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Thermal history — A review of human energy development

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Abstract. Since the construction of the first thermal power plant in 1875, mankind has achieved great success in the field of energy. Today, the pursuit of clean energy is also a major breakthrough. Through examples and comparisons, this paper classifies human energy by means of power generation, and expounds the evolution, history and development experience of energy. Mankind is now entering the era of nuclear energy on a large scale, which is an important node in the history of power generation. This article summarises the past, reviews the era of nuclear energy, and discusses the future development of energy. In the history of energy evolution, from steam power to clean energy, mankind has experienced constant innovation and progress. The advent of the nuclear energy era has provided mankind with more efficient and sustainable energy choices, and also led the development direction of future energy.

Keywords: Thermal, Nuclear, Power, Electricity, Wind, Plants.

1. Introduction

It is only hundreds of years since the electric power system was invented, but it has revolutionized the world [1]. Human beings are becoming more and more proficient in the use of energy—from small units to large units, from high energy consumption to low energy consumption, from high pollution to no pollution—many signs prove the importance of energy and the inexhaustible supply it provides to the world's industries. Since the first Industrial Revolution, electricity has enabled the rapid development of technology and offered much help for human innovation. Meanwhile, the human story is full of blindness, ignoring the significant impact of the industrial effect on the environment, so environmental issues have become an enormous problem that endangers economic and human development [2].

Nowadays, humans have stepped into the era of clean energy on a large scale, striving for no pollution, low energy consumption, and easy transportation. During this period, productivity increased rapidly, and human beings found a balance between industrial development and environmental protection [3]. This article takes the perspective of a review paper: comparing and summarizing the history of human energy development, looking back at the history of clean energy, summarizing the past, and unfolding expectations for future point.

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2. Steam Turbine/Internal Combustion Engine

2.1. Thermal power generation (coal-fired power generation, oil-fired power generation and natural gas power generation)

As the most essential power generation method in the world, thermal power generation accounts for about 65% of the world's total power generation. Still, it plays an irreplaceable role [4], just like Figure 1 [5].

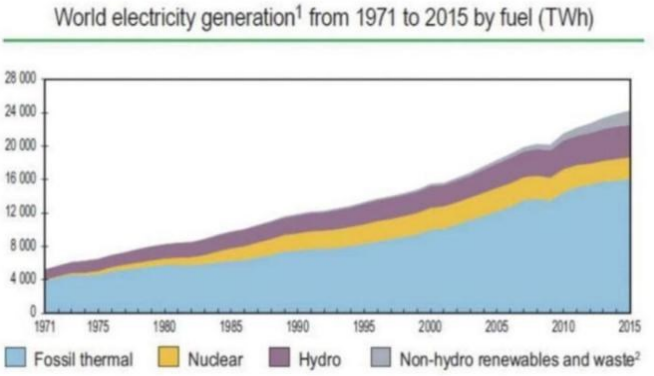

Figure 1. World electricity generation from 1971 to 2015 by fuel (TWh) [5]

Therefore, to better summarize the power system, it is necessary to review the history of thermal power generation. Since the first thermal power plant in Paris provided lighting for nearby residents in 1875, the faint light is like a beacon in the fog, illuminating the development direction for people. Just 30 years later, by 1912, the capacity of turbogenerators reached 25,000 kilowatts; by 1929, the United States had reached 100,000 kilowatts. The electric power industry has already taken shape from a budding state. From 1950 to 1980, the world's power generation increased by 7.9 times, roughly doubling every 10 years [6]. Most power stations have more than one million kilowatts of generating units, and researchers' goal has shifted from power generation to power generation efficiency and environmental protection issues.

In power plants, efficiency stands for productivity. Higher efficiency means that power plants can generate more electricity to support people's activities in the same environment. After World War II, for the first time, humans made the temperature and pressure exceed the liquid-gas critical value of water (374 degrees, 218 atmospheres). Since efficiency largely depends on steam temperature and pressure, research is ongoing worldwide to improve both. More recently, there has been interest in advanced combustion technologies that use oxygen instead of air for combustion [7], allowing boilers to operate with steam at temperatures and pressures of 760 °C, further improving overall thermal efficiency.

