

AN OVERVIEW ON ELECTRICAL POWER GENERATION FROM THE GREEN ENERGY SOURCES

Abstract

The electrical power generation through the renewable energy sources has been in the focus from the recent three decades. Owing to limit the adverse effect on the environment that emerges from the conventional power generation process, a bigger priority is given for the techniques that harness electricity from renewable sources. This chapter exactly focused on summarizing the various techniques that are available in harnessing the power from the renewable energy sources that could be helpful for the students and the scholars of the research community to get all the techniques in one place.

Keywords: Renewable sources, Indian electrical energy scenario, green energy sources.

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I. INTRODUCTION

Currently, between 15% and 20% of the world's total energy demand is met by renewable energy sources. Traditional biomass, mostly fuel wood used for cooking and heating, makes up the majority of the supply, particularly in poor nations in Africa, Asia, and Latin America. Conventional biomass, primarily fuel wood used for both heating and cooking, makes up the majority of the supply, particularly in poor nations in Africa, Asia, and Latin America. The usage of massive hydropower, which accounts for about 20% of the world's electrical supply, also makes a significant contribution. The present contribution of new renewable energy sources (solar energy, wind energy, contemporary bio-energy, geothermal energy, and minor hydropower) is around 2% [1].

According to a number of scenario studies that looked into the potential contribution of renewables to the world's energy supplies, with the right policies in place, their contribution could increase from the current level of about 20% to more than 50% in the second half of the twenty-first century. You may lower your exposure to both present and future energy cost exposures by using distributed renewable generating energy. By either reducing peak demand or releasing its energy at precisely calculated times, a well-designed renewable energy solution will lower your demand costs, enabling customers to use cost savings for other essential business operations.

1. Renewable Energy Evolution: The evolution of renewable energy has been marked by significant advancements and milestones over the years, as societies increasingly recognize the need to transition away from fossil fuels for a sustainable future. Here's a brief overview of the key stages in the evolution of renewable energy:

- **Early Beginnings:** The use of renewable energy sources, such as wind and water mills, dates back centuries for tasks like grinding grain and pumping water. These early technologies laid the foundation for later developments.
- **Hydroelectric Power:** In the late 19th and early 20th centuries, hydroelectric power plants emerged, generating electricity from flowing water. This marked the first large-scale use of renewable energy for electricity generation.
- **Solar and Wind Energy:** Solar water heaters gained popularity in the mid-20th century. The 1970s saw the development of photovoltaic solar cells, while wind turbines evolved into more efficient designs, contributing to the growth of solar and wind energy.
- **Technological Advancements:** Research and development efforts led to improvements in renewable energy technologies, making them more efficient and cost-effective. Solar panels, wind turbines, and energy storage solutions saw substantial advancements.
- **Grid Integration:** The integration of renewable energy into existing power grids became a focus, requiring upgrades and the development of smart grid technologies to manage variable energy sources.

- **Global Growth:** Renewable energy capacity expanded rapidly worldwide, with countries like Germany, China, and the United States leading the way in installations of wind and solar energy systems.
- **Energy Storage:** Advances in energy storage technologies, like lithium-ion batteries, improved the reliability and flexibility of renewable energy systems, enabling around-the-clock energy availability.
- **Electrification and Transportation:** Renewable energy sources are increasingly powering electric vehicles and electrifying various sectors, reducing greenhouse gas emissions in transportation and industry.
- **Global Commitments:** International agreements like the Paris Agreement reinforced the importance of transitioning to renewable energy to mitigate climate change, leading to more ambitious renewable energy targets.

The evolution of renewable energy is an ongoing process, driven by technological innovation, policy support, and growing environmental awareness. As we continue to address the challenges of climate change and energy sustainability, renewable energy is expected to play an increasingly central role in our energy landscape.

2. Scenario of Electricity Generation in India [2]

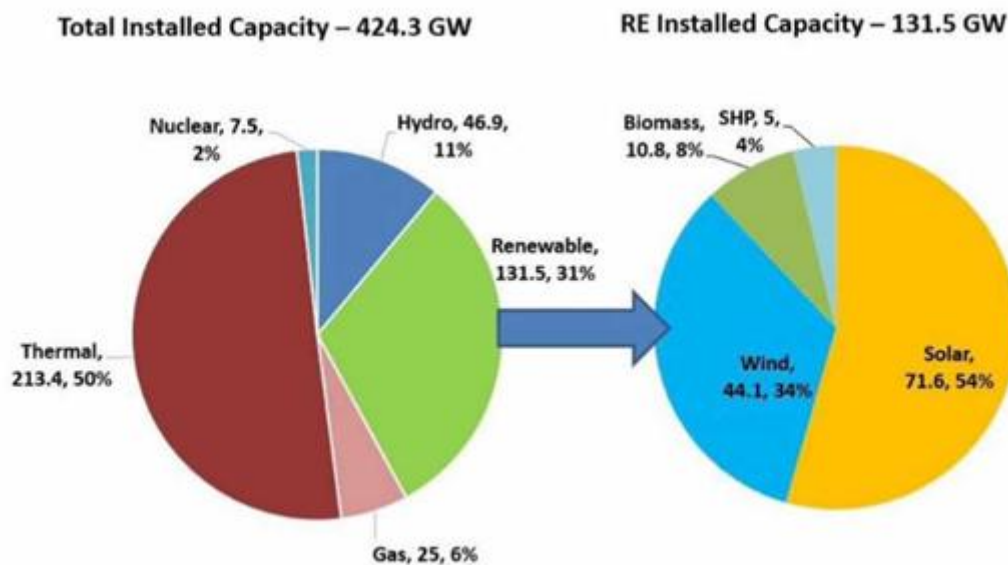


Figure 1: Energy Scenario in India as on 30th August 2023.

3. **Solar Energy:** The most plenteous energy in the world is the Solar Energy. Through the photovoltaic systems and the concentrators the solar energy can be used to convert into the electrical energy. The solar thermal system otherwise called concentrated solar power employs solar power in different ways to produce electricity. Solar energy can be used in a variety of applications such as the generation of electricity, water heating in domestic or

industrial applications, cooling, and light. In the last 5 years, the solar energy installed capacity is increased by 11 times. As of March 2019, around 42 solar parks have been approved in almost 17 states. The fully operated solar parks are at Kurnool and Bhadla II. The largest solar park is under installation in Pavagada.

4. **Wind Energy:** It is the most sustainable form of energy and over the world, harnessing the power from wind is happening like a revolution. Moreover, it is clean, versatile, and possesses the economic benefits. In summary, wind energy stands as a pivotal player in the transition to a sustainable and low-carbon energy future. Its growth continues to be driven by technological innovations, increasing cost competitiveness, and a global commitment to reduce greenhouse gas emissions. As we move forward, further research and investment in wind energy will play a vital role in addressing the world's energy needs while protecting our environment.
5. **Hydro Power:** The other type of renewable energy is Hydro Power where the energy possessed by water due to its motion is used for electricity generation. Here, the stored energy is converted into kinetic energy by initiating the flow of water between two points at different heights. It is the largest renewable energy resource used for generating electricity. The Hydropower plays an inevitable role in accomplishing India's Renewable Energy plans in electricity generation. But, environmental and financial concerns play adversely.

The overall output of hydropower is about 90%-95%. In India, the projects under the capacity of 25 MW belong to the category of a small hydropower plant. India's estimated hydropower potential is 1,45,320 MW capacity. The installed capacity at the end of February 2020 is 45,700MW.

6. **Biomass Energy:** Biomass is the use of organic material that arises from plants and animals to produce electricity. Chemical energy from the biomass is discharged as heat when biomass is burnt. The energy from biomass is free from fluctuations and no storage requirement as in the case of wind and solar. The biomass can be used directly or converted into liquid biofuels or biogas which can be used as fuels. Wood wastes, animal manures, agricultural wastes, food waste, and garbage are burned and converted into biofuels to generate electricity. The Ministry of New and Renewable energy has promoted a new scheme to support the biomass-based cogeneration in all sugar mills. Biomass contributes 18000MW of energy among total generated renewable energy in India.

