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Renewable Energy Integration in Bangladesh: Opportunities and Challenges for Thermoelectric and Thermionic Systems

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Abstract:** This paper presents a comprehensive analysis of the potential of thermo electric and thermionic power generation technologies in Bangladesh, with a focus on utilizing the heat generated from industry, thermal power stations, and solar irradiance. The study assesses the current energy landscape in the country and highlights the need for alternative and sustainable sources of energy to meet the increasing demand. The paper reviews the relevant literature and discusses the principles and working mechanisms of thermoelectric and thermionic power generation technologies. It also examines the feasibility of these technologies in the context of Bangladesh and provides recommendations for their implementation. The paper concludes that thermoelectric and thermo ionic power generation have the potential to significantly contribute to the country's energy mix, reduce its dependence on non-renewable sources, and promote sustainable development. The recommendations offered in this study are expected to help policymakers, industry stakeholders, and researchers in making informed decisions towards a sustainable and resilient energy future in Bangladesh.

***Keywords:** Thermoelectric, Thermionic, Renewable.*

1. INTRODUCTION

Bangladesh, a developing country with a population of over 160 million [5] and a rapidly growing economy, is grappling with the daunting challenge of meeting its surging energy needs. The lion's share of the country's current energy supply comes from non-renewable sources such as coal, oil, and natural gas, which are finite resources and pose significant environmental concerns. To overcome this energy conundrum, the government and various stakeholders have been on the hunt for alternative and sustainable sources of energy. One such

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avenue is the application of thermoelectric and thermionic power generation, a technology that is gaining traction worldwide as a potential panacea for the twin problems of energy security and environmental sustainability.

Thermoelectric power generation is founded on the Seebeck effect [6], a process that transforms the temperature difference between two materials into electricity. Meanwhile, thermionic power generation utilizes the thermionic emission process to convert heat energy from a high-temperature source into electrical power. These innovative technologies can harness heat from diverse sources, such as thermal power stations, solar irradiance, and industrial waste heat, to generate electricity.

Bangladesh boasts abundant heat sources that can be tapped into using thermo electric and thermo ionic power generation. The country has a substantial number of thermal power plants that produce copious amounts of waste heat, including coal and gas-fired plants [7]. In addition, the country's industrial sector generates a significant amount of waste heat that can be harnessed. Furthermore, being located in the tropics, Bangladesh receives high levels of solar irradiance, making it an optimal location for solar thermal energy utilization [8]. These combined factors make Bangladesh an ideal candidate for implementing thermoelectric and thermionic power generation technologies to meet its energy needs sustainably.

The implementation of thermoelectric and thermionic power generation technologies holds great promise for Bangladesh, with the potential to deliver numerous benefits. Firstly, it can reduce the country's reliance on non-renewable sources of energy and improve its energy security. Secondly, these technologies can mitigate climate change and promote environmental sustainability by reducing greenhouse gas emissions. Thirdly, they can bolster the country's socio-economic development by creating job opportunities, promoting local manufacturing, and cutting energy costs.

Despite these benefits, the adoption of these technologies in Bangladesh faces significant obstacles, including high capital costs, a lack of awareness and technical know-how, and regulatory barriers [9]. This paper seeks to evaluate the potential of these technologies in Bangladesh and provide recommendations for their implementation.

The objective of this paper is to conduct a comprehensive analysis of the potential of thermoelectric and thermionic power generation technologies in Bangladesh. The paper will undertake a thorough review of the relevant literature and examine the principles and mechanisms of thermoelectric and thermionic power generation technologies. The feasibility of these technologies in Bangladesh will be assessed, including the availability of heat sources, the technical and economic viability, and the regulatory framework. Additionally, the paper will identify potential barriers to the adoption of these technologies and provide recommendations to overcome them.
The paper will be structured in the following way. The first section will present an overview of the current energy landscape of Bangladesh, including the sources of energy and energy demand. The second section will discuss the principles and working mechanisms of thermoelectric and thermionic power generation technologies. The third section will evaluate

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the potential of these technologies in the context of Bangladesh, including the availability of heat sources, technical and economic viability, and the regulatory framework. The fourth section will identify potential barriers to the adoption of these technologies and provide recommendations for overcoming them. Finally, the paper will conclude by summarizing the key findings and underscoring the potential of thermo electric and thermo ionic power generation technologies in advancing a sustainable and resilient energy future for Bangladesh.

