment, the turbine rotor consists of asset of blades with aerodynamically shaped cross-sections. Physics phenomena occurring during flow around the blades is analogous to those found in air propellers, except the fact that the process is reversed, I .e. the wind drives the rotor and not vice versa [26,27].

2.4.2 Component

The main components of a wind turbine system are illustrated in Figure 9, including a turbine rotor, a gearbox, a generator, a power electronic system, and a transformer for grid connection [28].

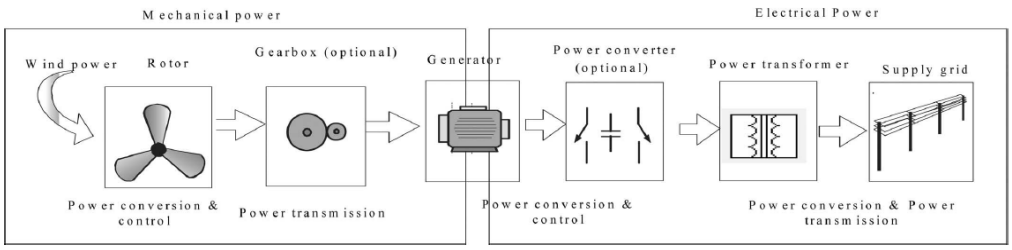

Figure 8: Main components of a wind turbine system [28]

2.4.3 Type of Turbines

Turbines can be classified based on their axis, whether it is horizontal or vertical. Axis here refers to their main shaft about which the rotating parts revolve. In this sense, a wind turbine can be classified as a horizontal-axis wind turbine (HAWT) or a vertical-axis wind turbine (VAWT).

Since in most cases wind blows horizontally, a wind turbine whose axis is horizontal (HAWT) is sensitive to the direction of wind. This is not true for a turbine with vertical axis (VAWT), because no matter what the direction of wind, such a turbine can catch the wind [29].

2.4.3.1 Horizontal – axis wind turbine (HAWT)

A wind farm contains a number of horizontal wind turbines [31, 31]. These wind turbines are positioned and aligned in clusters facing the wind direction. Each wind rotor generates a turbulent region called wake. [32,33] Majority of Mega utility-scale wind turbines that are manufactured nowadays are variable-speed, variable-pitch, and horizontal-axis turbines.[34]Horizontal axis machines have some advantages such as low cut-in wind speed and easy furling. In general, they show relatively high power coefficient. However, the generator and gearbox of these turbines are to be placed over the tower which makes its design more complex and expensive. Another disadvantage is the need for the tail or yaw drive to orient the turbine towards wind. [35]

Classification of horizontal axis wind turbine.

1. Depending on the number of blades, horizontal axis wind turbines are further classified as single bladed, two bladed, three bladed and multi bladed

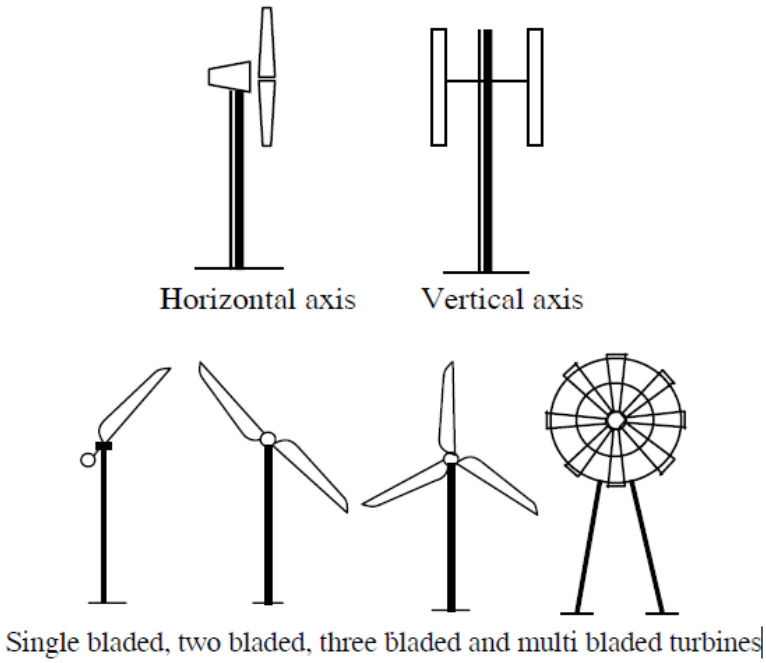

Figure 9: Wind turbine classification based on blade[36]