Non-Conventional energy in India has been reviewed. Because of the depletion of fossil fuels, the need for alternate energy becomes more important. To be environmentally safe, the energy sources must be with low environmental influence and low greenhouse gas emissions. India has gained the application of various renewable energy technologies to utilize in various sectors.

II. VARIOUS GREEN ENERGY GENERATION SOURCES

1. Solar Photovoltaic (PV) Systems [3]

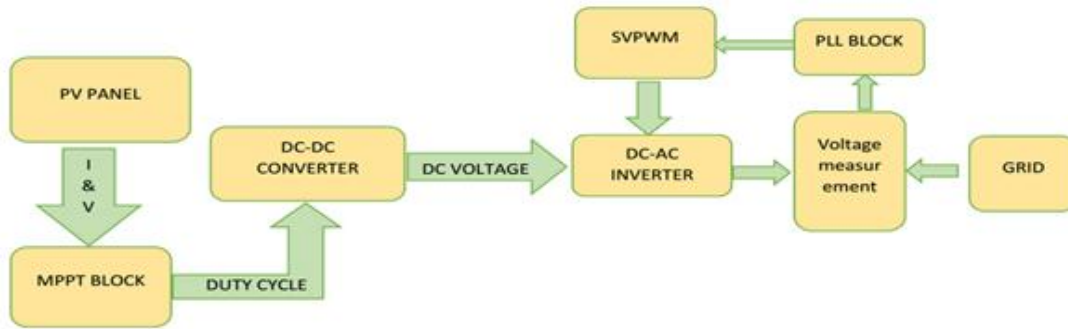


Figure 2: Block Diagram of Solar Photovoltaic (PV) Systems

These Systems Typically Consist of:

- **Solar Panels:** Photovoltaic panels, often made from silicon, capture sunlight and generate direct current (DC) electricity when exposed to sunlight.
- **Inverter:** An inverter converts the DC electricity from the panels into AC.
- **Mounting and Racking:** These components secure the solar panels to rooftops or ground-mounted structures, ensuring they are properly angled to receive sunlight.
- **Solar Charge Controller (for off-grid systems):** In off-grid setups, a charge controller regulates the flow of electricity from the panels to batteries, preventing overcharging and damage.
- **Batteries (for off-grid systems):** It stores excess electricity generated at day time for use at night or on cloudy days.
- **Grid Connection:** Grid-tied PV systems are tied up with local utility grid. Excess electricity can be sent back to the grid, and power is drawn from the grid when the solar panels are not producing enough energy.
- **Monitoring System:** Many PV systems have monitoring equipment that tracks energy production and system performance.

Solar PV systems are environmentally friendly, reduce electricity bills, and can have a positive impact on reducing greenhouse gas emissions when integrated into the energy mix. They are widely used for residential, commercial, and industrial applications.

2. Solar Thermal System [4]:

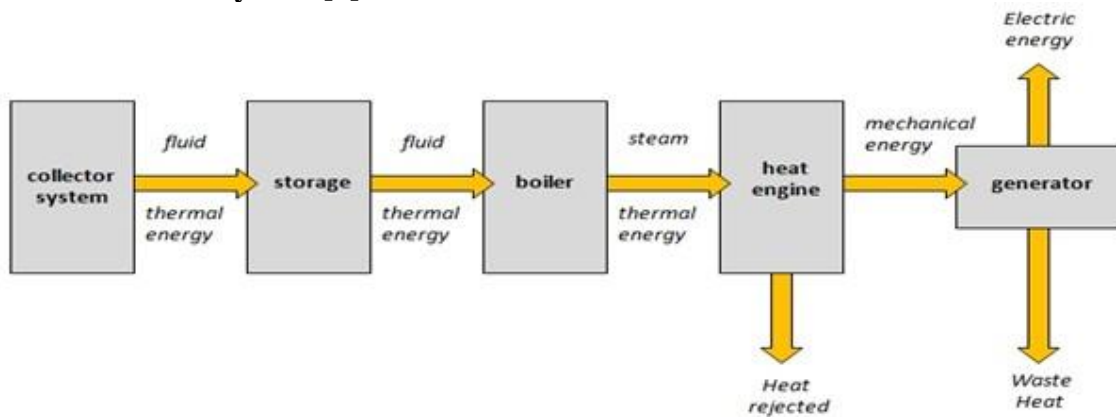


Figure 3: Block Diagram of Solar Thermal System

Solar thermal systems use sunlight to heat a fluid (usually water or a heat transfer fluid) to produce thermal energy, which can be used for various purposes, including space heating, hot water production, and electricity generation. There are several types of solar thermal systems:

- **Flat-Plate Collectors:** They consist of a flat, insulated box with a dark-colored absorber plate, covered by a transparent cover (usually glass or plastic). Sunlight heats the absorber plate, and the heat is transferred to a fluid passing through pipes or channels within the collector.
- **Evacuated Tube Collectors:** These collectors use rows of glass tubes, each containing an absorber tube. The vacuum between the inner and outer tubes provides excellent insulation, making them efficient in colder climates.
- **Parabolic Troughs:** These are used for larger-scale applications, such as electricity generation. Parabolic-shaped reflectors focus sunlight onto a receiver tube running along the trough's focal line. The concentrated heat is then used to generate steam, which drives a turbine for electricity production.
- **Solar Dish Collectors:** These systems use a large, parabolic dish to concentrate sunlight onto a receiver located at the dish's focal point. The receiver absorbs the concentrated heat, which can be used for various applications, including electricity generation or high-temperature industrial processes.
- **Solar Pond:** In this unique system, a large, shallow pond with a dark-colored bottom collects and stores solar energy as heat. The water at the bottom of the pond gets heated, and this thermal energy can be used for space heating or other purposes.

Solar thermal systems have the advantage of providing heat directly, making them highly efficient for water heating and space heating in residential and commercial buildings. They can also be integrated with existing heating systems.

Additionally, some advanced solar thermal power plants use these systems to generate electricity on a larger scale, contributing to renewable energy production

3. Wind Turbines [5] :

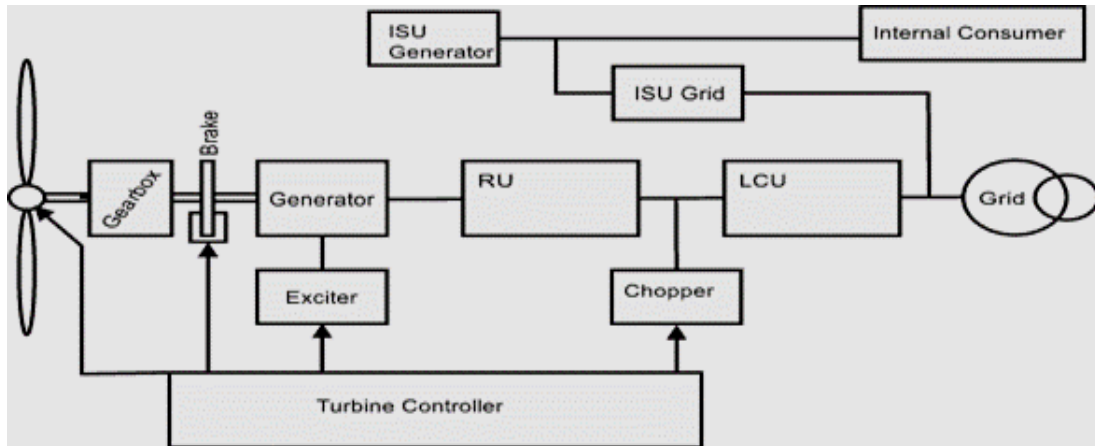


Figure 4: Block Diagram of Wind Turbine

Wind turbines are devices that harness the kinetic energy of the wind and convert it into electrical energy. They are a key technology in renewable energy generation. Here are the main components and functions of a typical wind turbine:

- **Rotor Blades:** The portion of a wind turbine that is most noticeable is the rotor blades. They take the wind's kinetic energy and turn it into rotational energy.
- **Hub:** The hub is the central component to which the rotor blades are attached. It connects the blades to the main shaft.
- **Main Shaft:** The main shaft is connected to the hub and transfers the rotational energy from the rotor blades to the generator.
- **Generator:** The generator is in charge of transforming the rotating shaft's mechanical energy into electrical energy. Synchronous or asynchronous generators—often referred to as "induction generators"—are used by the majority of wind turbines.
- **Yaw System:** Wind turbines are equipped with a yaw system that allows them to turn and face into the wind to maximize energy capture. This system includes sensors and motors to adjust the orientation of the turbine.
- **Nacelle:** The nacelle is a housing that contains the generator, gearbox, and other critical components. It is located behind the rotor blades and sits atop the tower.
- **Gearbox (if applicable):** In some wind turbines, a gearbox is used to increase the rotational speed of the main shaft, allowing the generator to operate at its optimal speed.