Present Energy Situation in Bangladesh

Thermoelectric and thermionic power generation are two related technologies that convert heat into electricity. They have many practical applications, from powering spacecraft to generating electricity from waste heat in industrial processes. Despite their differences, both technologies rely on the same basic principles of thermoelectricity and thermionic emission. In Bangladesh, there are several energy resources available, including natural gas, liquefied gas, coal, biomass and biofuel, hydro energy, wind energy, and solar energy. However, natural gas is the primary energy source, with 2725 million cubic feet of gas and 9263.7 million cubic feet of condensate produced in the fiscal year 2015-16. Coal production for the same fiscal year was 345751.44 metric tons. In terms of energy consumption by fuel type, natural gas accounts for 51.05%, followed by heavy fuel oil at 28.15%, high speed diesel at 5.74%, power import at 5.16%, coal at 7.86%, and renewable energy at 2% [11]. This information is presented in Figure 1. Additionally, there are 9200 km of transmission lines, 332000 km of distribution lines, and a 10% growth rate in electricity in 2016.

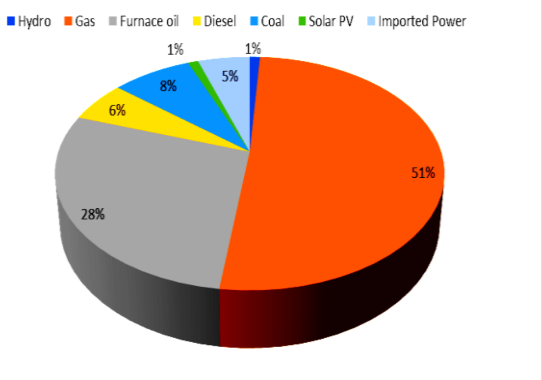

Figure 1: Present energy consumption in Bangladesh

Basic Principles of Thermoelectric and Thermionic Power Generator

Thermoelectric and thermionic power generation are two related technologies that convert heat into electricity. They have many practical applications, from powering spacecraft to generating electricity from waste heat in industrial processes. Despite their differences, both technologies rely on the same basic principles of thermoelectricity and thermionic emission.

Thermoelectricity

Thermoelectricity is a fascinating technology that has been around since the 19th century when Thomas Seebeck first discovered the Seebeck effect in 1821. This phenomenon involves generating an electric current by connecting two different metals or semiconductors, forming a

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circuit with junctions held at different temperatures. The temperature difference drives the flow of charge carriers from the hotter to the colder junction, resulting in an electric potential difference (voltage) between the two junctions. This voltage can be harnessed to generate electricity. The amount of voltage produced is proportional to the temperature difference between the junctions and the specific properties of the thermoelectric material employed. Schematic of a thermoelectric generator is shown in figure 2.

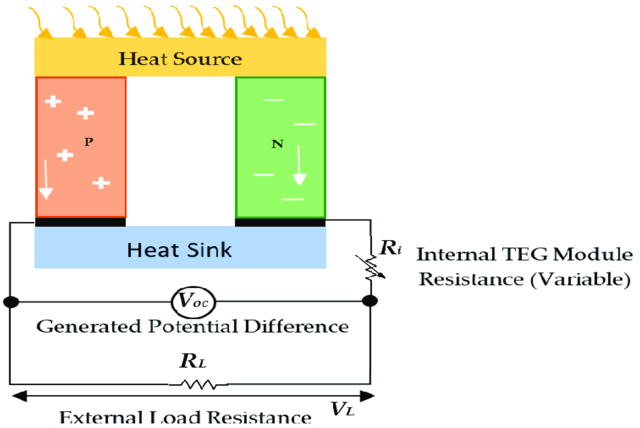

Figure 2: Schematic of a thermoelectric generator [2]