2. Based on the direction of receiving the wind, HAWT can be classified as upwind and down wind turbines [35]

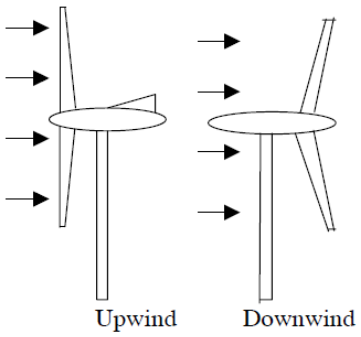

Figure 10: Upwind and Downwind turbine [35]

2.4.3.2 Vertical-axis wind turbine (VAWT).

Vertical axis wind turbines are those whose rotor axis is in vertical direction. These turbines do not have any yawing mechanism or self-starting capability. The generator location for these turbines is on ground and their height of operation is very low hence making them easier for maintenance. The ideal efficiency for these turbines is more than 70%. [36] One advantage of a vertical-axis turbine is the fact that all the other equipment such as generator and gearbox do not need to be on the top of the tower [29]. Other than that, VAWT can receive wind from any direction. Besides, the generator and the gearbox of such systems can be housed at the ground level, which makes the tower design simple and more economical. Moreover the maintenance of these turbines can be done at the ground level. [35].
The major disadvantage of some VAWT is that they are usually not self-starting. Additional mechanisms may be required to 'push' and start the turbine, once it is stopped. As the rotor completes its rotation, the blades have to pass through aerodynamically dead zones which will result in lowering the system efficiency. There are chances that the blades may run at dangerously high speeds causing the system to fail, if not controlled properly.[35]

Classification:
1. Darrieus Wind Turbine

The Darrieus wind turbine is a type of vertical axis wind turbine which consists of a number of straight or curved blades mounted on a vertical framework. These turbines work from the lift forces produced during rotation.

2. Savonius Wind Turbine:

Savonius wind turbines are drag based wind turbines consisting of two to three scoops. These turbines have an 'S' shaped cross section when looked from above. As they move along the wind, they experience lesser drag and this difference in drag helps these turbines to spin. Due to the drag, the efficiency of these turbines is less when compared to other types of turbines.[36]

Some other classification can be made based on the size of the turbine, rotor diameter and power rating. Micro scale turbine usually been used in rural area for power generation.

Table 4: Classification of turbine based on power rating [26, 27]

Scale	Rotor diameter	Power rating
Micro	Less than 3m	50W to 2kW
Small	3m to 12m	2kW to 40kW
Medium	12m to 45m	40kW to 999kW
large	46m and larger	More than 2.0MW

2.4.4 Advantage and Disadvantage

Table 5: Advantages and disadvantages of wind turbine

ADVANTAGE	DISADVANTAGE
It's a clean fuel source. Wind energy doesn't pollute the air like power plants that rely on combustion of fossil fuels, such as coal or natural gas. Wind turbines don't produce atmospheric emissions that cause acid rain or greenhouse gases	Good wind sites are often located in remote locations, far from cities where the electricity is needed. Transmission lines must be built to bring the electricity from the wind farm to the city.
Wind is a domestic source of energy. The nation's wind supply is abundant. Over the past 10 years, cumulative wind power capacity in the United States increased an average of 30% per year, outpacing the 28% growth rate in worldwide capacity.	Wind resource development might not be the most profitable use of the land. Land suitable for wind-turbine installation must compete with alternative uses for the land, which might be more highly valued than electricity generation.
It's sustainable. Wind is actually a form of solar energy. Winds are caused by the heating of the atmosphere by the sun, the rotation of the Earth, and the Earth's surface irregularities. For as long as the sun shines and the wind blows, the energy produced can be harnessed to send power across the grid.	Turbine blades could damage local wildlife. Birds have been killed by flying into spinning turbine blades. Most of these problems have been resolved or greatly reduced through technological development or by properly siting wind plants.[37]
Wind turbines can be built on existing farms or ranches. This greatly benefits the economy in rural areas, where most of the best wind sites are found. Farmers and ranchers can continue to work the land because the wind turbines use only a fraction of the land. Wind power plant owners make rent payments to the farmer or rancher for the use of the land, providing landowners with additional income. [37]	The installation of wind turbines in order to meet 10–15% of global energy demand might cause surface warming by increasing the temperature by 1 °C on land.[38]

3.0 PERFORMANCE AND EFFECIENCY ANALYSIS

3.1 Efficiency

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The turbine efficiency for different type of turbine are depends on the several parameters like capacity, velocity of the driving force, the turbine blade, the materials used, the cooling invention and others. To obtain high efficiency, some improvement on the components, materials, airflow pressure and other factors can help to increase the efficiency. Table 2 show the general efficiency range of the turbine without considering the type of turbine used.

