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## ***Augmentation of Solar-derived Pyroelectric Generation***

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### ***Abstract***

*Because of their great thermodynamic efficiency and low heat sink requirements, pyroelectric thermal energy harvesters are a fascinating alternative to thermoelectric devices. Thermoelectric generators create voltage from a spatial temperature gradient using the seebeck effect. Pyroelectricity, on the other hand, may capture the temporal variations of heat energy. The use of renewable energy sources such as solar and wind energy is possible with the non-Olsen cycle technique of pyroelectricity generation. The goal of this research is to investigate the potential of a Lead-zirconate-titanate (PZT-5H) pyroelectric material to collect energy using the Non-Olsen cycle method. The PZT-5H is exposed to solar radiation, and the mechanical setup is used to achieve a periodic temperature change in the material. A revolving chopper disc and a vertical axis wind turbine make up the mechanical arrangement (savonious type). The savonious wind turbine gives mechanical input to the chopper disc, allowing solar irradiation to fall on the PZT-5H material on a periodic basis, resulting in a temperature variation over time. Because the time changing temperature may be obtained from naturally accessible sources like as sun and wind energy, this approach appears to be more cost effective than the Olsen cycle method. Optical concentrators are used to increase sun irradiation in order to optimise production.*

***Keywords:*** *Pyroelectricity, Seeback effect, Voltage, PZT-5H material, Thermal energy harvesters*

## INTRODUCTION

With the growth of modern industry across the world, issues such as energy scarcity and pollution of the environment have emerged. Solar energy is becoming increasingly significant as a renewable and environmentally acceptable energy source. Solar energy may be captured in a variety of methods, including solar thermal power plants, solar thermoelectric generators, and photovoltaic systems. Because they offer direct electrical output and are sustainable for small-scale installations, the latter two are more beneficial than solar thermal power plants. The seebeck effect is used in solar thermoelectric generators to create voltage from a spatial heat gradient. These are based on temperature gradients that cause heat to flow through the thermoelectric generator, with only a tiny portion of that heat being converted to electrical energy. It necessitates a period of simultaneous heating and cooling, which is difficult to set up and sustain. Pyroelectricity is a novel family of ferromaterials that might be a perfect thermoelectricity replacement.

When some materials are heated or cooled, they have the capacity to create a transient voltage. The polarisation of the material varies when the temperature changes because the locations of the atoms

inside the crystal structure vary somewhat. A voltage is generated across the crystal as a result of the polarisation shift. The pyroelectric voltage eventually diminishes owing to leakage if the temperature remains constant at its new value.

To create useful electrical power, a pyroelectric may be heated and cooled repeatedly. Lower working temperatures, less bulky equipment, and fewer moving parts are all possible advantages of pyroelectric generators for generating electricity (as opposed to the traditional heat engine plus electrical generator).

Many research on pyroelectric-based energy harvesting have been conducted, the majority of which have used the Olsen cycle [1], which is based on the thermodynamic Ericsson cycle and has two isothermal and two isoelectric field processes. This cycle has been demonstrated for a variety of materials, including polymers, single crystals, and relaxor ferroelectrics, as well as for a variety of electrical fields and temperature ranges.

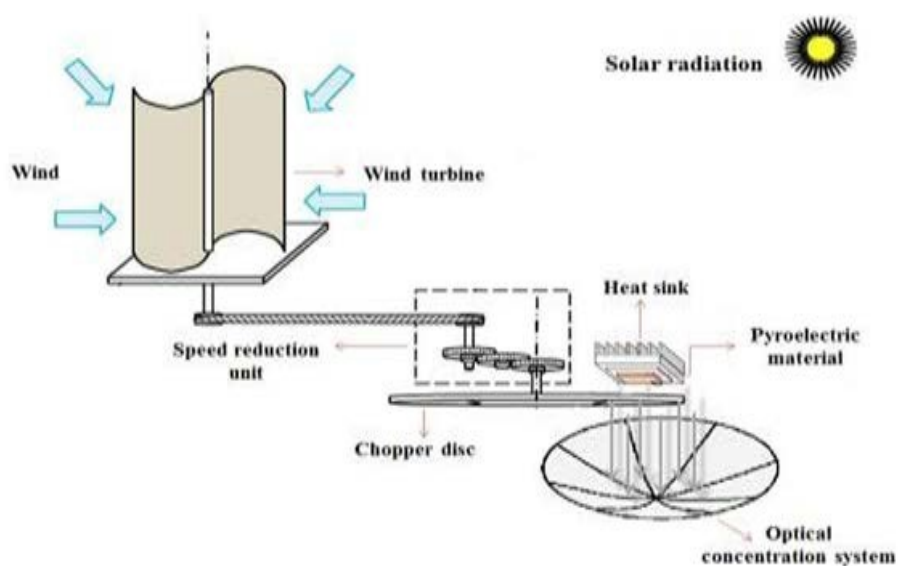
In the presence of electric fields, Navid et al. conducted the Olsen cycle by immersing purified and porous 60/40 poly(vinylidene fluoride-tri fluoro