Coal is the primary fossil fuel used to generate electricity. However, coal-fired power plants are also among the top sources of air pollution, and greenhouse gas (GHG) emissions from burning fossil fuels are considered a significant cause of global climate change [8]. Based on research on clean energy in recent years, scientists can reduce air emissions and pollutants produced by coal combustion, remove particulate matter and sulfur dioxide, and reduce SO2 emissions by 67% in 2020 compared to 1995 levels [9].

Overall, thermal power generation will remain the primary method of power generation in the next few decades, and researchers are further optimizing the technology so that thermal power generation can reduce pollution and continue to assist people.

2.2. Geothermal Energy

With the development of the times, people pay more and more attention to environmental issues. At the same time as thermal power generation, human beings are also gradually exploring the Earth's energy

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reserves, hoping to find new clean energy sources to reduce environmental pressure - one of which is geothermal energy. Geothermal resources are "non-polluting and renewable" [10] and are formed by the decay of related substances inside the Earth. Using geothermal resources for power generation is undoubtedly a new idea for environmental protection and sustainable development.

Compared with other types of power generation technologies, geothermal energy for power generation has only been commercially produced since 1913, and the development time is relatively short. Utilization has increased rapidly over the past 30 years to a scale of hundreds of MPa. According to the United Nations World Energy Assessment Report, the electricity cost of geothermal energy is only 2-10 cents/kWh, the lowest cost of all clean energy. In addition, comparing the four more mature renewable energy sources (geothermal, wind, solar and tidal energy), 70% of the power generation comes from geothermal, accounting only for 42% of the total installed capacity. In contrast, geothermal energy is competitive with conventional energy sources and can contribute to reducing greenhouse gasses [11].

Despite the many advantages of geothermal energy, geographical factors still limit the further development of geothermal energy. Today, the more common geothermal power generation technologies are condensing steam power generation technology and flash evaporation power generation technology. But no matter what kind of technology, their basic principle is to convert geothermal heat into steam, and the smoke is introduced into the steam turbine to expand and do work, as shown in Figure 2. [12]

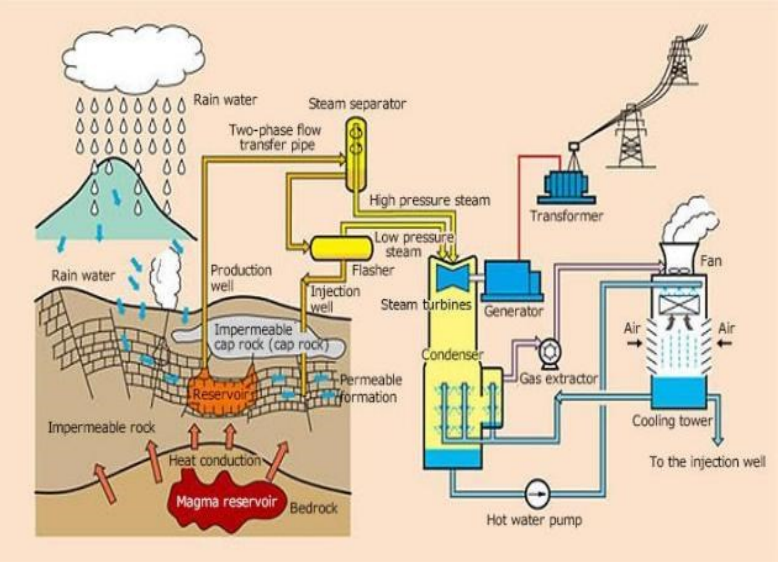

Figure 2. Basic configuration of a geothermal power plant [12]

To prevent further heat loss, this also requires that power plants can only be built close to heat sources; oceans, mountains, or hills are not ideal places.

