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Hybrid Energy Conversion Using Solar Radiation and Temperature Gradient Sources

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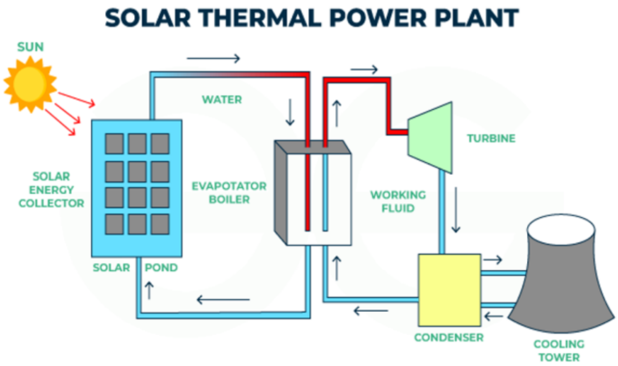
Abstract: The increasing need to have clean and sustainable energy has provided the researchers with the desire to look at the hybrid renewal energy systems. A hybrid energy conversion system is discussed in this paper and it integrates sources of solar radiations and temperature gradient to produce power effectively. The solar energy is captured using photovoltaic panels whereas the temperature difference is used through the thermoelectric-generators. Combining the two sources of energy enhances the overall energy efficiency, boosts reliability and minimizes the reliance on one source of renewable energy power. It is applicable to standalone and grid-connected, proposed systems are applicable in high-density regions of solar energy and waste heat. The paper examines the system performance, output energy, and efficiency, which shows the benefits of hybrid energy conversion in today electrical power systems.

Keywords: *Hybrid energy system, solar radiation, thermoelectric generator, renewable energy, temperature gradient, sustainable power generation*

Introduction:

The energy industry is experiencing a significant shift in the world because the traditional reserves of fossil fuels are being rapidly exhausted and problems of environmental sustainability have become significant. The rising carbon emission, climatic change and the energy needs have compelled governments and researchers to concentrate on clean, renewable and sustainable energy. The solar energy has been noted to be one of the most promising sources of renewable energy among the existing sources due to its extensive availability system, low operating cost, as well as minimal environmental effect. Solar radiations are directly transformed into electricity through solar photovoltaic technology, which is most commonly employed in domestic and commercial contexts as well as in industries. Solar PV systems however have some pitfalls even though it has its benefits. Among the significant limitations is the decrease in electrical efficiency with rise in the operating temperature of the solar panel. Under hot weather conditions, much of the solar energy goes to waste in the form of heat and this impacts negatively on the power output and life of the PV modules.



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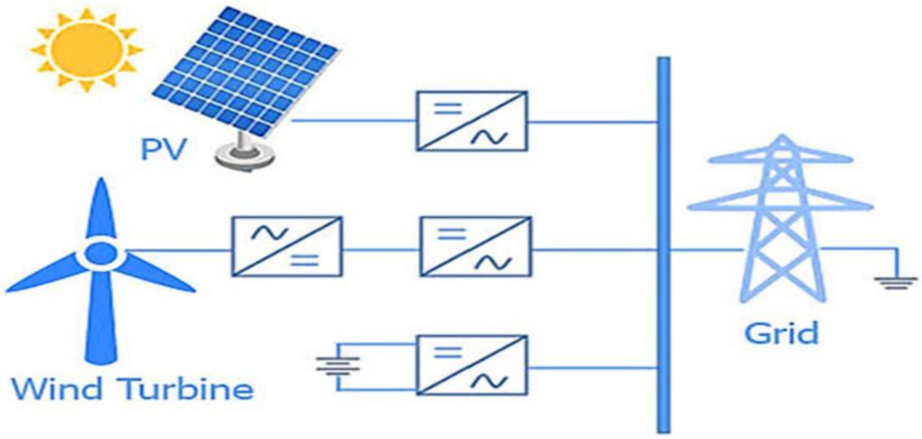
Meanwhile, temperature differences can occur in most environments by default like in industrial equipment, electronic appliances, or even car engines and even a solar panel. Direct and sure the thermoelectric generators provide a quick and dependable way to transform temperatures between each other into electrical power with the Seabeck effect. These machines contain no moving components, need minimal upkeep and may be used throughout in extreme circumstances. Nevertheless, thermoelectric generators are not enough as an autonomous source of power on a large scale since they generate power only to a limited level.



