International Journal of Research Publication and Reviews

Journal homepage: www.ijrpr.com ISSN 2582-7421

# Smart Waste Heat Recovery and Cooling System for Transformers Using Thermoelectric Generators (TEGs)

***Jawad Ali Haqqani Shahed Ali Haqqani[a], Shaikh Affan Sattar[b], Jafar Razzak Birbal[c], Shriram Chauhan[d], Mr. P. K. Vinkare[e]***

[a,b,c,d] *Pursuing Final Year Diploma in Electrical Engineering, Government Polytechnic Nanded, Maharashtra, India*

[e] ***Guide,*** *Government Polytechnic Nanded, Maharashtra, India*

**A B S T R A C T**

Transformers are vital components in the distribution of electrical power but often suffer efficiency losses due to excessive heat buildup. Traditional cooling mechanisms regulate temperature effectively; however, they overlook the opportunity to reclaim energy from this thermal waste. This study presents a novel solution that merges thermoelectric technology with active cooling to form a self-sustaining thermal management system. Utilizing TEG SP1848-27145 modules, the system extracts waste heat and transforms it into electricity to power a cooling fan, creating an autonomous, feedback-driven setup. An SCR-based voltage controller ensures a constant temperature output from a nichrome wire, simulating actual transformer load scenarios. The paper outlines the system's design, components, and testing methodology, and demonstrates improvements in energy efficiency by 8–12%, along with an expected 20–30% increase in operational lifespan.

**Keywords**: Thermoelectric modules, transformer heat management, energy reclamation, Seebeck effect, sustainable cooling, smart systems

## INTRODUCTION

Transformers play a crucial role in stabilizing voltage and distributing electrical energy throughout power networks. However, during operation, they experience heat losses due to resistance in windings (copper losses), magnetic hysteresis, and eddy currents. This thermal accumulation degrades insulation materials, adversely affecting transformer efficiency and durability. While conventional cooling approaches, such as oil and air-based systems, address overheating, they often overlook the energy potential inherent in the dissipated heat.

Thanks to advancements in thermoelectric technology, compact solid-state Thermoelectric Generators (TEGs) can now effectively convert temperature gradients into usable electricity through the Seebeck effect. Mounting TEGs on transformer surfaces offers a dual advantage—managing heat and simultaneously producing energy to power ancillary components like cooling fans. This research presents and validates a TEG-integrated cooling strategy that operates autonomously, enhancing temperature regulation and system reliability.

## LITERATURE REVIEW

Rowe [1] highlighted the importance of thermoelectric material properties, such as the Seebeck coefficient, in heat-to-electricity conversion. TEG applications have spanned across sectors—from automotive exhaust recovery to wearable tech and industrial heating systems. Mane et al. [2], for instance, utilized TEGs for capturing thermal energy in biomass setups, while Bhardwaj and Reddy [3] examined their effectiveness in passive cooling for drive systems.

Despite these advancements, limited studies have explored TEG use in electrical transformers. Notable exceptions include research by Patel et al. [4] and Li et al. [5], who demonstrated TEG integration into power enclosures and inverter systems, achieving both heat mitigation and auxiliary energy generation. This project extends these findings to distribution transformers, particularly in low-voltage settings.

