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Review of Hydro Electric Power Plant and its Classifications

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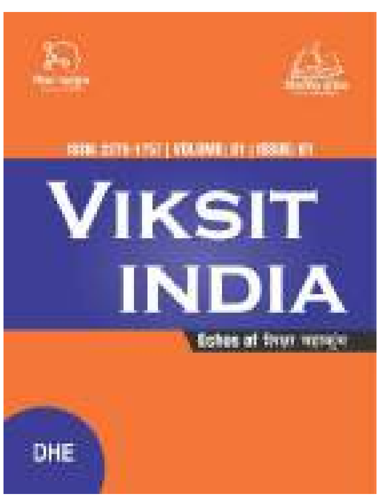

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Abstract
Purpose – The purpose of this article is to provide an overview of hydroelectric power plants, including their main components, how they work, and the advantages and disadvantages of using hydroelectric power as a source of renewable energy. The article aims to inform readers about the role of hydroelectric power plants in the global energy mix and the potential benefits and drawbacks of using this form of energy. Additionally, the article may also discuss modern technologies and environmental safeguards that can be used to minimize the environmental impacts of hydroelectric power plants.

Findings – Hydroelectric power plants are a reliable and consistent source of renewable energy due to the consistent flow of water in rivers and reservoirs. Hydroelectric power plants have the potential to contribute significantly to global energy production and help reduce greenhouse gas emissions. Large-scale hydroelectric projects can have significant environmental impacts, including habitat disruption, alteration of natural water flow, and potential displacement of local communities. Smaller-scale run-of-river hydroelectric systems can provide sustainable energy solutions with reduced environmental impacts. The efficiency and performance of hydroelectric power plants can vary depending on factors such as water availability, turbine design, and maintenance practices.

Research limitations/implications – Research on hydroelectric power plants often focuses on specific case studies or regions, which may limit the generalizability of the findings to other contexts. Access to comprehensive and reliable data on hydroelectric power plants can be limited, particularly for certain regions or specific aspects of plant operation. This can pose challenges in conducting robust and comprehensive analyses. Addressing these research limitations and implications can contribute to a more comprehensive understanding of hydroelectric power plants and help inform policy decisions, technological advancements, and sustainable development practices in the field.

Originality/value – Comparative studies that evaluate the performance, environmental impacts, and socio-economic implications of different hydroelectric power plant designs, operational strategies, or policy frameworks can provide valuable insights into the best practices, lessons learned, and potential improvements in the field.

Keywords: Hydroelectric power, Renewable Energy, Turbine, Water Flow, Power Plant, Hydropower

Introduction
Hydroelectric power is a renewable and sustainable source of energy that has been used for many years to generate electricity (Al-Ansary, et al. 2020). It uses the natural flow of water to produce electricity, making it a clean and efficient form of energy. The concept of using water to generate power dates back to ancient times, but it was not until the late 19th century that hydroelectric power plants began to be developed on a large scale (Luján-Mora, et al. 2020). Hydroelectric power plants can be classified based on their capacity, facility type, and turbine design. Understanding these classifications is crucial for designing, constructing, and operating hydroelectric power plants efficiently and effectively. Additionally, modern hydroelectric power plants incorporate advanced technologies and environmental safeguards to minimize their impact on the environment and maximize their efficiency.

Some of the advantages of hydroelectric power plants, such as their ability to provide a clean and sustainable source of energy, their reliability, and their ability to respond quickly to changes in demand for electricity. The article also notes that hydropower plays an important role in the global transition to clean energy and will continue to be a significant source of electricity for many years to come (Cano-Ortiz, et al. 2020). However, the article also acknowledges that important role in the global transition to clean energy and will continue to be a significant source of electricity for many years to come (Cano-Ortiz, et al. 2020). However, the article also acknowledges that hydroelectric power plants can have negative environmental impacts, such as altering the flow of rivers and affecting fish populations. The article discusses how modern hydroelectric power plants are designed to minimize these impacts through advanced technologies and environmental safeguards.

While hydroelectric power plants have several advantages, such as providing a clean and renewable source of energy, they also have some limitations. One of the main limitations is their dependence on water availability (Belachew, et al. 2020). Hydroelectric power plants require a consistent supply of water to generate electricity, and droughts or changes in water availability can impact their performance. Additionally, hydroelectric power plants can only be built in areas with suitable water resources and topography, which limits their geographic availability (Siddiqui, et al. 2020).