3. Motors (clean energy)

3.1. Wind energy

As humans gradually value environmental issues, finding new energy sources with high efficiency is imminent. Therefore, wind energy, a new energy source that human beings have buried before [13], has gradually been excavated by researchers. As one of Earth's most common climate phenomena, wind can be seen everywhere. The sun's differential heating of the Earth's surface causes the winds; as an indirect form of solar energy, the wind is always supplemented by the sun. According to statistics [14], the wind energy on the Earth continuously provides about 10 million megawatts of energy, and it does not emit

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any greenhouse gasses. Fossil energy is reduced, and clean energy is encouraged; wind energy is undoubtedly an environmentally friendly, efficient, and safe source of energy.

The wind power generation principle can be simply understood as Michael Faraday's electromagnetic induction phenomenon [15]. Its primary components are magnets and coils, like Figure 3. [16]

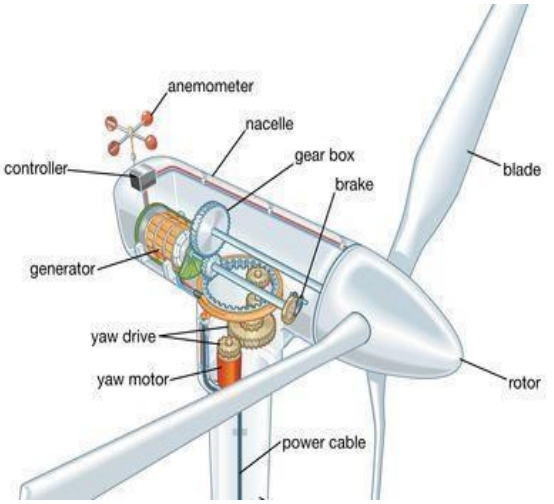

Figure 3. Wind turbine made [16]

The magnets are rotating electromagnets (rotors), and the coils are embedded in slots (stators) made of silicon steel sheets. When the rotor rotates, the coils in the stator will cut the magnetic induction lines and generate an induced current. Additionally, wind turbines should not only be built in windy places throughout the year but also the size and stability of wind speed are critical. The operating wind speed must be greater than 2-4 meters per second to drive the blades. When the wind speed reaches 10-16 meters per second, it can generate electricity at full load. Each wind turbine can operate independently, so each generator can be an independent power plant which belongs to a distributed power generation system, which further improves the overall operating efficiency [17].

As an inexhaustible energy source, wind energy should be able to be effectively utilized by people. However, the limitations of the technology also make its costs outweigh its benefits. The economics of wind energy are not high. In most wind farms, the efficiency of wind power generation is only 20%-40%, far lower than that of thermal power generation. At the same time, offshore wind power generation costs as high as $222/MWh, much higher than other energy sources.

Moreover, the rapid growth of wind energy also harms animal ecology. Wind turbines are devastating to bats [18]. In North America, bat mortality has increased significantly near wind turbines. Since bats use sound waves to navigate and have degenerated eyes, they can easily bump into moving leaves. At night, moving leaves can also become "tombstones" for birds, which researchers must pay attention to.

As the most common clean energy, wind energy has tremendous research potential. Countries are also vigorously developing wind energy technology, increasing wind turbines, and effectively reducing fuel and emissions.

3.2. Hydroelectric power

Hydroelectric power is a well-established renewable energy source that derives its energy from the movement of water from high to low altitudes. The history of using hydropower for more than 135 years and the earliest use of hydropower resources can be traced back to the Han Dynasty in China from 202 BC to 9 AD [19] when the water collection cart drove the pestle and hammer to crush the grain. 1827 French engineer Benoit Fourneyron developed a turbine that produced about 6 horsepower—the earliest water turbine. Because of the long history and well-researched hydropower, it has become a mature, predictable and price-competitive technology [20]. It is currently the most widely used renewable energy

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in human society [21]. Among all known energy sources, hydroelectric power has the highest conversion efficiency - 90% and its power generation does not require any fuel, and the cost will not be affected in any way. At the same time, hydropower has flexibility, and it only takes 60-90 seconds to output full power, which is faster than thermal power and can quickly help the transmission network to adjust. Today, only 25 per cent of the world's 45,000 dams are used for hydroelectric power, with the rest dedicated to other purposes. With this in mind, hydroelectric power holds great research potential to further contribute to humanity.