- **Tower:** The tower provides the height necessary to capture higher, more consistent wind speeds. Towers can vary in height, with taller towers capturing more wind energy.
- **Anemometer and Wind Vane:** These devices detect wind direction and speed, feeding information to the turbine's control system to enhance efficiency.
- **Control System:** The control system manages the turbine's operation, adjusting the blade pitch, rotor speed, and yaw position to optimize energy production and protect the turbine in high winds.
- **Brakes:** Wind turbines have mechanical or electrical brakes to stop the rotor in high winds or for maintenance purposes.

Wind turbines come in various sizes, from small turbines for residential use to large utility-scale turbines. They are typically grouped together in wind farms to generate electricity for homes, businesses, and the grid. Wind energy is a clean and renewable source of power, making it an essential component of efforts to reduce carbon emissions and combat climate change.

4. Hydropower [6] : Here's how hydroelectric power works:

- **Dam or Diversion Structure:** In many hydroelectric power plants, a dam is built across a river to create a reservoir, or a diversion structure is constructed to redirect a portion of the river's flow. This creates a controlled flow of water.
- **Penstock:** The controlled flow of water is channeled through a large pipe called a penstock. The pressure from the falling or flowing water increases as it descends through the penstock.

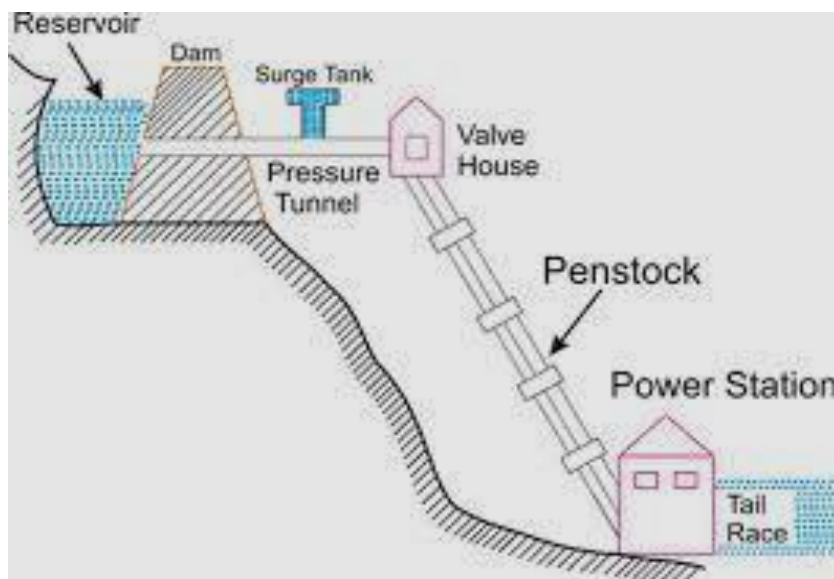


Figure 5: Schematic Diagram of Hydro Power

- **Turbine:** The high-pressure water is directed onto the blades of a turbine. The force of the water causes the turbine to spin.
- **Generator:** The spinning turbine is connected to a generator. As the turbine turns, it rotates the generator's rotor, which is surrounded by a stationary set of coils. This motion induces a flow of electrons in the coils, generating electricity.

Hydropower systems can vary in scale, from small micro-hydro systems used for remote communities to large, multi-megawatt hydroelectric dams. There are two primary types of hydropower systems:

- **Conventional Hydropower:** This refers to large-scale hydropower projects involving dams and reservoirs. They can provide a consistent and reliable source of electricity but can have environmental impacts on river ecosystems and local communities.
- **Run-of-River Hydropower:** These systems don't involve the construction of large dams and reservoirs. Instead, they divert a portion of the river's flow, often through a small dam or weir, and generate electricity from the natural flow of the river. Run-of-river systems typically have fewer environmental impacts.

Hydropower has several advantages, including its reliability, low greenhouse gas emissions, and ability to store energy by regulating water flow. However, it can also raise environmental and social concerns, especially with large dam projects. Balancing the benefits and impacts of hydropower is essential in its responsible development.

5. Biomass Energy [7] :

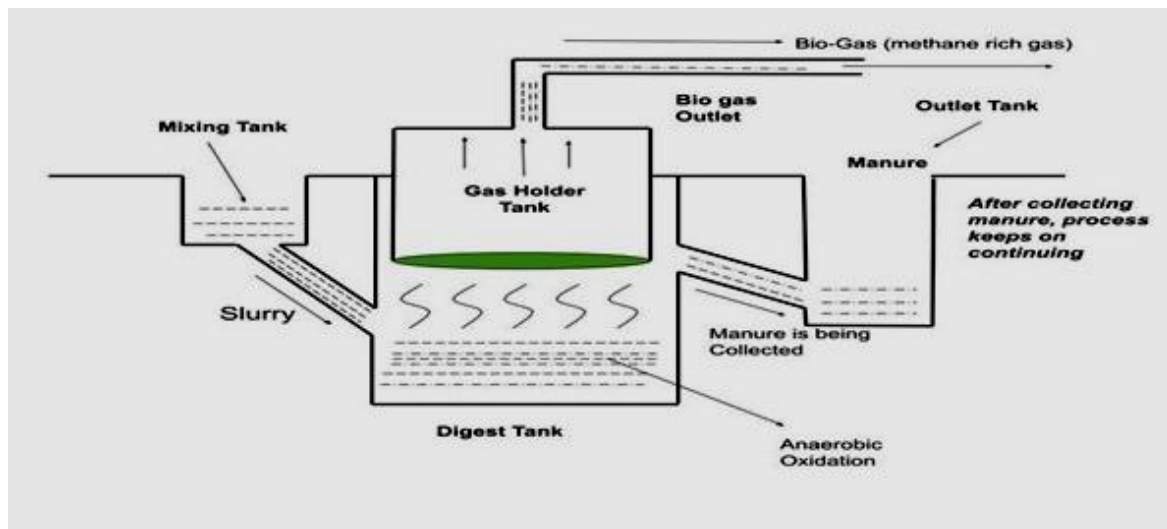


Figure 6: Schematic Diagram of Biomass Energy

Biomass energy is a renewable energy source that is derived from organic materials, typically plant and animal waste, agricultural residues, wood, and dedicated energy crops. It is a versatile source of energy that can be converted into heat, electricity, or biofuels. Here are the main aspects of biomass energy:

- **Biomass Sources:** Biomass energy can be obtained from various sources, including:
 - **Wood:** Logs, wood chips, sawdust, and wood pellets.
 - **Crop Residues:** **Leftover materials from crops like corn stover, wheat straw, and rice husks.**
 - **Animal Manure:** Livestock waste, such as cow dung and poultry litter.
 - **Energy Crops:** Plants grown specifically for biomass energy production, like switchgrass and miscanthus.

- **Advantages**
 - **Renewable:** Biomass is a renewable resource as long as it is managed sustainably.
 - **Reduced Greenhouse Gas Emissions:** Biomass can be carbon-neutral if the carbon released during combustion is offset by the carbon absorbed by the plants during growth.
 - **Waste Reduction:** Biomass energy can utilize agricultural and forestry waste, reducing the need for disposal.

- **Challenges**
 - **Environmental Impact:** Unsustainable biomass harvesting and land-use changes can have negative environmental consequences.
 - **Resource Availability:** Availability and quality of biomass feedstock can vary depending on location and seasonal factors.
 - **Efficiency:** Biomass energy conversion can be less efficient than some other renewables like solar or wind.