For steam turbine thermodynamic efficiency or isentropic efficiency, it is refered to the ratio of power actually generated from the turbine to what would be generated by a perfect turbine with no internal losses using steam at the same inlet conditions and discharging to the same downstream pressure where the actual enthalpy drop is divided to the isentropic enthalpy drop. Turbine thermodynamic efficiency is not to be confused with electrical generating efficiency, which is the ratio of net power generated to total fuel input to the cycle. Steam turbine thermodynamic efficiency measures how efficiently the turbine extracts power from the steam itself.

Hydro power is a very efficient source of renewable energy. Hydropower systems are very efficient because of the density of water, the force of gravity and the technological advantages of today. These systems can cover up to 90% of the energy of water into electric energy, which is an astonishing number. With this high efficiency the cost of hydroelectricity has dropped with evolving technologies, and is estimated to be about 40% less expensive than using fossil fuels.

Turbine efficiency for gas turbine can be develop by technical improvements such as material engineering advancements and cooling innovations. Both of this factors allowed for the turbine to operate at higher temperatures and thus increase the efficiency [39]. Moreover, increase on the firing temperature also can improve turbine efficiency. Turbine efficiency also can be affected if there is any changes in inlet air condition, the environment temperature and mean sea level [40]. The efficiency for gas turbine used in power plant is approximately 22% to 48% depending on the type of Brayton cycle and the working fluid [41].

For wind turbine, the efficiency with which a rotor can extract power from the wind depends on the dynamic matching between the rotor and the wind stream. Hence, the performance of a wind rotor is usually characterised by the variations in its power coefficient with the tip speed ratio [42].

Table 6: Efficiency range for different type of turbine

Type of Turbine	Efficiency Range (%)	References
Gas Turbine	22.0 – 48.0	[10]
Hydraulic Turbine	83.0 – 93.0	
Wind Turbine	0.0 – 59.3	(43)
Steam Turbine	75.6 – 77.8	[44]

3.2 Performance

Generally, turbine performance characteristic was dependent on the operating condition and others. The turbine performance can be qualified by its efficiency, power output, specific fuel consumption and work ratio. Several parameters such as component efficiency and turbine working temperature will affect the turbine performance. There is a research done on gas turbine [40] in order to study the effect of ambient temperature where the turbine performance was decreases as the temperature increases and resulted on the drop of power output.

While for wind turbine, the performance can be negatively affected by the existence of uncertainties like wind condition, manufacturing tolerances and roughness induced by insect contamination [45]. Some simulation methods are used to analyse the factors that affect the turbine performance.

The steam turbine performance can be evaluated based on isentropic efficiency. The isentropic efficiency will differentiate the actual performance with an ideal, isentropic turbine. Several assumptions when calculating this efficiency were included where the heat lost to the surroundings is assumed to be zero. The starting pressure and temperature is the same for both the actual and the ideal turbines, but at turbine exit the energy content ('specific enthalpy') for the actual turbine is greater than that for the ideal turbine because of irreversibility in the actual turbine.

Thus, performance of the turbine is important in order to obtain high efficiency and therefore, it can compensate the high energy demand for future development.

4.0 FUTURE DEVELOPMENT OF TURBINES

From simple wind turbines that was used in 1800s to grind grains until large, high performance turbines that used in power plant to generate electricity, turbines has evolved along with time. Thus, the future development of turbines more on in improving the efficiency and performance of turbines not based on evolution on varying the function. This review will be discussed the future developments of turbines based on their driving fluid.

4.1 Gas Turbines

It has been identified that substantial benefits can be achieved with the use of closed-cycle gas turbine for power generation. As the energy demand keep on increasing, instead of power plant, the closed-cycle gas turbine can provide promising alternatives to the conventional power conversion system for nuclear, solar, geothermal, fossil and waste heat for terrestrial, space and marine power generation applications. However, there still remain technical limitation in the areas of heat source technologies, heat exchangers, seals, bearings, materials and turbo machinery development which required further attention before full scale commercial deployment can be realised [10].

