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Hybridization of Photovoltaic and Thermoelectric Energy Harvesting Systems at Seismic Nodes

Dauda Duncan

Department of Electrical, Computer and Telecommunications Engineering, Botswana International University of Science and Technology, Private Bag 16, Palapye, Botswana.

Mmoloki Mangwala

Department of Electrical, Computer and Telecommunications Engineering, Botswana International University of Science and Technology, Private Bag 16, Palapye, Botswana.

Bokani Mtengi

Department of Electrical, Computer and Telecommunications Engineering, Botswana International University of Science and Technology, Private Bag 16, Palapye, Botswana.

Adamu Murtala Zungeru

Department of Electrical, Computer and Telecommunications Engineering, Botswana International University of Science and Technology, Private Bag 16, Palapye, Botswana.
ORCID: 0000-0003-2412-6559

Bakary Diarra

Department of Electrical, Computer and Telecommunications Engineering, Botswana International University of Science and Technology, Bamako, Mali.

Joseph Chuma

Department of Electrical, Computer and Telecommunications Engineering, Botswana International University of Science and Technology, Private Bag 16, Palapye, Botswana.

Abstract

Seismic data is one of the most important data for analysis and interpretation of subsurface, but remote seismic node fails frequently. This is one of the main constraints that limits seismic network to acquire continuous seismic data and near real-time prediction of seismicity of an area. There are several ambient energy sources at the remote seismic nodes. Optimization of their energy transducers and DC-DC converters is inevitable. In this study, solar and thermal sources are utilized with maximum power point tracking (MPPT) algorithm. The algorithm is based on the Neural Network model to supply the duty cycle across the converter optimally. Historical data were generated from Perturb and Observe algorithm in PSIM for the Neural Network Model to train the data and predict the duty cycles for both within and outside the data. The proposed system delivered an over 75% conversion rate of the Photovoltaic module's power. The system was modeled in Simulink under the ideal conditions of its components. It could face few constraints during prototype implementation due to the unusual characteristics of the thermoelectric elements. However, certain additional electrical energy was achieved for a low duty power load, such as a remote seismic node. The significant contributions are to identify operating constraints and design optimal hybrid energy harvesting systems at a remote seismic node.

Keywords: Converter, Energy, MPPT, Photovoltaic, Thermoelectric.

I. INTRODUCTION

The continuous and reliable geophysical database provides appreciated and meaningful details about the interior of the earth [1]. Seismic data is one of the most important data for analysis and interpretation of subsurface [2]. A remote seismic node is an embedded system that could be a permanent or temporary node. It detects, measures, and stores earth vibration in an electrical signal manner. It usually consists of sensing, processing, and storing units, while the Global Positioning System (GPS) and telecommunication backbone could be optional. Energy harvesting systems extract available ambient energy, which could be solar, thermal, radio-frequency, or vibration sources, and convert them into usable electrical power.

The performance of a solar energy harvesting system depends strongly on the temperature and irradiance of the ambient environment. For delivering reliable and continuous electrical energy at the remote seismic nodes, the above considerations are investigated. The optimization of these considerations enables the delivery of steady and continuous power supply to remote sensor deployment like seismic node [3]. Apparently, in thermoelectric technique, any thermal gradient results in electricity generation, and it is relatively reliable as well as quiet in nature. It has no moving parts, unlike other resonant generated energy transducers. It is capable of converting the wasted thermal gradient created by the photovoltaic(PV) transducer into electrical energy [4]. The thermal gradient across the thermoelectric transducer and the application of the Seebeck effect is the essential factors that cause the transitioning of charge carriers to its output as a terminal voltage [5]. Thermal heat is permanently available [6], and the small thermal gradient is usually experienced [7]. The thermoelectric elements could be cascaded in series to deliver usable voltage for remote nodes [8]. Hence, the solution is suitable for seismic deployments.