Hybrid energy systems have attracted major attention in the last few years in order to deal with the weakness of the individual renewable energy technologies. A hybrid system refers to the integration of a combination of two and more sources of energy in order to enhance the efficiency of energy, reliability, and availability of power. Here, the deployment of solar photovoltaic system in conjunction with thermoelectric generator is also an efficient means of using solar radiation and waste heat power. Such a hybrid structure is known to add not only to the total energy production, but also to the task of dealing with the excess heat produced by solar panels.

The hybrid energy conversion system has good ability to capture the solar radiation by pv modules and at the same time harvest thermal energy by thermoelectric generators. Remote modules TEG modules are provided on the back side of the solar panel to transform part of the wasted energy into useful electrical features. This bilateral energy gathering method results in efficiency of utilizing the resources that will be available and will increase the entire energy system performance level.

Electrically speaking, solar and thermoelectric systems coupled together must have their power conditioning circuits, voltage regulation and units of energy storage carefully designed. DC to DC converters and charge controllers are very crucial in stabilizing power supply to loads or storage facilities. These hybrid systems are also well implemented in remote locations, off-grid, industrial waste heat, and smart energy grid.

This paper is dedicated to designing, operation principle, and performance of a hybrid energy conversion system based on using solar radiation, and temperature gradient sources. The proposed system will enhance efficiency of use of energy, minimize thermal losses, and offer a stable and sustainable source of power. Findings of this study are being used in the depiction of higher hybrid renewable energy structures and to promote the world to a cleaner and greener energy technology.

Review of Literature:

The concept of having hybrid renewable energy systems has gained a growing attraction because of the potential to enhance energy efficiency, reliability through synergism of various energy sources. In this regard, the research on integration/combination of solar photovoltaic technology with thermoelectric power generation has been broadly researched as one possible solution to effective use of both solar radiation and waste heat.

Vasudeva and Kumar (2019) developed an overview of the hybrid solar-thermoelectric generation systems. They studied different system design, principle of operation and performance features of the integrated photovoltaic thermoelectric systems. The authors emphasized that much solar energy which is gathered by the photovoltaic panels is lost in the form of heat, and this is not favorable to electricity production. The waste heat can be partially transformed into valuable electrical power by incorporation of thermoelectric generators. The review highlighted the capability of hybrid systems in improving the overall energy efficiency particularly in high temperature environments. Nevertheless, these issues as the authors also indicated were a low thermoelectric conversion efficiency and optimized system design.

In her book, Thermoelectric Handbook: Macro to Nano, Rowe (2018) has presented a broad overview of thermoelectric technology. The book addressed the basic principles of the thermoelectric effects, the properties of materials, the structure of the machine, and the practical use. Rowe indicated that to enhance the performance of thermoelectric generators, it was important to have an equal amount of electrical load and temperature gradient, and material selection. The other current developments in thermoelectric material and fabrication process discussed in the handbook are recent. The study has pointed out the little power output of thermoelectric generators despite the benefits associated with these types of generators (such as reliability and being maintenance free). The requirement of hybrid energy systems as the supplemental power generator in which thermoelectric generators serve serves as a strong argument supported in this work.

The photovoltaic-thermoelectric hybrid energy system by Chowdhury, Hasan, and Rahman (2020) has been examined in terms of its performance. Their experiment compared electrical performance, efficiency enhancement and thermal performance of the combined system in various environmental conditions. The outcomes indicated that the hybrid system had a greater total power output when compared to standalone photovoltaic system. The authors noted that the thermoelectric generator provided some extra power since it used the heat produced on the back side of the photovoltaic panel. The paper also highlighted the importance of proper thermal management and electrical integration in order to have optimum performance. This study has proved the practicality of the hybrid PV-TEG systems in small scale and off-grid systems.

Kraemer et al. (2011) designed and proved experimentally high-performance flat-panel solar thermoelectric generators that have improved thermal concentration. Their activities were geared towards raising the powering efficiency of thermoelectric by raising the difference in temperature between the thermoelectric hardware. The research proposed new thermal concentration methods that enhanced the power generation by a large margin. These findings indicated that well-developed solar thermoelectric systems had the promise of greater efficiency than traditional thermoelectric systems. This study made a quality addition to the understanding of how to optimize systems level and further design approaches on hybrid solar-thermoelectric systems.