ethylene) [P(VDF-TrFE)] in hot and cold silicone oil baths and harvesting maximum energy density up to 426 J/L/cycle[2]. Kandilian et al. did a dipping experiment on a single crystal of  $68\text{PbMgNb}_2\text{O}_{12}-32\text{PbTiO}_3$  (PMN-32PT) and achieved a 100 mJ/cm/cycle energy density, equivalent to a power density of 4.92 mW/cm [3].

Lee et al. recently reported that oil bath tests on a 290- $\mu\text{m}$ -thick lanthanum-doped lead zirconate titanate (8/65/35 PLZT) ferroelectric relaxor crystal yielded a maximum energy density of 888 J/L/cycle [4]. The other well-known way for performing an Olsen cycle is to push a working fluid, generally silicone oil, back and forth between heating and cooling

heat exchangers through a stack of pyroelectric material.

With lead zirconate stannate titanate (PZST) as the pyroelectric material, Navid et al. obtained a power density of 38.4 W/L at 0.5-Hz frequency [5]. Nguyen et al. conducted similar tests using 60/40 P(VDF-TrFE) and found a maximum energy density of 130 J/L at a frequency of 0.061 Hz [6]. Instead of using convective heat transfer, Lee et al. created thermal oscillations to carry out the Olsen cycle by alternately putting 60/40 P(VDF-TrFE) on a hot and cold source. For temperatures between 25 and 110 degrees Celsius, the authors observed an energy density of 155 J/L/cycle at 0.066 Hz [7].



**Fig. 1 Schematic diagram of the pyroelectric energy harvesting system**

However, there have been non-Olsen-cycle attempts to harvest energy from pyroelectric materials. Using a resistive heater, Xie et al. observed a peak power density of 0.23 W/cm at a rate of change in temperature of 15 Cs on a lead zirconate titanate (PZT-5A) ceramic [8]. Mane et al. utilised a heat lamp as a radiation source and a spinning disc with an opening as a radiation chopper to heat three distinct materials, including PZT, a prestressed PZT composite, and single crystal PMN-30PT, at various intervals. Because of its high pyroelectric coefficient, PMN-30PT achieved the highest power density of 8.64 W/cm at a temperature rate of 8.5 Cs [9]. The absence of thermal sources with a significant time changing temperature limits the possibilities of directly tapping ambient thermal sources using pyroelectricity instead of pumping working fluid or utilising a heat lamp. Zhang et al. recently shown that when the pyroelectric material PZT is exposed to solar radiation, it may generate energy by utilising natural variations in solar radiation intensity as well as wind fluctuations [10]. The scientists carried out a laboratory experiment that simulated the real-world condition and obtained a power density of 4.2 W/cm at a rate of change in temperature of 0.53 Cs and a wind speed

of 2 ms. Similarly, Sebald et al. observed natural temperature fluctuations on a coat and used the temperature profile to determine a mean power density of 1 W/cm from a 0.75 Pb(Mg Nb )O - 0.25PbTiO (PMN-0.25PT) ceramic [11]. Because the natural variations of solar radiation are too slow and tiny to create fast temperature changes, the energy collected by these principles is relatively low.