- **Applications:** Biomass energy is used in various applications, including heating for homes and businesses, electricity generation, and as a source of biofuels for transportation.

- **Bioenergy Sustainability:** To ensure the sustainability of biomass energy, it's crucial to manage feedstock resources carefully, minimize environmental impacts, and promote responsible land use.

Biomass energy plays a role in reducing greenhouse gas emissions and diversifying the energy mix, but its success depends on sustainable practices and efficient technologies.

6. Geothermal Energy [8]

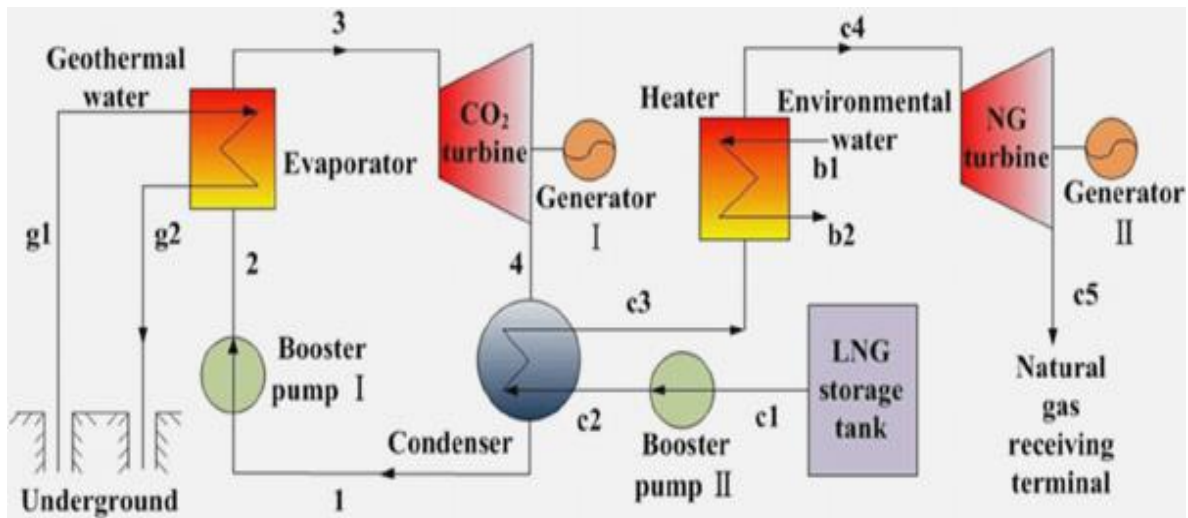


Figure 7: Schematic Diagram of Geothermal Energy

The Working is as Follows:

- **Heat Source:** The Earth's interior contains an abundant reservoir of heat, primarily generated from the decay of radioactive isotopes and heat left over from the planet's formation.
- **Geothermal Reservoirs:** Underground reservoirs of hot water and steam, known as geothermal reservoirs, store this heat. These reservoirs are typically found in regions with active volcanoes, tectonic plate boundaries, or areas with natural hot springs.
- **Production Wells:** Geothermal energy is extracted by drilling wells into the geothermal reservoirs. These wells tap into the high-temperature fluids (water or steam) present underground.
- **Geothermal Fluid Extraction:** When production wells are drilled, geothermal fluids, which can reach temperatures of several hundred degrees Celsius, are brought to the surface. These fluids contain the heat that will be used to generate electricity or provide direct heating.
- **Electricity Generation:** The extracted geothermal fluid is passed through a heat exchanger at the surface, where it transfers its heat to a working fluid (usually a secondary fluid with a lower boiling point). The working fluid vaporizes and drives a turbine connected to a generator, producing electricity.
- **Direct Use:** In some applications, geothermal fluids are used directly for space heating, district heating, greenhouse heating, or industrial processes. In these cases, the hot fluid is circulated through a distribution system to provide the required heat.

- **Reinjection:** After the heat is extracted from the geothermal fluid, it is often reinjected back into the reservoir. This helps sustain the reservoir's long-term productivity and ensures the resource remains viable.
- **Advantages**
 - It is a continuous and reliable energy source, providing baseload power.
 - It produces minimal greenhouse gas emissions, making it an environmentally friendly energy option.
 - It can be used for various applications, including electricity generation and direct heating.
- **Limitations**
 - It is location-dependent, as viable geothermal resources are concentrated in specific regions.
 - Initial drilling and exploration costs can be high.
 - There is the risk of resource depletion if not managed sustainably.

Geothermal energy is an essential part of the renewable energy mix and plays a crucial role in reducing carbon emissions while providing reliable and efficient energy solutions.

7. Tidal and Wave Energy [9] : Tidal and wave energy are forms of renewable energy that harness the power of the ocean's tides and waves to generate electricity. They both have the advantage of being predictable and highly sustainable energy sources. Here's an overview of each

- **Tidal Energy:**

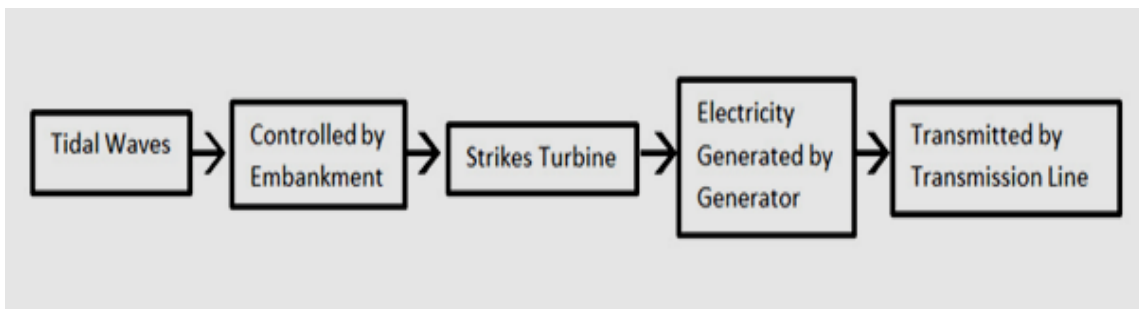


Figure 8: Block Diagram of Tidal Energy

- **Tides:** Tides are the rise and fall of sea levels caused by the gravitational pull of the moon and the sun on Earth's oceans. This movement of water creates kinetic energy that can be harnessed for power generation.
- **Tidal Range and Currents:** Tidal energy is primarily captured in two ways:
 - **Tidal Range Energy:** This method involves building tidal barrages or dams across estuaries or tidal basins. As the tide rises and falls, water is allowed to flow through turbines in these structures, generating electricity.

- Tidal Current Energy: Turbines, similar to underwater wind turbines, are placed on the seabed in areas with strong tidal currents. These turbines are turned by the movement of water, converting kinetic energy into electricity.

- **Wave Energy:**

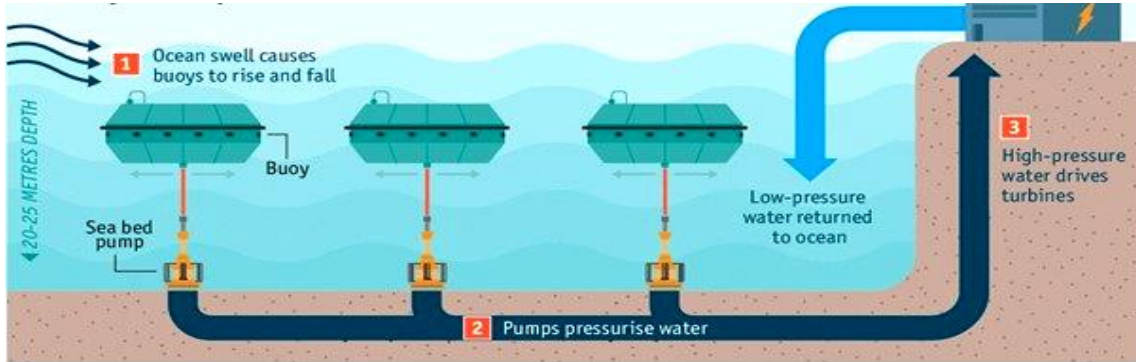


Figure 9: Schematic of Wave Energy

- **Waves:** Wave energy is generated by the movement of water near the ocean's surface due to the wind. As waves travel, they contain kinetic energy that can be converted into electricity.
- **Wave Energy Capture:** Various devices have been developed to capture wave energy, including:
 - ❖ **Point Absorbers:** These float on the surface and move up and down with the waves, driving a hydraulic system that generates electricity.
 - ❖ **Oscillating Water Columns:** These use the motion of waves to create air pressure variations in a chamber, which then drive a turbine.
 - ❖ **Attenuators:** These long, floating structures move with the waves and contain multiple energy capture systems along their length.