A layout of the energy harvesting system at a case study is shown in Fig. 1, which comprises a PV module and lead-acid battery as the only source of energy without any form of optimization. Linear mode regulation is used, which is characterized by low efficiency. Broadband seismometers are active electronic feedback sensors, and they require reliable, steady, and continuous power to function optimally [9]. Linear mode regulator also takes a lot of life from a conventional battery. Fig. 2 is a diagram of the proposed energy harvesting system that intends to deliver a continuous and sustainable electrical energy.

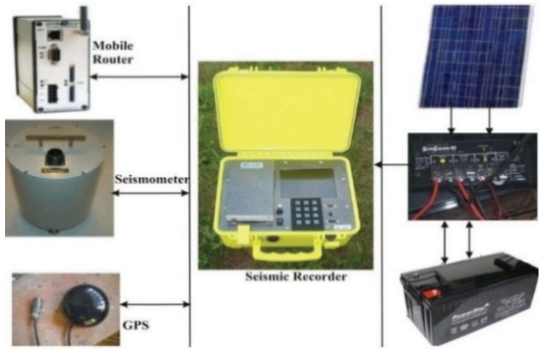

Fig. 1: A Layout of Energy Harvesting System at Nsukka Seismic Node

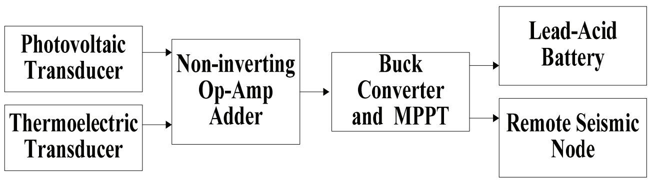

Fig. 2: Proposed Hybrid Energy Harvesting at Remote Seismic Node

This paper intends to identify and demonstrate the constraints of PV and thermoelectric techniques in a hybrid energy harvesting system. Maximum Power Point Tracking (MPPT) and a buck converter at seismic nodes are simulated in the Simulink environment. The two main contributions of this study are (1) identification of operating constraints to enable a continuous and affordable supply of the seismic system, and (2) designing a hybrid energy harvesting system at the remote seismic node.

The remainder of the paper is organized as follows; Section 2 discusses related works to the study. Section 3 investigates materials and methods in PV, thermoelectric energy transducers, and buck converter with its MPPT. In Section 4, we provide the findings, simulated results, and discussions of the design. Section 5 covers the conclusion of the study.

II. RELATED WORK

Several approaches to energize remote nodes by energy harvesting systems have been reported in the literature. However, each remote node requires different considerations of energy transducers and energy conversion for a particular remote node. Most of the approaches are deployed for a relatively short period and need no optimizing of their subsystems, and unsuitable for a seismic node, which operates endlessly. A continuous and sustainable energy harvesting system requires logical optimization at the conversion stage of the design and implementation [10] [11].

Hybrid Energy Harvesting System aims at capturing more than one source of ambient energy, process, and store them in a usable manner. Integrating energy sources improves continuity in seismic data acquisition. However, optimizing their constraints is challenging. A hybrid energy harvesting system could be a combination of PV, radio frequency (RF), vibration, or thermal sources. Table I shows the different sources of energy and their respective peripherals.

Table I: Hybrid Energy Harvesting and their transducers combinations

S/No.	Combination	Conversion Type	Type of Converter	Type of MPPT	Expected Efficiency	Application /Topology	Remarks	Reference
1	Thermoelectric	Temperature gradient	MOSFET is driven by PWM and control by a micro-controller	MPPT Tracking efficiency of 99.85%	98.7% Theoretical tracking	Buck or Boost converters for Remote, Space, and Automobile	The Thermoelectric transducer, MPPT, and SMPS were utilized, but battery alone and low-cost Microcontroller	[12]
2	Thermoelectric	Temperature gradient	DC-DC switch is driven and modulated by PWM	Open-circuit Algorithm MPPT	Not Available	Boost Converter	Open Circuit Algorithm is the simplest MPPT to developed, but parameters are difficult to determine [13]	[14]
3	Thermoelectric	Temperature Gradient	MOSFET Switch based on Burst mode to control the output voltage and reduce wastage of energy for maximum power to be	Fractional open circuit voltage MPPT	Functional overall efficiency 81%	Boost and buck	With reduced power losses, the overall efficiency is improved	[15]