Most hydropower uses similar technologies, as shown in Figure 4. [22]

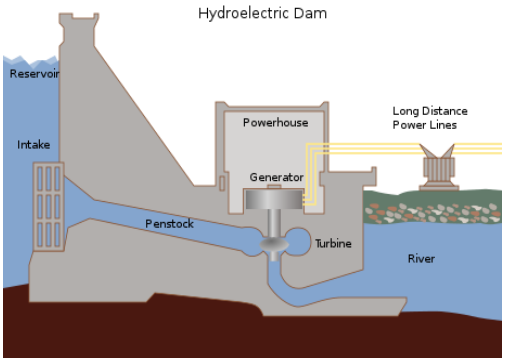

Figure 4. Hydroelectric Dam [22]

But there are still two distinct types of hydropower in the world: tidal power and pumped storage hydropower. Tidal power generation utilizes the sea level, using the energy generated during high tide and low tide, and the seawater entering and leaving the reservoir drives the generator to generate electricity. Tides, by contrast, are more predictable and more efficient than wind and solar power. However, geographic constraints also limit its feasibility. In the UK, only eight sites are suitable for tidal power generation, which can also meet 20% of the country's electricity needs [23]. Pumped-storage hydroelectricity is essentially a way of storing energy, not a source of energy. When the power demand is low, to ensure that the excess electricity can be stored and continuously generated, the excess electricity can drive the water pump to pump the water to a high level for storage. When the power demand is high, high-level water can be used to generate electricity again, which significantly increases the utilization rate of the generator set, which is very important to the industry.

On the other hand, the disadvantages of hydroelectric dams should not be underestimated. The dam's life is limited, generally only 50-200 years. At the same time, termite boreholes and natural disasters may cause embankment failures, threatening urban and economic development. Large reservoirs can also flood large swathes of land upstream, disrupting the biosphere. Reservoirs also raise water temperatures, reducing fish populations. And these damages are permanent and irreversible. Finally, with the advancement of technology, these problems will be solved, the potential of hydropower will be further increased, and energy will be provided more efficiently.

3.3. Photovoltaic power generation

The world's energy needs sustainable clean energy as a driving force. Solar energy is truly inexhaustible and does not emit carbon dioxide. It is clean energy in the true sense. According to statistics, the Earth's surface receives more than 140,000 terawatts of power, of which 36,000 terawatts are usable [24]. In 2012, the world consumed 17 terawatts of electricity. If solar energy can be used to generate electricity, the world's energy problems will be significantly alleviated.

In simple terms, general photovoltaic power generation utilizes the photovoltaic effect. The solar panel is covered with semiconductor structures. When sunlight shines on the semiconductor, a voltage difference is generated between different parts to obtain power output, like Figure 5. [25]

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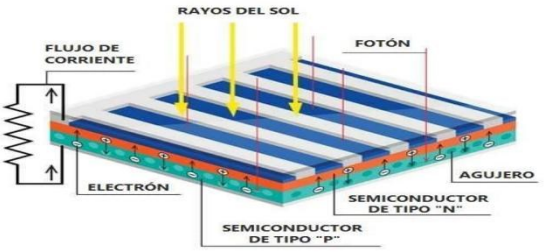

Figure 5. Photovoltaic power phenomenon [25]

At a suitable temperature, the greater the light intensity, the more current will be generated, but too high a temperature will also lead to a smaller output power. The latest molten salt tower solar thermal power station has given full play to the advantages of solar energy. The sunlight is reflected by multiple mirrors and collected by the heat collector, melting the salt into a liquid state up to 210 degrees. During the cooling process, a large amount of steam will be generated, and the steam turbine will be driven to generate electricity. At the same time, molten salt has good heat storage and can still generate heat at night or on cloudy days. Solar power has three characteristics: permanence, cleanliness and flexibility [26]. Compared with conventional thermal power generation, photovoltaic power generation has no environmental pollution; solar generation can be used flexibly, ranging from a power station of one million kilowatts to a small enough that each household can have an independent solar power generation system. All of those are its advantages.