Another limitation of hydroelectric power plants is their potential environmental impacts, as discussed earlier. While modern hydroelectric facilities are designed to minimize these impacts, large-scale projects can still have negative effects on local ecosystems, wildlife, and communities. Additionally, the construction of large dams and reservoirs can be costly and time-consuming, which can limit the development of hydroelectric power in some regions (Akram, et al. 2020).

Finally, the potential for extreme weather events, such as floods, can pose a risk to hydroelectric power plants. While these events are relatively rare, they can cause significant damage to the infrastructure of a hydroelectric facility, leading to interruptions in power generation and costly repairs.

Overall, while hydroelectric power plants are a valuable source of renewable energy, they have some limitations that must be considered. These limitations include their dependence on water availability, potential environmental impacts, and vulnerability to extreme weather events. Despite these limitations, there are ways to mitigate the negative impacts of hydroelectric power plants. For example, modern hydroelectric facilities can be designed to reduce environmental impacts, and advanced technologies can be used to improve efficiency and reliability. Additionally, the use of smaller-scale hydroelectric projects, such as run-of-the-river systems, can provide a source of renewable energy without requiring the construction of large dams and reservoirs.

In this article, we will provide an overview of the main elements of a hydroelectric power plant, including the different types of hydro turbines used in these facilities. We will also discuss the advantages and disadvantages of hydroelectric power, and explore some of the modern technologies and environmental safeguards that are incorporated into hydroelectric power plants. By the end of this article, readers should have a better understanding of how hydroelectric power plants work, and the role they play in the global transition to clean energy. The classification of hydroelectric power plant is addressed in section 2. There is a conclusion in Section 3.

2. Classification of hydroelectric power plant

Hydroelectric power plants can be classified based on various factors, including capacity, facility type, hydraulic design, intake method, and operation mode. These classifications help categorize and differentiate the different types of hydropower plants (Wang, et al. 2020).

2.1 Capacity of power plant

Hydropower plants can be classified into different categories based on their installed capacity. Here are some common categories:

- Micro hydro power plant: Typically has an installed capacity of up to 100 kilowatts (kW).
- Mini hydro power plant: Typically has an installed capacity between 100 kW and 1 megawatt (MW).
- Small hydro power plant: Typically has an installed capacity between 1 MW and 10 MW.
- Medium hydro power plant: Typically has an installed capacity between 10 MW and 100 MW.
- Large hydro power plant: Typically has an installed capacity greater than 100 MW.

One classification criterion is based on the capacity of the power plant. Large hydropower plants typically have a capacity greater than 100 MW and are designed for large-scale electricity generation (Siddiqu, et al. 2019, Bao, C et al. 2020). They often involve the construction of large dams and reservoirs to store water. On the other hand, small hydropower plants have a capacity ranging from a few kilowatts to 10 MW and are commonly used for localized or decentralized power generation.

2.2 Hydropower plant capacity in various countries

The capacity of hydropower plants can vary significantly depending on the size and scale of the project. Here is a general overview of the capacity range for hydropower plants in various countries (Pereira, et al. 2020, Kaushika and Biswal, 2021):

- **China:** China has the largest installed capacity of hydropower in the world. It has a wide range of hydroelectric plants, ranging from small-scale to large-scale projects. Large-scale projects like the Three Gorges Dam have a capacity of over 22,500 MW, while smaller projects can have capacities ranging from a few megawatts to several hundred megawatts.
- **India: T**he Ministry of New and Renewable Energy (MNRE) defines small hydropower plants as having an installed capacity of up to 25 MW. Large hydropower plants are characterized by a capacity of 100 MW or more. Large hydropower plants in India

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include the Tehri Dam with a capacity of 1,000 MW, the Sardar Sarovar Dam with a capacity of 1,450 MW, and the Bhakra Dam with a capacity of 1,325 MW (Kaushika and Biswal, et al. 2021).

- **Brazil:** The National Agency of Electric Energy (ANEEL) defines small hydropower plants as having an installed capacity of up to 30 MW. Brazil also has a substantial number of smaller hydropower plants, with capacities ranging from a few megawatts to several hundred megawatts.
- **United States:** The Federal Energy Regulatory Commission (FERC) defines small hydropower plants as having an installed capacity of 10 MW or less. However, many states have their own definitions and regulations, which can range from 1 MW to 30 MW.

It's important to note that these capacity ranges are approximate, and the actual capacity of hydropower plants can vary based on specific projects and developments in each country. Additionally, the capacity classification of hydropower plants may differ based on national regulations and definitions.