A thermoelectric device is composed of numerous thermocouples, each of which is made up of two dissimilar materials. When one end of a thermocouple is exposed to heat and the other end is kept cool, the Seebeck effect generates a voltage across the thermocouple, which can be employed to power an electrical load. The effectiveness of a thermoelectric generator is determined by the quality and characteristics of the thermoelectric materials used, such as their thermoelectric figure of merit, which measures their ability to transform heat into electricity [10]. Assuming that the thermoelectric generator is added to the Payra Coal Power generator in Bangladesh, we can calculate the efficiency of the combined system using the following equation:

Efficiency = (Net electricity generated / Heat input) x 100%

where Net electricity generated = Electricity generated by the thermoelectric generator + Electricity generated by the coal power generator, and Heat input = Heat input to the coal power generator.

Let's assume that the thermoelectric generator is able to generate an additional 50 MW of electricity, and the heat input to the coal power generator is 3000 MW. Then the net electricity generated would be 1050 MW.

Thus, the efficiency of the combined system would be:

Efficiency = (1050 / 3000) x 100%

Efficiency = 35%

This means that the combined system would have an overall efficiency of 35%. It's worth noting that the efficiency of the thermoelectric generator depends on the quality and properties of the thermoelectric materials used, as well as the temperature difference between the hot and cold junctions.

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A. Thermionic Generator

Thermionic power generation works through the thermionic emission process, which occurs when a material emits electrons due to thermal excitation. At high temperatures, some electrons near a metal's surface gain enough thermal energy to escape into the surrounding vacuum or gas. The emitted electrons are then captured by a positively charged electrode, resulting in the generation of an electrical current. This process forms the basis of thermo-ionic power generation, which can be utilized through a thermo-ionic device comprising two electrodes separated by a gas-filled gap. The hotter electrode emits electrons, which are attracted by an electric field to the cooler electrode, thus producing an electrical current that can power an electrical load. Schematic of a thermionic generator is shown in figure 3.

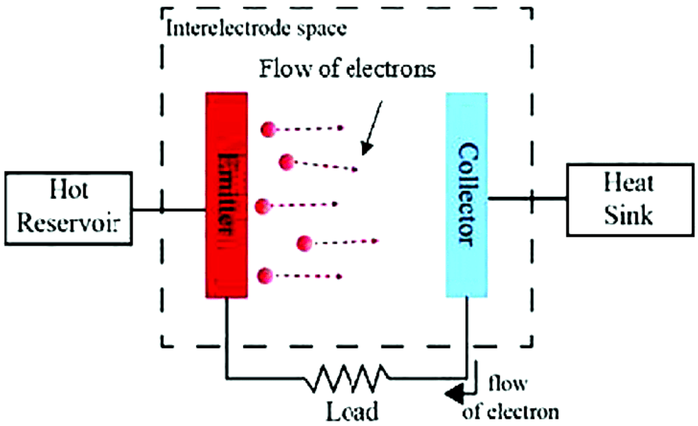

Figure 3: Schematic of a thermionic generator

The efficiency of a thermionic generator [3] depends on various factors, such as the temperature of the hot electrode, the electrodes' geometry, and their material properties. The efficiency of a thermionic power generator relies on multiple factors, such as the geometry of the electrodes, the material properties of the electrodes, and the temperature of the hot electrode. To determine the efficiency of a thermionic generator, the following equation can be used:

$$\textbf{Efficiency} = (P_o / P_i) * 100\%$$

Here, P_o is the power output of the generator, and P_i is the power input needed to maintain the hot electrode at a high temperature.

The maximum theoretical efficiency of a thermionic generator can be calculated using the following formula, assuming a rectangular geometry for the electrodes and a temperature difference of 500 K between the hot and cold electrodes:

$$\textbf{Efficiency} = (T_c / T_h) * (1 - e^{(-q / kTh)})$$

T_c and T_h denotes the temperatures of the cold and hot electrodes, respectively, q is the work function of the electrode material, k is the Boltzmann constant, and e is the base of the natural logarithm for instance, if the hot electrode is kept at a temperature of 2000 K, the cold electrode is at 1500 K, and the work function of the electrode material is 4.5 eV, the maximum theoretical efficiency of the thermo-ionic generator would be approximately 10.8%.