8. Hydrogen Fuel Cells [10] :

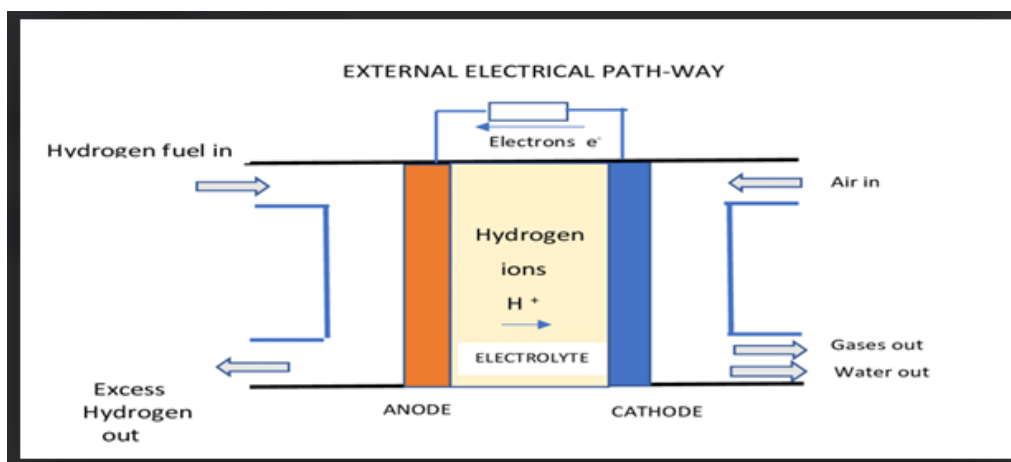


Figure 10: Schematic Diagram of Hydrogen Fuel Cell

Hydrogen fuel cells are advanced energy conversion devices that generate electricity by chemically reacting hydrogen with oxygen. They offer a clean and efficient way to produce electricity and power various applications. Here's how hydrogen fuel cells work and their key characteristics:

- **Basic Principle:** Hydrogen fuel cells operate based on the electrochemical reaction between hydrogen (H₂) and oxygen (O₂), which produces electricity, heat, and water as byproducts.
- **Components of a Fuel Cell:**
 - **Anode:** At the anode side of the fuel cell, hydrogen molecules are split into protons (H⁺) and electrons (e⁻). The protons pass through an electrolyte to the cathode.
 - **Electrolyte:** The electrolyte is a membrane that selectively allows the passage of protons while blocking electrons. It typically consists of a polymer electrolyte membrane (PEM) or a solid oxide material.
 - **Cathode:** At the cathode side, oxygen from the air combines with protons and electrons that have traveled through the electrolyte. This reaction generates water (H₂O) and releases electrons, which flow through an external circuit, creating an electric current.
 - **External Circuit:** The flow of electrons through an external circuit generates electrical power that can be used to run various devices or systems.

9. Advanced Energy Storage [11] : Advanced energy storage refers to innovative and sophisticated technologies designed to store electrical energy efficiently and effectively for various purposes. These technologies are crucial for enhancing the reliability and integration of renewable energy sources, stabilizing the electrical grid, and optimizing energy use. Here are some key examples of advanced energy storage systems:

- **Lithium-Ion Batteries:** Electric vehicles (EVs), portable gadgets, and grid-scale energy storage are just a few examples of the many uses for lithium-ion batteries. These types of batteries are currently being developed in more advanced forms with higher power density, extended cycle life, and better safety features.
- **Flow Batteries:** The energy in flow batteries is stored in two different electrolyte tanks, and it is discharged by circulating the salts in the electrolytes over a cell stack. They are useful for massive amounts grid applications due to their benefits including scalability and high cycle life.
- **Solid-State Batteries:** Instead of the liquid or gel electrolytes used in traditional lithium-ion batteries, solid electrolytes are used in solid-state batteries. They provide greater energy density, quicker charging, and enhanced security.
- **Supercapacitors:** Supercapacitors, or ultracapacitors, store energy electrostatically and can deliver high power rapidly. They are often used for short-term energy storage, such as in regenerative braking systems in vehicles.

- **Flywheel Energy Storage:** Flywheels store energy as rotational kinetic energy. They are known for their rapid response time and are used for short-duration backup power and grid frequency regulation.
- **Thermal Energy Storage:** This method stores energy in the form of heat. Phase-change materials and sensible heat storage systems are used to capture and release thermal energy. These are often used in conjunction with concentrated solar power (CSP) systems.
- **Hydrogen Storage:** Hydrogen can be stored and used as an energy carrier. Hydrogen storage methods include high-pressure gas storage, cryogenic storage, and chemical hydrogen storage materials.
- **Advanced Compressed Air Energy Storage (A-CAES):** Air is compressed and stored as energy in underground caverns using A-CAES devices. The air that is compressed is expanded to produce energy as needed.
- **Advanced Pumped Hydro Storage:** Traditional pumped hydro storage involves pumping water uphill to store energy and then releasing it by flowing downhill through turbines. Advanced designs include modular and smaller-scale versions suitable for decentralized applications.
- **Advanced Materials:** Research is ongoing to develop advanced materials for energy storage, such as new electrode materials for batteries and innovative materials for thermal energy storage.

Advanced energy storage systems play a critical role in enhancing the reliability and efficiency of energy systems, facilitating the integration of intermittent renewable energy sources like wind and solar, and providing grid services like frequency regulation and peak shaving. Continued research and development in this field are essential for achieving a more sustainable and resilient energy infrastructure.

10. Ocean Thermal Energy Conversion (OTEC) [12] :

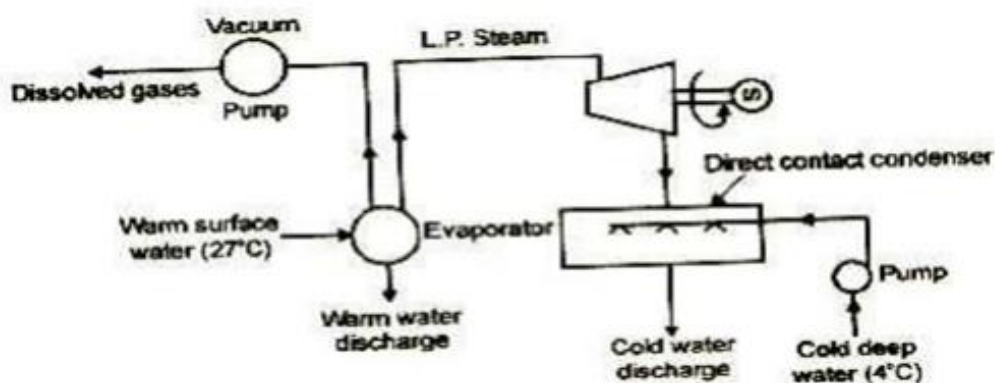


Figure 11: Block Diagram of OTEC-Open Cycle.