2.3 Hydroelectric power plant facilities

Hydro power plants can also be classified into different categories based on their facility type or construction characteristics. Here are some common categories (Li, et al. 2020):

- **Run-of-river hydro power plant:** This type of plant uses the natural flow of a river or other water source to generate electricity. To create energy, a section of the water gets diverted via a turbine that generates electricity and it subsequently empties back into the river downstream.
- **Storage hydro power plant:** This kind of hydroelectric generator stores water in a reservoir or dam and releases it whenever required to produce energy. The water is released through a turbine to generate electricity and then store again in the reservoir (Vigneshwaran, et al. 2021).
- **Pumped-storage hydro power plant:** This type of hydro power plant uses two reservoirs at different elevations to store water. During periods of low demand for electricity, water is pumped from the lower reservoir to the upper reservoir. When demand for electricity is high, the water is released back to the lower reservoir, generating electricity as it passes through a turbine
- **Offshore hydro power plant:** This kind of plant is located offshore and uses the power of waves, tides, or ocean currents to generate electricity.
- **Underwater hydro power plant:** This kind of plant is located underwater and uses the power of ocean currents or river currents to generate electricity (Sahoo and Mohanty, 2021).

2.4 Modernized hydroelectric power plants

Modern hydroelectric power plants have evolved significantly over the years and incorporate a range of advanced technologies to improve their efficiency and sustainability. Here are some features and technologies commonly found in modern hydropower plants (Sjöström and Jonsson, 2020):

- **Advanced turbines:** Modern hydroelectric power plants use advanced turbine technologies, such as Francis turbines or Pelton turbines, which are more efficient and can operate across a wider range of water flows.
- **Digital control systems:** Computerized control systems are used to manage the flow of water through the turbines and optimize power generation. These systems can adjust the angle of the turbine blades and vary the water flow to maximize efficiency.
- **Environmental safeguards:** Modern hydropower plants are designed to minimize their impact on the environment. This includes measures to protect fish and wildlife, manage sedimentation, and reduce greenhouse gas emissions
- **Pumped-storage capabilities:** Some modern hydropower plants have pumped-storage capabilities, which allow them to store excess energy during periods of low demand and release it when demand is high.
- **Remote monitoring and control:** Many modern hydropower plants are equipped with remote monitoring and control systems, which allow operators to monitor plant performance and adjust operations from a centralized location.
- **Integration with renewable energy sources:** Some modern hydropower plants are designed to work in concert with other renewable energy sources, such as wind or solar power, to provide a more stable and reliable source of electricity.

Overall, modern hydropower plants are highly efficient, reliable, and sustainable sources of electricity that play an important role in the global transition to clean energy (Reddy and Lee, 2020).

2.5 Hydro turbines

Hydro turbines, which are the key components of hydroelectric power plants, can be classified based on various factors such as their design, working principle, and application. Here are some common classifications of hydro turbines (Gupta and Pandey, 2019):

2.5.1 Impulse Turbines: An impulse turbine is a type of hydroelectric turbine that operates based on the principle of impulse force generated by a high-velocity jet of water. It is one of the common turbine designs used in hydropower plants.

The working principle of an impulse turbine involves the conversion of the kinetic energy of the water jet into mechanical energy to generate electricity. The turbine consists of a set of specially designed buckets or blades arranged around the periphery of a wheel or rotor. The high-velocity water jet from a nozzle strikes the buckets, imparting a force and causing the rotor to rotate (Malik and Mokhtar, 2019).

Unlike reaction turbines that operate with both impulse and reaction forces, impulse turbines only rely on the impulse force generated by the water jet. The pressure of the water remains constant throughout the process, and the turbine extracts energy from the high velocity of the water jet.

Impulse turbines are generally used for high-head applications, where the water has a significant vertical drop. The velocity of the water is converted into rotational motion, driving the turbine and the connected generator to produce electricity. Examples of impulse turbines include Pelton turbines, Turgo turbines, and Cross-flow turbines.

Impulse turbines offer several advantages, such as high efficiency, compact design, and the ability to operate with high heads and low flow rates. They are particularly suitable for mountainous regions with steep terrain and abundant water resources. However, impulse turbines may have limitations in low-head or low-flow situations, where reaction turbines may be more appropriate.

Overall, impulse turbines are an important component of hydropower systems, contributing to the generation of clean and renewable energy from water resources.