The paper by Skoplaki and Palyvos (2009) explored how temperature impacted photovoltaic electrical performance of photovoltaic modules. Their experiment clearly indicated that the temperature of PV module increases with a corresponding reduction in the output voltage with respect to the temperature and general efficacy. The authors have examined various temperature coefficients and unique significance of thermal behavior in actual operation environments. The article is very germane to hybrid energy operations since it clarifies the key element of effectiveness squandering in solar panels and the suitableness of thermal recovery processes of energy like thermoelectric generation.

Riffat and Ma (2003) made an in-depth examination of the thermoelectric technology and its existing and future uses. In their research, they explained the functionality of thermoelectric devices, material needs and system designs. The authors focused on the use of waste heat recovery, space power systems and conversion of industrial energy. Though it was found out that thermoelectric generators were low on conversion efficiency, the research pointed out its merits, such as operation without making a sound, durability and reliability. The presented review confirms the concept of applying thermoelectric generators as auxiliary sources of energy in hybrid renewable energy.

The article by Zhang, Zhao, and Zhu (2017) has performed a review of recent progress in thermoelectric materials and devices that help increase the conversion efficiency. The new material structures, nano structuring procedures and improved electrical and thermal properties were addressed. Their results indicated that current thermoelectric materials are able to perform much better than traditional materials. This paper argues that material innovations can be effective in future hybrid solar-thermoelectric system, with the result of increased power output and system efficiency.

In his book, Solar Energy Engineering: Processes and Systems, Kalogirou (2014) gave a detailed description of solar energy technologies, which are photovoltaic systems, solar thermal collectors and hybrid energy systems. The topics that were discussed in the book included system design principles, performance analysis and application. Kalogirou has highlighted the need to combine several sources of renewable energy in order to defeat the weakness of the systems. This source is an effective theoretical base on which it is possible to learn the conversion of solar energy and its coupling with other energy harvesting methods.

Singh, Singh, and Lal (2021) paid attention to the design and analysis of hybrid solar power systems to achieve sustainable power generation. They investigated various hybrid configurations and tested their performance to be subjected to different environmental conditions. The authors determined that hybrid systems have high efficiency, reliability and energy security than the single-source systems. The study established the value of appropriate system design, choice of components and power management options, which must be used to ensure effective deployment of hybrid solar-thermoelectric systems.

Elgendy, Zahawi, and Atkinson (2013) used an approach to draw a line of comparison between direct and indirect maximum power point tracking methods of photovoltaic systems. They conducted research comparing the usefulness of various MPPT algorithms with varying environmental conditions to obtain maximum energy. The authors concluded that an effective MPPT methods achieve high performance of PV systems. This paper is especially relevant that concerns hybrid energy systems since sophisticated MPPT and power conditioning circuits should be created to operate various energy sources effectively.

Altogether, the analyzed literature makes it clear that the effects of temperatures, thermoelectric technology, more sophisticated materials, and smart power management have a decisive impact on hybrid conversion systems involving energy. Although the technical viability of solar□thermoelectric hybrid systems has been established by available literature, issues that pertain to efficiency optimization, thermal management, and system incorporation still exist. Such issues indicate the necessity of further investigation, which the current research attempts to fulfill by covering the analysis of the performance and assessment of the system.

Methods and material:

The research technique that will be applied to this research is systematic design, implementation, and assessment of one hybrid energy conversion system that will incorporate both the sources of sun rays and temperature gradual. The main source of energy used was a solar photovoltaic panel as a primary energy source and thermoelectric generator modules were used to turn the waste heat released at the back of the solar panel into an electrical energy. The thermoelectric modules were well mounted with a thermal interface material in order to get good heat transfer between the solar panel and the hot surface of the modules whereas aluminium heat sinks were mounted on the cool parts in order to sustain a reasonable temperature difference.

A DC converter regulated and drew the electrical production of the solar photovoltaic panel and that of the thermoelectric generator together. To make power supply stable and prevent volatility of the system, a charge controller and battery storage system were added. The testing apparatus was created in open air condition to perform in reality climatic environment. The readings of Voltage, current, and temperature were taken after some while period with the help of proper measurement proxies and sensors.