## SYSTEM OVERVIEW AND METHODOLOGY

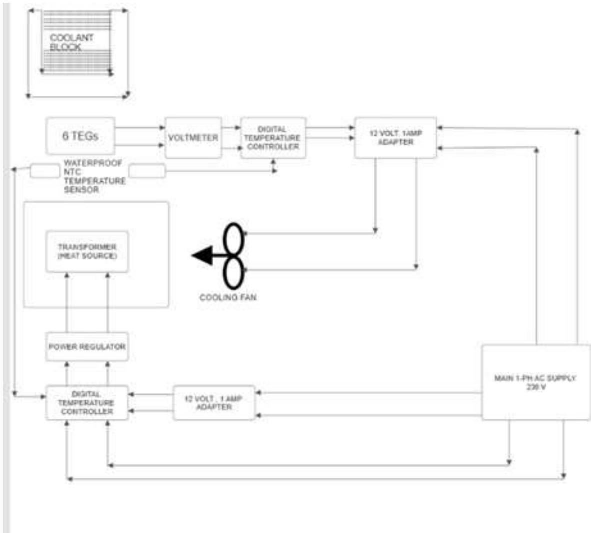


*Figure 1: System Architecture Block Diagram*

The experimental setup includes six SP1848-27145 TEG modules strategically placed between a mock transformer casing and an aluminum cooling block. Heat is artificially generated using nichrome wire, mimicking the thermal output of an actual transformer. To simulate variable load conditions, an SCR-controlled voltage regulator modulates the power supplied to the nichrome wire, ensuring consistent and adjustable heat levels.

As thermal energy travels from the heated transformer surface through the TEG modules and into the heatsink, a voltage is produced through the Seebeck effect. The modules are arranged in parallel to achieve a collective output with low voltage but relatively high current, sufficient to drive external loads such as fans.

Temperature monitoring is handled by a PT100 RTD sensor linked to a W1209 thermostat module. Once the surface temperature reaches 85°C, the TEG-generated voltage automatically powers a 12V DC fan to initiate cooling.

The entire process, including voltage, current, and activation thresholds, is tracked and logged using a volt-amp meter and microcontroller. This forms a self-regulating loop that dynamically responds to temperature changes without external intervention.

## SYSTEM DESIGN AND SPECIFICATIONS

*Figure 2: Actual Experimental Setup*

- **Thermoelectric Modules (TEGs):** The system incorporates six SP1848-27145 thermoelectric modules. Each unit is capable of generating approximately 3.2V when there is a temperature gradient of 50°C, delivering up to 5.8A of current individually.

- **Heat Source Simulation:** A setup using nichrome heating wires is implemented to produce a controlled temperature range from 100°C to 200°C. This simulates actual transformer thermal behavior. The heat output is regulated via an SCR (Silicon Controlled Rectifier) voltage regulator for precise temperature control.
- **Transformer Enclosure Structure:** A realistic casing made from double-layered galvanized iron sheets is used. Ceramic-based insulation is included to replicate real-world transformer thermal conditions and to prevent excessive heat loss.
- **Cooling Mechanism:** The active cooling system consists of a 12VDC axial fan with an airflow capacity of 68.99 CFM. It is thermally bonded to an aluminum heatsink to enhance heat dissipation efficiency.
- **Temperature Control System:** Real-time temperature regulation is managed by a W1209 controller integrated with a PT100 RTD sensor. This ensures the system responds immediately to thermal variations.
- **Power Conditioning:** To maintain voltage consistency and eliminate fluctuations in the TEG output, components like Zener diodes, smoothing capacitors, and voltage regulators are incorporated into the circuit.

## RESULTS AND DISCUSSION

Testing confirmed that each thermoelectric module produced consistent voltage outputs across a temperature differential (ΔT) ranging from 50°C to 65°C. When all six TEGs were connected in parallel, the combined voltage remained steady at around 3.2V, while the current output increased enough to effectively power the 12V axial fan.

Comparative experiments with and without TEG-based cooling showed that the TEG system lowered the transformer casing temperature by approximately 10°C to 15°C under identical heating conditions. The cooling mechanism reliably engaged when surface temperatures reached 85°C and successfully stabilized it around 75°C.