## **DESIGN OF THE PROPOSED ENERGY HARVESTING SYSTEM**

### ***A. Operating Principle***

The expected energy harvesting system is based on an optical concentration system that increases the intensity of solar radiation on the pyroelectric material, as illustrated in Fig.1. Higher temperatures can be reached by focusing solar radiation, which may not be achievable with regular exposure to solar energy. And the intensity of the incident focused radiation on the pyroelectric material must be adjusted in order for the pyroelectric material to heat in a predictable manner.

A spinning mechanical chopper disc positioned between the reflector and the pyroelectric material can be used to modulate the light. Through the use of a wind turbine connected to the optical

concentration system, the energy necessary to rotate the chopper may be obtained from the kinetic energy of the wind. The mechanical energy from the wind turbine is transferred to the chopper disc through a speed reduction device and a belt drive mechanism. The speed reduction device is required to lower the chopper disc's rotational speed so that the active material can have a longer heating and cooling phase.

### ***B. Selection of Components***

Optical concentrators can be reflecting, such as those that use a parabolic trough, or refractive, such as those that use Fresnel lenses [12], [4], [13]. These concentrating devices, on the other hand, require tracking systems in order to accurately follow the sun, and they can only concentrate the sun's beam or direct radiation. Due to chromatic aberrations, an imaging type Fresnel lens really transfers the picture of the sun onto the receiver but falls short of the maximum concentration limit [14], [15]. In addition, the cost of a Fresnel lens is greater than that of a parabolic reflector with trackers. As a result, the energy collecting system employs parabolic reflectors.

The optical concentration unit, which will be positioned in the direction of the sun,

must be connected to the wind turbine, which gives mechanical input to the chopper disc. As a result, a vertical axis wind turbine (VAWT), which can catch wind from any direction regardless of its orientation [2], would be a suitable choice.

When comparing the two popular types of vertical axis wind turbines, Savonius and Darrieus, the former is preferred due to its simple design and high starting torque, whilst the latter is not self-starting and frequently requires an induction motor or a Savonius rotor as a starter [16]. However, when the tip speed ratio is less than one, the Savonius turbine is less efficient in collecting power from the wind, generating peak power coefficient [17]. As a result, it is better suited to applications with low revolutions per minute (rpm), as is the case now. The schematic diagram of the completely built pyroelectric energy collecting system is shown in Figure 2.

### ***C. Experimental Setup***

An experimental setup illustrated in Fig.2 was used to explore the performance potential of the previously stated energy harvesting technology. The pyroelectric material is lead zirconate titanate (PZT), which has dimensions and characteristics shown in Table 1.



**Fig.2. Experimental setup of the pyroelectric energy harvesting system**

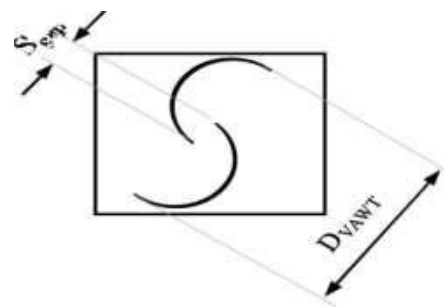
The Curie temperature of the PZT-5H is 195oC, as shown in Table 1, and therefore the crystal's temperature may be safely increased up to 115oC without causing harm to its pyroelectric characteristic. The materials are put on a wooden plate that serves as a heat sink for the materials.

**Table 1: Dimensions and Properties of PZT pyroelectric material**

Properties	Value
Area (A <sub>pyro</sub> )	$5 \times 10^{-4} \text{m}^2$
Thickness (t <sub>pyro</sub> )	$5 \times 10^{-4} \text{m}^2$
Density ( $\rho$ )	$7500 \text{kg/m}^3$
Curie temperature (T <sub>c</sub> )	195°C
Specific heat (c)	440 J/kg °C
Pyroelectric coefficient (p)	$452 \mu\text{C/m}^2\text{K}$

To get the desired length, a steel pipe with a diameter of 10.16 cm and a diameter of 30 cm is cut vertically into exactly two halves and placed on a stand as illustrated in Fig.3.

The savonius wind turbine has a “S” form with a bucket gap width of 3 cm and a diameter of 17 cm.