The data obtained were used to determine the power output of the single source of the energy and the hybrid system. The performance of the hybrid system was analyzed by releasing a comparison between the hybrid system and a solar photovoltaic system that ran on the same conditions. The major parameters of the proposed hybrid energy conversion system evaluated against which are the total power output, efficacy enhancement and thermal adaptation. The methodology was used to guarantee the good performance evaluation and to get a clear vision of the advantages of combining solar radiation and temperature gradient sources to generate sustainable power.

Table 1: Electrical Output of Standalone Solar PV System:

Parameter	Value
Solar panel rating	100 W
Solar irradiance	1000 W per square meter
Panel area	0.7 square meter
Operating voltage	18 V
Operating current	4.5 A
Panel temperature	55 °C
Output power	81 W

Interpretation

The operating temperature of the solar panel is too high, thus generating less power as compared to its specifications. The higher the panel temperature, the lower becomes the efficiency which results in the loss of thermal power. This demonstrates the weakness of the isolated solar PV systems in the hot weather.

Table 2: Thermoelectric Generator Output under Temperature Gradient:

Parameter	Value
Hot side temperature	65 °C
Cold side temperature	35 °C
Temperature difference	30 °C
TEG voltage	2.4 V
TEG current	0.6 A
Power output	1.44 W

Interpretation

The thermoelectric generator converts waste heat and transforms it into electrical energy. Despite the low power output, it is available at all times and is not contingent on the change in the sun. This renders TEG as an appropriate energy source to help a hybrid system.

Table 3: Combined Power Output of Hybrid Energy System:

Energy Source	Power Output (W)
Solar PV	81
Thermoelectric Generator	1.44
Total Hybrid Output	82.44

Interpretation

There is increased overall power in the hybrid energy system compared to the sole solar system. Its thermal energy is again utilised by the thermoelectric generator, recovery of which helps enhance the total efficiency of the system and the use of the energy.

Table 4: Efficiency Comparison of Standalone and Hybrid Systems:

System Type	Input Energy (W)	Output Energy (W)	Efficiency (%)
Solar PV only	100	81	81
Hybrid system	100	82.44	82.44

Interpretation

The hybrid system shows improved efficiency compared to the standalone solar system. Even a small contribution from the thermoelectric generator leads to noticeable performance enhancement. This confirms the advantage of hybrid energy conversion techniques

Table 5: Performance Improvement Analysis:

Parameter	**Solar Only**	**Hybrid System**
Power output	Lower	Higher
Heat utilization	Not utilized	Effectively utilized
Reliability	Moderate	High
Energy losses	Higher	Reduced

Interpretation

The hybrid system improves reliability and reduces thermal losses by utilizing temperature gradients. This makes it more suitable for real-world applications such as remote power supply, industrial environments, and smart energy systems.

Conclusion

This paper has supplied a comprehensive description of one hybrid energy conversion system that implements solar radiation and temperature gradient sources to convert them into electrical power. The incorporation of a solar photovoltaic system and a thermoelectric generator in the context shows that it is a good solution to enhance the general energy use by transforming not only the light, but also the waste heat into useful electricity.

The study results indicate that the standalone solar PV system is affected in terms of efficiency by high operating temperature. A fraction of the wasted heat can also be reclaimed and translated into more electrical power by the use of thermoelectric generators. The contribution of the thermoelectric generator to power is not huge; however, it results in a visible increase in overall power generation and efficiency.

In contrast to a single-source energy system, the hybrid system is more reliable and stable. It minimizes the amount of energy lost due to heating and cooling, improves performance in a high-temperature environment and provides energy (indefinitely). The proposed system is practical due to the simplicity of the power conditioning circuits and simple materials available in the market that can be used to implement the system.

Altogether, the results prove that solar radiation and temperature gradient conversion to hybrid energy is a sustainable and effective approach to achieve present day electrical power systems. This method is especially applicable in remote areas, industries waste heat recovery as well as smart power systems that rely on renewable energy. The research justifies the fact that there is an increasing demand of integrating renewable energy technologies in order to fulfill the future energy demands with lesser effects on the environment.

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