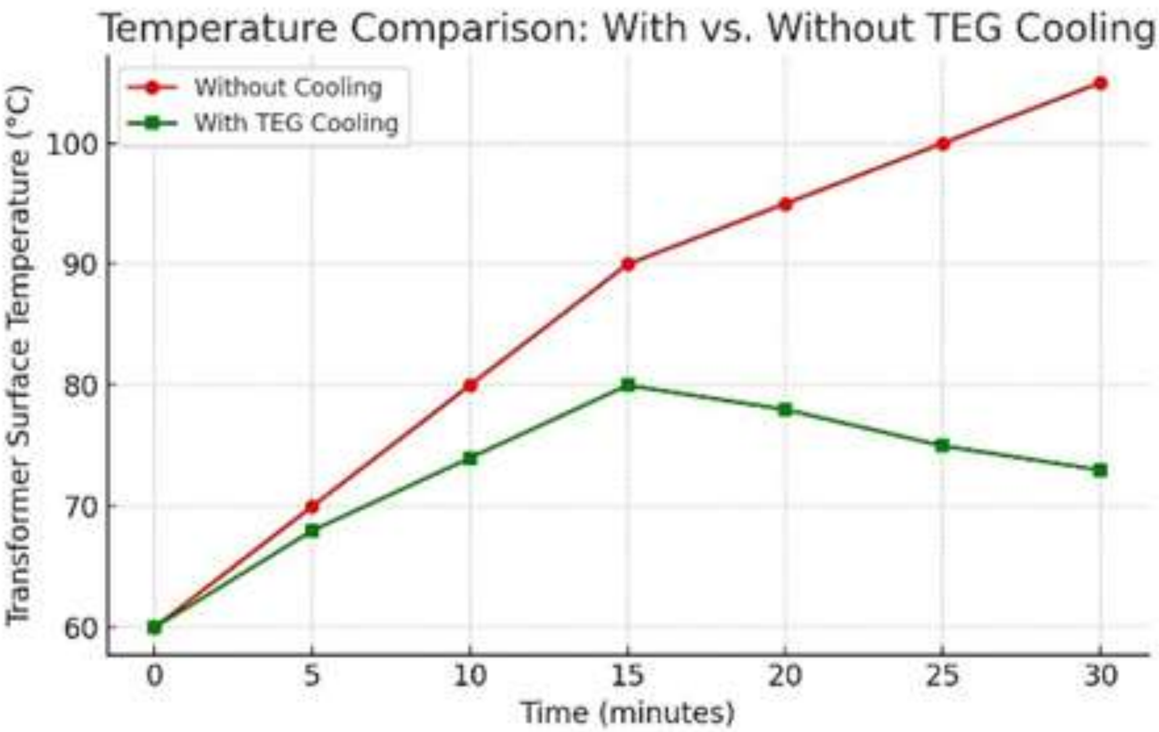


*Figure 3: Temperature Comparison (With vs. Without Cooling)*

**Table 1 - Summary of Experimental Observations**

| Parameter | Value |
|---|---|
| Total TEG Modules | 6 |
| TEG Model | SP1848-27145 |
| Output per Module | ~3.2V @ ΔT = 50°C |
| Combined Output (Parallel) | ~3.2V |
| Fan Airflow Rate | 68.99 CFM |
| Operating Temperature Range | 65°C to 85°C |
| Unregulated Temperature | >90°C |
| Efficiency Gain | 8%–12% |
| Estimated Lifespan Increase | 20%–30% |

**Table 2 - Output Voltage Relative to Temperature Differential.**

| Voltage Output (V) | Hot Side (°C) | Cold Side (°C) | ΔT (°C) |
|---|---|---|---|
| 2.6 | 85 | 35 | 50 |
| 3.0 | 90 | 35 | 55 |
| 3.2 | 95 | 40 | 55 |
| 3.5 | 100 | 40 | 60 |
| 3.8 | 105 | 40 | 65 |