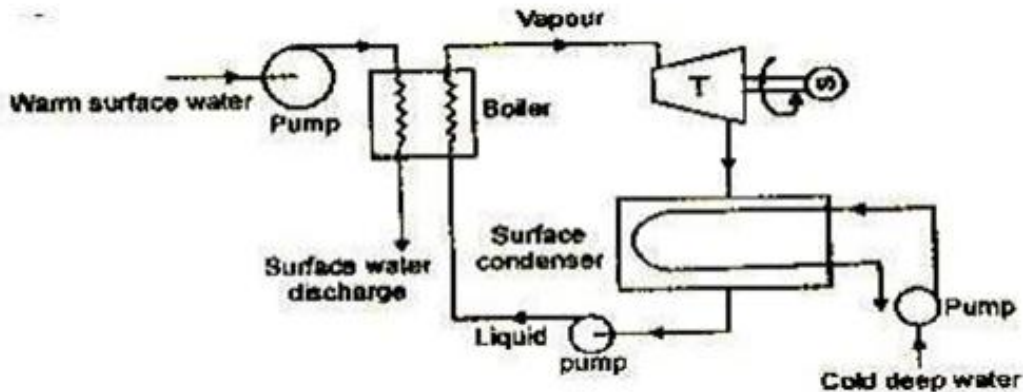


Figure 12: Block Diagram of OTEC-Closed Cycle.

Using the temperature differential between warm surface saltwater and chilly deep ocean water, OTEC is a renewable energy technology that produces electricity. It is a promising but relatively underdeveloped method for producing clean and continuous power. Here's how OTEC works and some key points about it:

- **Temperature Gradient:** OTEC systems rely on the temperature gradient that exists in the ocean. The surface water is typically warmer, while deeper water is colder. This temperature difference can be substantial in tropical and subtropical regions.
- **Open-Cycle and Closed-Cycle OTEC:** There are two main types of OTEC systems:
 - **Open-Cycle OTEC:** In this system, warm surface seawater is pumped into a low-pressure chamber, causing it to vaporize. The resulting steam is used to drive a turbine connected to a generator to produce electricity. Cold seawater from the ocean depths is then used to condense the steam back into water, and the cycle repeats.
 - **Closed-Cycle OTEC:** Closed-cycle systems employ a working fluid (such as ammonia) that has a lower point of boiling than water. The working fluid is heated by the warm water from the surface, which causes it to evaporate. The working fluid that has been vaporized powers a turbine that produces energy. The vaporized working fluid is condensed using cold saltwater, then the concentrated functioning fluid is recycled inside of a closed loop.
- **Advantages**
 - OTEC is a continuous and predictable energy source, unlike some intermittent renewables.
 - It produces electricity with no greenhouse gas emissions, making it environmentally friendly.
 - OTEC can provide desalinated freshwater as a byproduct.

- **Applications:** OTEC has the potential to be used for various applications, including:
 - Providing electricity to remote islands and coastal areas.
 - Supporting desalination processes to produce freshwater.
 - Producing hydrogen through electrolysis using the electricity generated.
 - Cooling applications in industries and power plants.
- **Research and Development:** OTEC technology is still in the research and development phase, and pilot projects have been conducted to demonstrate its feasibility. Advancements in materials and engineering are needed to make OTEC economically competitive.

11. Piezoelectric Devices [13] :

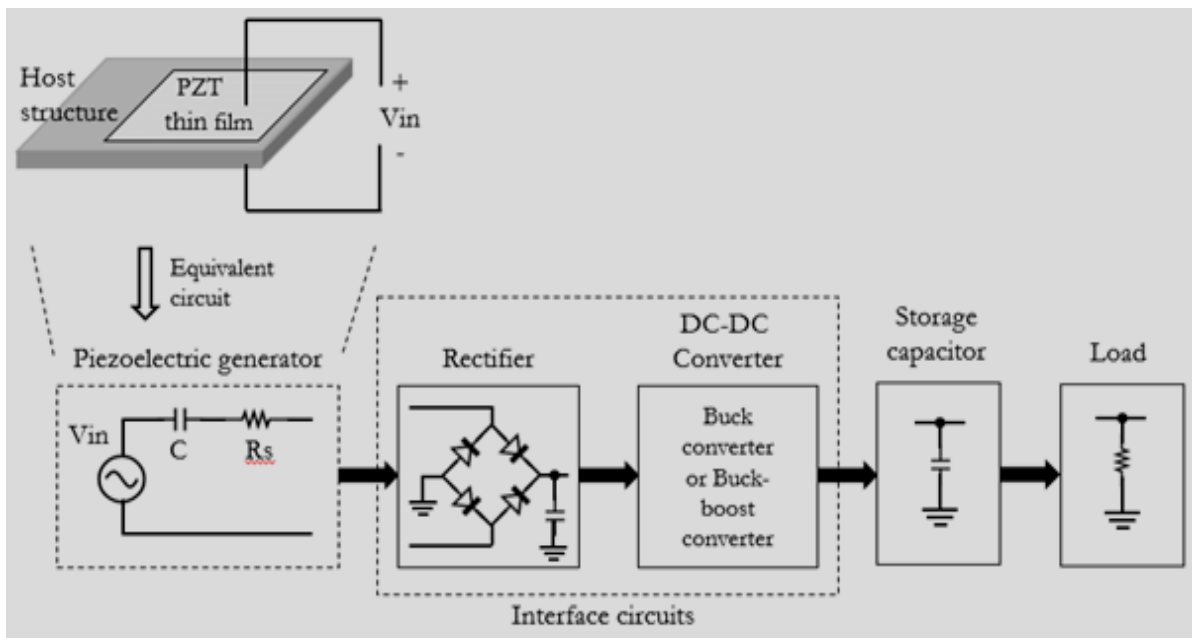


Figure 13: Block Diagram of Power Generation from Piezoelectric Device.

Here are Some Key Aspects and Applications of Piezoelectric Devices:

- **Piezoelectric Materials:** The piezoelectric effect may be seen in a few crystals and ceramics, including quartz, lead zinc titanate (PZT), and polyvinylidene fluoride, also known as (PVDF). When these materials are mechanically deformed (e.g., by applying pressure or bending), they generate an electric voltage across their surfaces.
- **Mechanical to Electrical Conversion:** Piezoelectric devices, such as piezoelectric sensors and transducers, are used to convert mechanical forces or vibrations into electrical signals. Examples include:

- **Piezoelectric Sensors:** These are used in various applications, including pressure sensors in industrial equipment, accelerometers in consumer electronics, and ultrasound transducers in medical imaging.
- **Piezoelectric Energy Harvesters:** These devices capture energy from vibrations or mechanical movements and convert it into electrical energy. They are used in wireless sensors and low-power electronics.
- **Electrical to Mechanical Conversion:** Piezoelectric devices can also work in reverse, converting electrical signals into mechanical motion. Common applications include:
 - **Piezoelectric Actuators:** These are used in precision positioning systems, such as in microscopy and optics, where precise and rapid movement is required.
 - **Inkjet Printers:** Many inkjet printers use piezoelectric actuators to eject tiny droplets of ink onto paper.
- **High-Frequency Applications:** Piezoelectric materials can generate high-frequency vibrations and electrical signals, making them valuable in applications like ultrasonic cleaning, ultrasonic imaging (e.g., ultrasound machines for medical imaging), and high-frequency sound generation in speakers and alarms.
- **Piezoelectric Generators:** These devices convert mechanical vibrations or pressure fluctuations into electrical energy. They can be used to power small electronic devices, such as remote sensors or wireless communication devices, in environments where conventional batteries are impractical.
- **Piezoelectric Filters:** Piezoelectric resonators are used in electronic filters to select and filter specific frequencies in electronic circuits, such as those found in radios and communication devices.
- **Materials Advancements:** Ongoing research focuses on developing new piezoelectric materials with improved properties, such as higher sensitivity and energy conversion efficiency.

Piezoelectric devices find applications in a wide range of industries, from healthcare and consumer electronics to automotive and industrial sectors. Their ability to efficiently convert between mechanical and electrical energy makes them valuable components in various technological solutions.