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However, in practice, the efficiency of the thermionic generator is lower than the theoretical maximum due to several factors like electrode contamination, thermal radiation losses, and electrode degradation. Therefore, it is crucial to perform performance tests and experiments on the thermo-ionic generator under actual working conditions to evaluate its actual efficiency.

Prospective to use Thermoelectric and Thermionic Power Generation in Bangladesh

Bangladesh, a rapidly developing country with a thriving economy [4] and a growing population, is facing an increase in demand for electricity. With limited access to primary energy sources, frequent power outages, and high energy costs, the country is grappling with numerous challenges in meeting its electricity demand. However, one potential solution that can address these challenges is the adoption of thermoelectric and thermo-ionic power generation technologies. These innovative technologies offer several advantages over conventional power generation methods, including the ability to generate electricity with high efficiency and low emissions, as well as the potential to reduce waste and increase energy security. Bangladesh can leverage these benefits by utilizing waste heat in industries such as textiles, cement, and steel, which are major sources of such heat. Besides waste heat, thermoelectric and thermo-ionic power generation can also be utilized to harness solar energy. Bangladesh has immense potential for solar energy, with an average of 4-6 kWh/m2/day of solar irradiance [12]. Several studies have demonstrated that thermoelectric generators can efficiently generate electricity from solar irradiance, making this approach a promising solution for meeting the country's energy needs. However, the widespread adoption of these technologies in Bangladesh faces several challenges such as high material and equipment costs, the need for skilled labor, and low awareness and understanding of the technology among potential users. Nevertheless, with the right policies, incentives, and support, these obstacles can be overcome, and thermoelectric and thermo-ionic power generation can play a pivotal role in Bangladesh's energy mix.

Analysis

Bangladesh's power generation potential through thermoelectric and thermionic technology depends on various factors, including waste heat availability, generator efficiency, and installation size. Here's a fascinating insight into the potential output of these sources:

B. Industry

The textile industry in Bangladesh is a considerable source of waste heat, with an estimated 75% of energy consumed resulting in waste heat. A considerable amount of untapped energy that can be utilized from waste heat generated by industries. Implementation of these technologies in Bangladesh could lead to reduced reliance on non-renewable energy sources, sustainable development, and decreased climate change impact.

C. Thermal Power Stations

Bangladesh has several thermal power stations that could be converted to thermoelectric generators to generate electricity from waste heat. For example, the Barapukuria coal-fired power plant generates 17% waste heat, which could generate up to 90 MW of electricity using thermoelectric generators. This would require installing 1,800 generators, each with a capacity of 50 kW, operating at 5% efficiency [13-15].

D. Solar irradiance

Bangladesh has an average of 4-6 kWh/m2/day of solar irradiance [12]. According to the International Energy Agency, thermoelectric generators can convert up to 5% of the solar irradiance into electricity. Hence, a $1m^2$ thermoelectric generator could produce approximately 0.2-0.3 kW of electricity in Bangladesh, depending on the irradiance intensity, generator efficiency, and size.

2. CONCLUSION

This research extensively investigates the potential of thermoelectric and thermo-ionic power generation in Bangladesh by utilizing waste heat from various sources such as the textile industry, thermal power stations, and solar irradiance. The study highlights the urgent need for sustainable energy sources to meet the country's increasing energy demand. It examines the mechanics and operations of these technologies, supported by relevant literature, and evaluates their feasibility in Bangladesh. The study concludes that the implementation of thermoelectric and thermo-ionic power generation technologies can transform the country's energy mix and promote sustainable development, reducing reliance on non-renewable energy sources. Policymakers, industry stakeholders, and researchers can benefit from the recommendations presented in this paper, paving the way towards a sustainable and energy-secure future for Bangladesh. By adopting these technologies, Bangladesh can overcome energy challenges and lead the way towards a greener future.

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