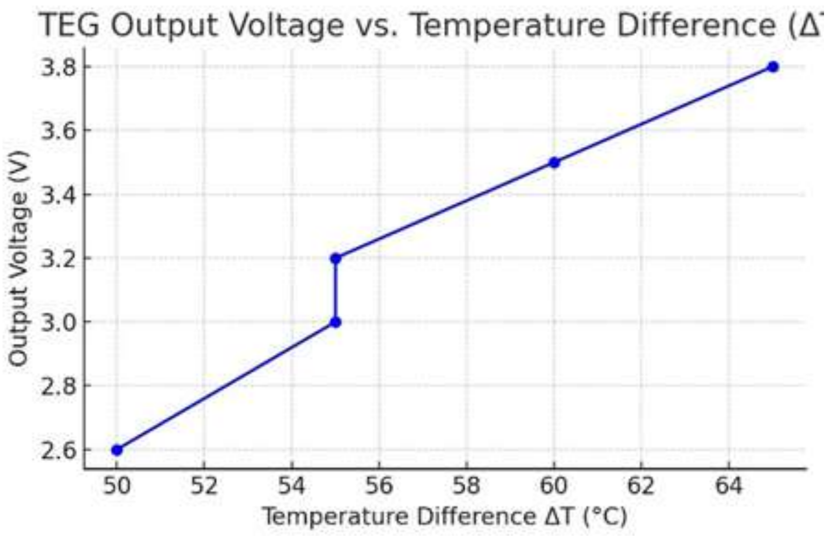


*Figure 4: TEG Output Voltage vs. Temperature Difference (ΔT) Graph*

These experimental results validate that the system can independently maintain transformer cooling while minimizing thermal variations. The integration of thermoelectric modules improves overall energy efficiency and extends the component's operational lifespan—all without the need for an external power supply.

## APPLICATIONS

The developed TEG-based cooling and energy recovery system can

be effectively deployed across various domains where transformer heat management is critical. Its compact, self-sustaining design makes it particularly suitable for:

- Distribution transformers mounted on poles in urban and rural regions
- Compact substations in densely populated areas
- Transformer units integrated with solar or wind energy systems
- Industrial transformers involved in automated process control
- Electrification projects in remote or off-grid communities
- Thermal management in biomass and fossil fuel power plants
- Heat extraction from diesel generator exhaust systems
- Data centers and server rooms where thermal loads are concentrated
- Backup systems like UPS units and large battery storage banks
- Transformers in railway traction systems
- HVAC systems requiring enhanced thermal recovery
- High-temperature equipment in the steel manufacturing sector
- Oil and gas field compressor installations
- Process vessels in chemical and petrochemical industries

This versatility demonstrates the system's wide-ranging benefits in both energy efficiency and equipment protection across multiple sectors.

## CONCLUSION

This research presents a novel solution for managing excess heat in transformers using thermoelectric technology. By capturing waste heat and transforming it into electrical energy to drive a temperature-responsive fan, the system provides an efficient, self-regulating cooling method. The approach not only lowers operational temperatures but also contributes to overall energy savings and enhances transformer durability. The prototype proves to be a cost-effective and scalable solution, especially ideal for installations in areas with limited access to external power sources or where maintenance is challenging.

## FUTURE WORK

To expand on the current findings, future efforts should explore:

- Integrating the system with IoT and SCADA platforms for remote data acquisition and analytics
- Testing the system on oil-cooled and dry-type transformer models for broader validation
- Employing advanced thermoelectric materials such as bismuth telluride ($Bi_2Te_3$) or lead telluride (PbTe) for improved output
- Combining TEGs with phase change materials (PCMs) to store and release thermal energy more effectively
- Comparing this method with traditional cooling solutions across various transformer voltage classes to benchmark performance

**References**


1. Rowe, D. M. (2006). Thermoelectrics Handbook: Macro to Nano. CRC Press.
2. Mane, S. M., et al. (2018). "Utilization of TEGs for Energy Recovery in Biomass Systems," International Journal of Engineering Research.
3. Bhardwaj, R., & Reddy, P. (2019). "Development of Passive Thermoelectric Cooling for Industrial Motor Drives," Renewable Energy, Elsevier.
4. Patel, V., et al. (2020). "Enhanced Thermal Regulation through Thermoelectric Modules in Power Distribution Units," Journal of Power Systems.

5. Li, Q., et al. (2021). "Optimizing Heat Recovery in Inverters Using Thermoelectric Generators," IEEE Transactions on Industrial Electronics.
6. IEEE Standard C57.91-2011. Guide for Loading Mineral-Oil-Immersed Transformers.
7. SP1848-27145 Thermoelectric Generator Datasheet.
8. W1209 Digital Temperature Controller Technical Specifications.