12. Kinetic Energy Harvesting [14] :

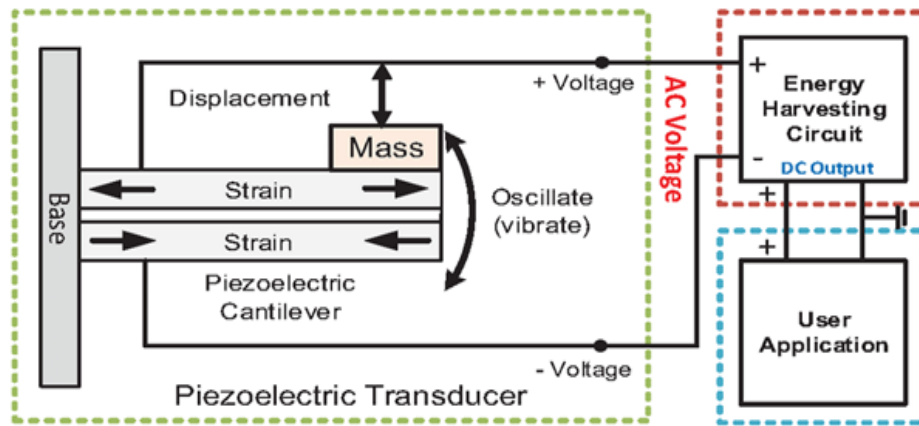


Figure 14: Kinetic Energy Harvesting Form Piezoelectric Transducer.

Kinetic energy harvesting, also known as kinetic energy scavenging or simply energy harvesting, is a technology that captures and converts mechanical motion or vibration into electrical energy. This harvested energy can then be used to power low-energy electronic devices or stored for later use. Here are the key aspects and applications of kinetic energy harvesting:

Basic Principle: Kinetic energy harvesting is based on the principle of converting mechanical motion or vibration into electrical energy using various transduction mechanisms. Common methods include electromagnetic, piezoelectric, and electrostatic conversion.

Applications:

- **Wireless Sensors:** One of the primary applications of kinetic energy harvesting is powering wireless sensor nodes and Internet of Things (IoT) devices. These sensors can monitor various environmental parameters, such as temperature, humidity, and pressure, and send data wirelessly to a central hub.
- **Wearable Electronics:** Kinetic energy harvesters are integrated into wearable devices like smartwatches and fitness trackers to recharge or extend the battery life of these devices by capturing energy from the wearer's motion.
- **Industrial Monitoring:** In industrial settings, kinetic energy harvesters can power sensors for equipment condition monitoring, predictive maintenance, and data collection without the need for frequent battery replacements.
- **Self-Powered Electronics:** Kinetic energy harvesting is used in self-powered electronics, including remote controls, low-power LED lights, and small electronic gadgets. These devices rely on harvested energy rather than disposable batteries.

- **Human-Powered Devices:** Kinetic energy harvesters can be incorporated into devices like crank radios and flashlights that are manually powered by users turning a crank or shaking the device
- **Vehicle and Transportation Applications:** Kinetic energy harvesting can be applied to vehicles, including capturing energy from the motion of cars or the vibrations of trains. This harvested energy can be used to power sensors or recharge auxiliary systems.
- **Environmental Monitoring:** Remote environmental monitoring stations in locations without a reliable power source can use kinetic energy harvesters to keep sensors and data communication equipment operational.

Transduction Mechanisms:

- **Piezoelectric:** Piezoelectric materials generate electrical voltage when mechanical stress is applied. These materials are commonly used in kinetic energy harvesters to convert vibrations and motion into electrical energy.
- **Electromagnetic:** Electromagnetic energy harvesters use the relative motion between magnets and coils to induce electrical current.
- **Electrostatic:** Electrostatic energy harvesters rely on the attraction and repulsion of charged plates due to mechanical motion to generate electrical energy.

Kinetic energy harvesting is a valuable technology for powering remote, low-power electronics, reducing the need for disposable batteries, and enabling sustainable, self-powered devices in various applications. Ongoing research aims to improve harvesting efficiency and expand the range of applications for this technology.

13. Algae Biofuel [15] :

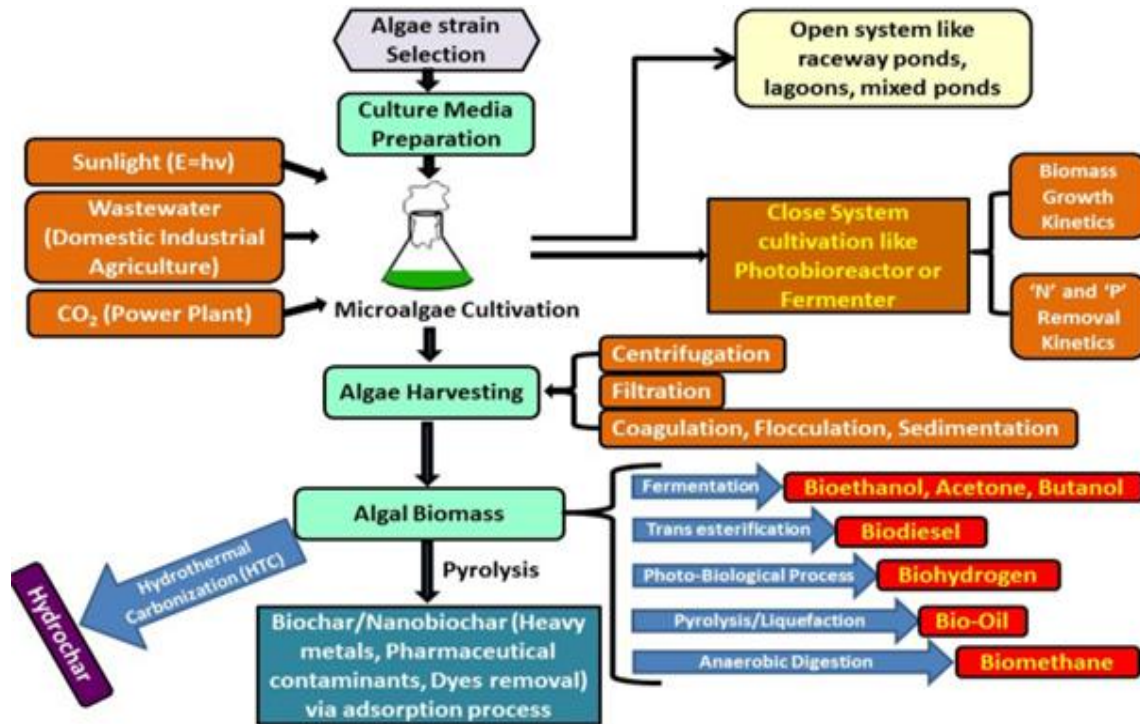


Figure 15: Block Diagram of Algae Bio-Fuel.

Algae biofuel, also known as algal biofuel or simply algae fuel, is a renewable energy source derived from the growth and conversion of certain types of algae into biofuels. These biofuels can be used as a sustainable alternative to traditional fossil fuels like gasoline and diesel. Here are the key points about algae biofuel:

- **Algae as a Feedstock**

- **Algae Diversity:** Algae are diverse, photosynthetic organisms that can grow in various aquatic environments, including ponds, lakes, oceans, and even wastewater treatment facilities. They come in various shapes and sizes, from microscopic single-celled algae to large seaweeds.
- **High Biomass Production:** Algae have a rapid growth rate and can produce a substantial amount of biomass quickly, making them a promising source for biofuel production.

Algae Biofuel Production:

- **Lipid Extraction:** Algae can accumulate lipids (fats and oils) in their cells. To produce biofuels, lipids are extracted from the harvested algae biomass. These lipids can be converted into biodiesel or renewable diesel.
- **Biochemical Conversion:** Alternatively, algae can be subjected to biochemical processes, such as anaerobic digestion or fermentation, to produce biogas (methane) or ethanol, respectively.

- **Hydrothermal Liquefaction:** Algae can also be converted into a bio-crude oil through a process called hydrothermal liquefaction, which involves high-temperature and high-pressure treatment.

Algae biofuels hold promise as a sustainable and renewable energy source, offering potential solutions to mitigate greenhouse gas emissions and reduce reliance on fossil fuels. However, further research and development are needed to improve the economics and scalability of algae biofuel production.