Heat Source Technology

Most of the high temperature heat sources proposed for closed-cycle GT application are still under development. To improve the efficiency of closed-cycle gas turbine, its need high temperature heat energy and this can be done by coupling the turbine with heat source technology [10]. By coupling this, the thermal efficiency of gas turbine can be improved and reduce the cost to compete with existing power plant.

Future Possibilities

The combination cycle (Brayton and Rankine cycle) are one of the future developments for gas turbine. Various research has done to study the effectiveness of combine cycle to improve efficiency but its requires complicated design. Besides, the new gas turbine in smaller size

called Micro turbine is also one of the future possibilities as its offer low capital and operational and maintenance cost with high speed generator power plant (25-200 kWe).

4.2 Steam Turbines

Currently, the challenge in steam turbines is to producing turbines that can withstand high temperature and high pressure for future coal-based power generation. The producing company such as Siemens is need of find available nickel alloys for very heavy and thick-walled parts (forgings and castings > 10 tons). The challenges in this project are material costs and machining effort which takes times. The current focus is improvement in terms of production procedures (large forging & castings, welding, machining), material properties for steam environment, thick-walled components, non-destructive evaluation, blade and seal technologies and design concepts, including cooling [4]

4.3 Water Turbine

4.3.1 Opportunities for more Turgo development

There is significant development which has been carried out on the Turgo turbine during the past century and how this has evolved as CFD analysis and computing techniques have made the detailed numerical calculation of the associated flows possible. It has shown that although we are beginning to use CFD analysis of this complex case, it has yet to be utilised to its full potential. A complete analysis of the Turgo turbine using CFD capturing the high speed, highly turbulent, multiphase flow across the blades is yet to be carried out. Research on Pelton turbines have shown that using Eulerian techniques it is possible to develop a CFD model which can accurately describe the flow across the Turgo runner, calculate the torque developed, the efficiency and capture small changes in the design in a reasonable timescale. With the continual improvements to computer processing speeds and CFD codes, these complex simulations are being run in shorter times and it is predicted that the future development of the Turgo turbine will be based around these numerical analyses.

4.3.2 Further development of Pelton turbines

The Pelton impulse turbine is a mature technology. However, this does not prevent researchers from developing this turbine further. Recently a vast amount of CFD based studies were performed on Pelton turbines with a few pioneers presenting parametric design optimisations. The inevitable progress in computational resources leads to a more detailed and complex analysis of Pelton turbines. In the near future simulations might evolve into full scale modelling that includes injectors, complete runner, turbine casing and multi jet operation. Moreover, current publications show design methods where optimisation algorithms are coupled to fast codes based on Lagrangian particle tracking such as FLS. These can provide initial design geometries very quickly however are limited when it comes to fine adjustment. Similar approaches of coupling the optimisation algorithms to Eulerian codes, which are very accurate, might be expected in the future, to provide the overall optimum design based on multi parametric design studies.[20]

4.3 Wind Turbines

There are two future developments in wind turbines which are airborne wind turbine and offshore wind turbine. At present, wind turbines are anchored to the seabed in water depths not

exceeding 30 meters. To reduce investment costs, researchers are also looking into the possibility of using existing offshore oil platforms that are nearing the end of their useful life, something that holds out considerable potential. A project is under way to build 200 wind turbines in the Beatrice oil field, in water depths of 45 meters. Each turbine will be equipped with 60-meter blades built to withstand the North Sea winds.[46] In parallel, since the beginning of 2000s, industrial research is investing on offshore installations. In locations that are far enough from the coast, wind resources are generally greater than those on land, with the winds being stronger and more regular, allowing a more constant usage rate and accurate production planning, and providing more power available for conversions. The foreseen growth rate of offshore installations is extremely promising; according to current forecasts, the worldwide installed power is envisaged in the order of 80 GW within 2020.

5.0 CONCLUSION

Knowledge regarding types of turbine used in power plants and its related information, needed in order to choose the correct type of turbines based on their driving fluid have been discussed in detail. This paper has attempted to cover some of the issues related to common types of turbines. It is hoped that this review helps students to have a better insight into the various aspects of the turbines used in power plant, so that the related issues can be tackled with better knowledge and confidence.

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