**Fig.3. Dimension of the Savonius Vertical Axis Wind Turbine**

A point focusing parabolic reflector composed of aluminium sheets is fastened securely to a stand facing the sun, as illustrated in fig.4. The pyroelectric substance attached to the wooden plate is placed precisely above the reflector, focussing the lens. The heat sink is placed 15cm away from the reflector, so the reflector's concentrated spot is approximately the same size as the pyroelectric substance. This guarantees that the pyroelectric material is heated uniformly throughout its surface and prevents additional pyroelectric effects from arising as a result of spot heating

[18]. The PZT-5H is mounted atop the heat sink, and conventional insulating tapes are utilised to secure the crystal at the outside borders, guaranteeing good thermal contact.



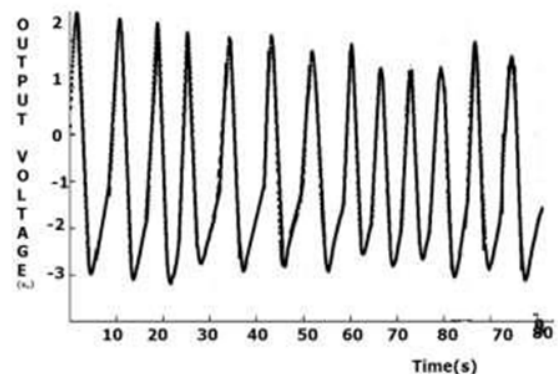
**Fig.4. Experimental Setup of the Parabolic Reflector**

A hollow rectangular aluminium frame with suitable bearing arrangement is connected to one of the steel frame's side supports to accommodate the Savonius wind turbine. The Savonius wind turbine's revolutions are transmitted to a two-stage gear speed reduction unit through a belt drive mechanism linked to the wind turbine's bottom tip. The chopper disc is composed of steel sheet in the shape of two "T"s positioned across from one another. And this disc is attached to the shaft of the speed reduction unit's final step. The thin steel chopper disc is sandwiched between the parabolic reflector and the ferroelectric ceramic, chopping the focused irradiation from the reflector onto the active material as it spins. The orientation of the entire steel

frame arrangement, including the wind turbine, is manually changed during the day to line the reflector with the sun's direction.

## EVALUATION THROUGH EXPERIMENTAL PROTOTYPE

On 5.11.2014, the completely constructed prototype was tested under real-world settings on a chilly day. The ambient temperature during testing was about 29°C. A graph of output voltage from with respect to time is shown in Fig.5, which was created using a multimeter attached to the electrode terminals. The output voltage of the PZT-5H achieved a high of 2.17 and a low of -3.19 V, respectively. The temperature of the PZT-5H reached a maximum of 33.45°C. The highest temperature change is 3.25°C.



**Fig.5. Output Voltage Vs. Time Waveform of Pyroelectric Material**

If the ambient temperature is high, such as during the summer, it is reasonable that very high temperature rates might have been attained. Because the pyroelectric material creates a temporary voltage at normal room temperature, if the solar intensity is more than the reflected solar light intensity from the parabolic reflector, the material will generate even more voltage because the rate of temperature change will be greater. The rate of cooling is high at first, then slows when the temperature of the ceramic reaches ambient temperature, which explains the output voltage's low slope region. When the irradiation intensity is low and the radiation chopping frequency is high due to high wind speed, the power density generated by the ceramic will be comparatively low.

## CONCLUSION

Solar energy is a costless source of energy for pyroelectric materials with a high temperature potential. By using the ambient solar and wind energy, a greater rate of change in temperature may be achieved, resulting in a larger output voltage. The findings also show that, with the use of focusing optics and an appropriate cooling mechanism, a temperature profile cycling between huge temperature gradients may be created,

which is something that is generally rare to discover in nature. In this thesis, a pyroelectric-based energy harvesting system is built and tested to transform the radiant energy from the Sun into usable electricity.

The main goal of this research is to increase the rate of change in temperature of the pyroelectric material, since this directly affects the power production from the pyroelectric material when using freely accessible solar and wind energy. The mechanical input from the Savonius wind turbine is combined with a well-known approach for increasing sun intensity using concentrating solar collectors based on parabolic reflectors to create the necessary large rate of change of temperature on the pyroelectric material PZT-5H. Variations in the produced power density are also reported to be dependent on the intensity of solar radiation and the wind speed.

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