14. Thermoelectric Generators [16] :

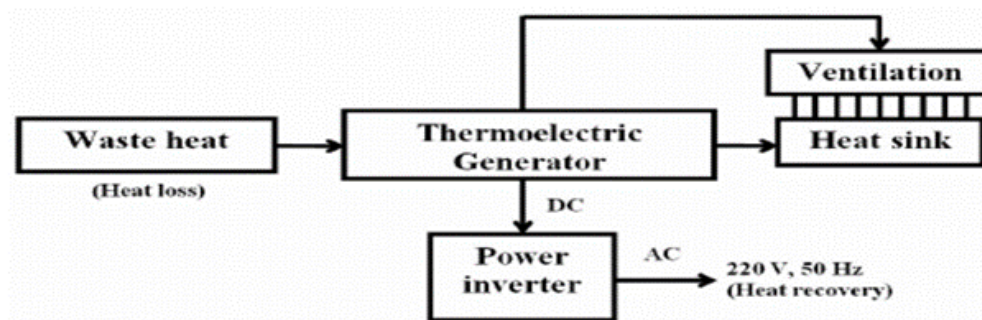


Figure 16: Block Diagram of Thermoelectric Generator

Thermoelectric generators (TEGs) are solid-state devices that convert heat into electricity directly through a phenomenon known as the Seebeck effect. This technology offers a unique way to generate electrical power from temperature differences, making it useful in various applications. Here's how thermoelectric generators work and some key aspects related to them:

- **Basic Principle:**

- **Seebeck Effect:** TEGs rely on the Seebeck effect, which occurs when a temperature difference is maintained across a conductor or semiconductor material. In the presence of this temperature gradient, electrons move from the hot side to the cold side of the material, creating an electric voltage.
- **Thermoelectric Materials:** To harness the Seebeck effect, TEGs use thermoelectric materials, which are typically semiconductors. These materials have special properties that allow them to efficiently convert heat into electricity.
- **Thermoelectric Modules:** TEGs consist of multiple thermoelectric modules, each containing pairs of n-type and p-type thermoelectric materials connected electrically in series and thermally in parallel. This configuration enhances the overall voltage output.
- **Heat Source and Heat Sink:** TEGs require a heat source and a heat sink to maintain a temperature gradient across the thermoelectric modules. The heat source should be at a higher temperature, while the heat sink is cooler.

- **Advantages:**

- **No Moving Parts:** TEGs are solid-state devices with no moving parts, making them highly reliable and durable.
- **Silent Operation:** They operate silently, without noise or vibration, making them suitable for various applications.
- **Low Maintenance:** TEGs require minimal maintenance due to their lack of moving components

Thermoelectric generators are a valuable technology for converting waste heat into electricity and providing power in remote or challenging environments. Ongoing research aims to improve their efficiency and expand their use in energy recovery applications.

15. Microgrids [17] : Microgrids are small-scale, localized energy systems that can operate independently or in conjunction with the main electrical grid. They are designed to generate, distribute, and manage electricity locally, often serving a specific geographic area or community. Here are the key aspects and benefits of microgrids:

- **Components and Features of Microgrids:**

- **Local Generation:** Microgrids typically include local sources of electricity generation, such as solar panels, wind turbines, combined heat and power (CHP) systems, and backup generators.

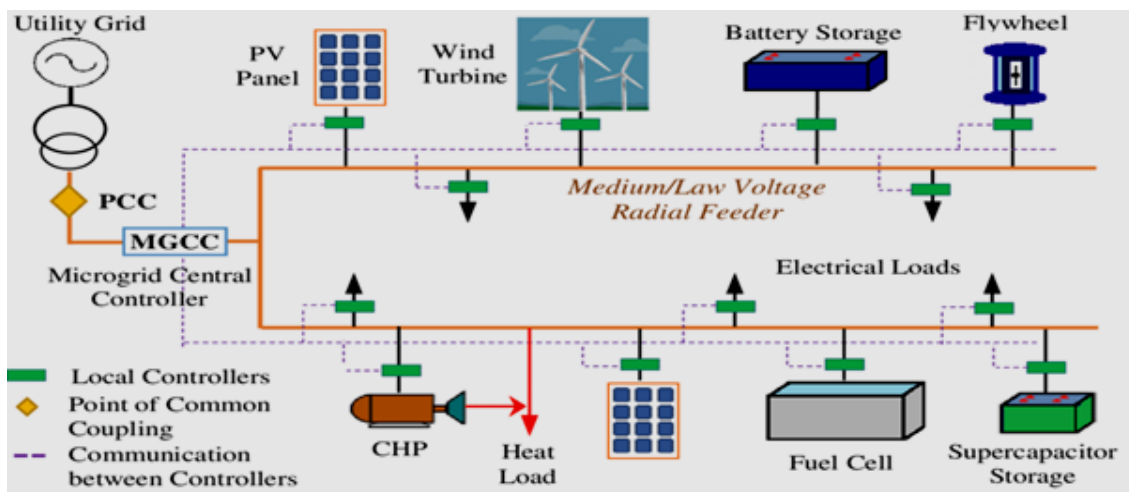


Figure 17: Schematic Diagram of Micro grid

- **Energy Storage:** To store extra energy to be utilized during times of substantial demand or when sources of clean electricity are not available, many microgrids contain energy storage technology, such as batteries.

- **Control Systems:** Advanced control systems and automation are essential components of microgrids. These systems manage energy generation, distribution, and consumption in real-time to ensure grid stability and reliability.
 - **Island Mode Capability:** Microgrids can operate in "island mode," meaning they can disconnect from the main grid during grid outages or emergencies and continue to provide electricity to the local community independently.
- **Applications of Microgrids**
 - **Remote and Off-Grid Areas:** Microgrids are often used in remote or off-grid areas where access to the main grid is limited or non-existent. They provide a reliable source of electricity for communities, industries, and institutions.
 - **Campuses and Military Bases:** Universities, corporate campuses, and military bases frequently use microgrids to ensure reliable power for critical operations and facilities.
 - **Residential Communities:** Some residential communities and housing developments have adopted microgrid technology to reduce energy costs and enhance energy security.
 - **Industrial and Commercial Facilities:** Microgrids can be deployed by industrial and commercial facilities to improve energy resilience and reduce operational downtime.

Microgrids play a vital role in the modernization of the electrical grid, enabling more decentralized and sustainable energy systems. They provide opportunities for increased energy efficiency, renewable energy integration, and enhanced grid resilience, making them a valuable solution for various applications and settings.

III. LIMITATIONS OF GREEN ENERGY SOURCES [18]

Green energy technologies have made significant progress in reducing environmental impact, but they still have limitations:

1. **Intermittency:** Solar and wind power generation depend on weather conditions, leading to intermittency issues. Energy storage solutions are needed to address this limitation.
2. **Energy Storage:** Current energy storage technologies (e.g., batteries) have limited capacity and can be expensive. Advancements are required to make energy storage more efficient and affordable.
3. **Land Use:** Large-scale renewable energy projects can require substantial land use, which may impact ecosystems and local communities.
4. **Resource Availability:** Green energy relies on natural resources like sunlight and wind, which are location-dependent and may not be consistently available everywhere.
5. **Energy Density:** Renewable energy sources often have lower energy density compared to fossil fuels, requiring more infrastructure and space for equivalent power generation.

- 6. Transmission and Grid Integration:** Building infrastructure to transmit renewable energy from remote locations to urban areas can be costly and complex.
- 7. Environmental Impact:** Some green technologies, such as the production of solar panels and wind turbine blades, involve resource extraction and manufacturing processes with environmental impacts.
- 8. Energy Transition Costs:** Transitioning from fossil fuels to green energy requires significant upfront investment, which can be a barrier for some regions and industries.
- 9. Technological Advancements:** Continued research and development are needed to improve the efficiency and cost-effectiveness of green energy technologies.
- 10. Policy and Regulatory Challenges:** Policy frameworks and regulations may need to be updated to incentivize and support the adoption of green energy.

Despite these limitations, green energy technologies are crucial for mitigating climate change and reducing reliance on finite fossil fuel resources. Ongoing innovation and investment aim to address these challenges and make green energy more accessible and sustainable.

IV. CONCLUSION

This chapter summarized the numerous ways of generating the electrical energy from the renewable energy sources pertaining to highlight the adverse effects that have been faced by the environment with the conventional power generation sources. In the developing nations like India, majority of the electrical sector is generating the power from the thermal power plants. From the year 2010 onwards a major focus had been made by the government of India to increase the generation of electricity from the renewable energy sector. This chapter highlighted the energy scenario and discussed the techniques in harnessing the power from renewable sources.

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