Low conversion efficiency has become the last shackle to limit photovoltaic power generation. The conversion efficiency of photovoltaic power generation is very low. The conversion efficiency of crystalline silicon photovoltaic cells is only 13%-17%, while that of other photovoltaic cells is only 5%-8%. The low conversion rate forces people to fill the vacancy only by expanding the floor area and the number of photovoltaic power generation units. Solar energy will undoubtedly become the best solution for world power generation if the conversion efficiency can be improved.

3.4. Nuclear power

In recent decades, with the exploration of atomic energy, people have gradually discovered the considerable energy contained in the atomic nucleus and its unlimited potential in the future. Scientists have discovered that the energy density of no energy source on Earth can match that of nuclear energy. With the same volume of fuel, the energy released by nuclear energy is several million times that of fossil energy. In 1954, the world's first commercial nuclear power plant came out. Humans have opened Pandora's box and started the long road to nuclear energy. As of 2021, 443 nuclear power plants are worldwide, and more than 30 countries have mastered basic nuclear power technology [27]. In fact, like other thermal power generation, nuclear power plants also use thermal energy to drive steam generators to generate electricity. The only difference is that instead of using any conventional fuel, nuclear power plants react with substances made of radioactive elements.

Today's more sophisticated nuclear power plants use the nuclear fission reaction, which involves bombarding atoms of unstable radioactive isotopes of heavy elements (like uranium-235) with neutrons, causing them to split into smaller atoms and release more neutrons. The neutrons then react with uranium-235 to form a chain reaction. This chain reaction will self-amplify [28], and if it is not precisely controlled, it will quickly get out of control and cause a nuclear leak. Nuclear fission technology is relatively simple, and various countries have relatively mature technologies, but the materials it consumes are also minimal, and they are rarely produced in nature. In addition, the nuclear waste generated by power generation is also full of radioactivity and needs special treatment, limiting the development of nuclear fission. Therefore, humanity needs a safer and more effective method to utilize nuclear energy—nuclear fusion.

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The basic principle of nuclear fusion is to use two or more light atomic nuclei to gather and form a heavy atomic nucleus. The mass of a specific heavy nucleus will be less than the sum of the two light nuclei before the reaction, and the resulting mass loss will be released in the form of energy, generating heat. Nuclear fusion products are stable isotopes without radiation pollution; at the same time, the reserves of nuclear fusion fuel are also substantial. Taking deuterium-tritium fusion, which is currently the easiest to achieve, as an example, one deuterium can be found in every 6,420 hydrogens in seawater, and tritium can also be stably prepared. The deuterium on the Earth can be said to be endless. However, human beings have not achieved controllable nuclear fusion so far because it is challenging for two nuclear to fuse, it is necessary to overcome Coulomb repulsion, and the reactants need to be heated to hundreds of millions of degrees. When humans can use nuclear fusion, endless energy will bring a qualitative leap in people's lives, and the world's third industrial revolution will also come.

4. Conclusion

In 1879, Einstein successfully created the world's first light bulb to today's nuclear fusion. The replacement and evolution of energy have undoubtedly brought enormous changes to human production and life. Looking back at the history of human energy evolution, the author is amazed at the rapid development of human beings and the progress that each power generation method has brought to human beings. In the future, there will also be more innovations to create a better future for people. Looking back at this paper, some limitations can still be improved. This article mainly classifies power generation methods, which tend to cause time confusion when compared with multiple types and is not concise and clear enough. At the same time, the understanding of the content is not deep enough, and the coverage of history and technology is not specific enough. For chapters, more attention should be paid to logic and chronological order so readers can read them better. For the future development of power generation, the world needs efficient and safe clean energy, and nuclear fusion and space power generation may become the focus of research.

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