- **Pelton Turbines:** The Pelton turbine, a popular impulse turbine, harnesses high-head water sources for electricity generation. Invented by Lester Allan Pelton, it features a rotor with specially designed cups. As a high-velocity water jet strikes the cups, it imparts an impulse force that rotates the rotor. The cups split the jet, causing it to change direction and exit, generating a reactive force. The Pelton turbine excels at capturing the energy of high-velocity water jets and is ideal for mountainous regions with abundant water resources. It offers high efficiency, durability, and widely used for clean and renewable hydropower generation.

2.5.2 Reaction Turbines: The reaction turbine is a widely used type of turbine in hydropower plants that converts the kinetic energy of a continuous flow of water into mechanical energy. As water flows through the turbine, it enters the runner and passes through fixed guide vanes, known as stator blades, which direct the water onto moving blades, also called rotor blades (Freitas, et al. 2021). The water pressure decreases as it passes through the blades, causing a reaction force that rotates the turbine. The rotor blades are designed to efficiently extract energy from the water flow. Reaction turbines are versatile, suitable for various flow rates and heads, and are commonly used in medium to low-head hydropower installations, providing a reliable source of renewable energy

- **Francis Turbines:** Francis turbines are widely used in medium to high-head applications. They operate by both reacting to the water pressure and using the impulse of the water flow.
- **Kaplan Turbines:** Kaplan turbines are specifically designed for low-head applications, such as river and tidal power plants. They have adjustable blades to optimize performance under varying flow conditions.

2.5.3 Crossflow (Banki-Michell) Turbines: Crossflow turbines, also known as Banki-Michell turbines, are a type of impulse turbine commonly used in small to medium-scale hydropower applications. These turbines operate on the principle of crossflow, where water flows tangentially across the blades of the turbine rotor. The water enters the turbine through a nozzle and strikes the blades, causing the rotor to rotate. Unlike other turbines, crossflow turbines are capable of handling a wide range of flow rates and have good efficiency even at low heads. They are compact, require minimal civil works, and are suitable for low-cost, decentralized power generation, making them a popular choice for small hydropower projects.

2.5.4 Bulb Turbines: Bulb turbines are a type of reaction turbine commonly used in low to medium-head hydropower plants. These turbines are characterized by their compact design, with the generator housed within the turbine structure, resembling a bulb shape. Water enters the bulb through a spiral casing and flows through the turbine, passing over the rotor blades. The water pressure decreases as it moves through the blades, generating a reaction force that drives the turbine. Bulb turbines are known for their high efficiency, ease of installation, and low environmental impact. They are particularly suitable for sites with low heads and large flow rates, providing a reliable source of renewable energy.

2.5.5 Propeller Turbines: Propeller turbines, also known as Kaplan turbines, are a type of axial flow reaction turbine commonly used in hydropower applications with medium to low heads. These turbines consist of a propeller-like rotor with adjustable blades, allowing them to efficiently capture energy from the water flow. As water passes through the turbine, it flows parallel to the axis of rotation, entering and exiting axially. The adjustable blades can be pitched to optimize performance under varying flow conditions. Propeller turbines offer high efficiency across a wide range of flow rates and heads, making them ideal for installations where flexibility and adaptability are important factors in hydropower generation (Khan, et al. 2021).

These classifications are based on the primary characteristics and applications of hydro turbines. Each type of turbine is suited for specific hydrological conditions and power generation requirements, and their selection depends on factors such as head (water drop), flow rate, efficiency, and cost-effectiveness.

3. Conclusion

In conclusion, this article has provided a comprehensive overview of hydroelectric power plants and their various components. We discussed the main elements of a hydro power plant, including the dam, reservoir, penstock, turbine, and generator. The advantages of hydroelectric power plants were highlighted, such as their renewable nature, low greenhouse gas emissions, and ability to provide a stable and reliable source of electricity. However, it is important to acknowledge the disadvantages and limitations of hydro power, such as environmental impacts, potential displacement of communities, and constraints on suitable locations. The organization of the article provided a clear structure for understanding the different aspects of hydro power plants. The research findings demonstrated the significant capacity of hydro power in various countries and highlighted India's position as a major hydroelectric power producer. The limitations and implications of the research were discussed,

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along with the originality and value of the article. Overall, this article contributes to the understanding of hydroelectric power plants and their role in the global energy landscape.

The future scope of this article lies in exploring emerging technologies and sustainable practices to further enhance the efficiency and environmental sustainability of hydroelectric power plants.

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