S/No.	Combination	Conversion Type	Type of Converter	Type of MPPT	Expected Efficiency	Application /Topology	Remarks	Reference
			attained					
4	Thermoelectric	Temperature Gradient	SMPS	Perturb Observe MPPT Algorithm	Not Available	Boost converter	P&O MPPT tracked fast under sudden changes in temperature and irradiances.	[16]
5	Thermoelectric	Temperature Gradient	MOSFET is driven by a micro-controller 93% Conversion Efficiency	Open Circuit MPPT Algorithm Track 99% power	Not Available	Remote, military, space, medical Buck Switched Mode Power Supply (SMPS)	Open Circuit MPPT is easy to implement since there is no need to measure current	[17]
6	Thermoelectric	Temperature Gradient	Bipolar DC-DC Converter	Open Circuit MPPT Algorithm	70% efficiency	Buck/Boost	Not Available	[18]
7	PV and Thermoelectric	Photocurrent and Thermocouple	Not Available	Not Available	Not Available	Not Available	The PV installed alone has an efficiency of 14%. The wasted thermal heat generated 100-140Wm^{-2} To increase the efficiency of PV transducer should be relatively decreased	[19] [20] [21]
8	PV and Thermoelectric	Photocurrent and Thermocouple	Not Available	Not Available	Not Available	Not Available	Thermoelectric was able to contribute 7% of the output power where MPPT and SMPS were employed	[22]
9	PV and Thermoelectric	Photocurrent and Thermocouple	Not Available	Not Available	Not Available	Not Available	Efficiency was increased by 3,6% without optimization	[23]
10	PV and Thermoelectric	Photocurrent and Thermocouple	Not Available	Not Available	Not Available	Not Available	Hybrid enhanced output power 2-20%. The efficiency of the photovoltaic increase up to 3.37%	[24]
11	PV and Thermoelectric	Photocurrent and Thermocouple	Not Available	Not Available	Not Available	Not Available	From 25^0C to 100^oC reduced by 25%. Hybrid at 83^0C, the efficiency increased by 10% without optimization of MPPT and SMPS	[25]
12	PV and Thermal	Photocurrent and Thermal Difference	MOSFET as a switch driven Microcontroller and modulated by PWM	MPPT employed	80%	Boost SMPS	Hybrid improved efficiency	[26]

In a thermoelectric energy harvesting system, the converter includes an inductor that has an accurate conversion rate. However, the high value of the inductor is needed to improve efficiency [27]. The author in [28] used a voltage multiplier based on a charge pump in the design, and low voltage levels of thermoelectric transducers were converted to usable forms.

Table I lists several approaches, and each approach observed that all the transducers contribute to the overall energy. Based on Table I and the literature review, a low power duty system such as the seismic PV module can serve as the primary source and assigned to bias an operational amplifier adder. Simultaneously, the thermoelectric module is merely a complement energy source to the PV source by contributing additional electrical energy. Relatively low ripples and high efficiency characterize a buck converter topology, and the neural network MPPT algorithm is employed to improve efficiency.

III. MATERIALS AND METHODS

III.I System Architecture at a Seismic Node

A typical seismic node consists of an embedded system, seismometer (sensor), data acquisition system, Global Positioning System (GPS) antenna, and its receiver, while telemetry is optional, as shown in Fig. 3. A case study at 06^0

52.022N 07^{0}25.045E in Southeast Nigeria, Nsukka Seismic Node on Nigerian National Network of Seismographic Stations(NNNSS) has five subsystems:

i. Broadband Seismometer

ii. Data Acquisition System

iii. Mobile Router

iv. GPS Receiver

v. Power Supply

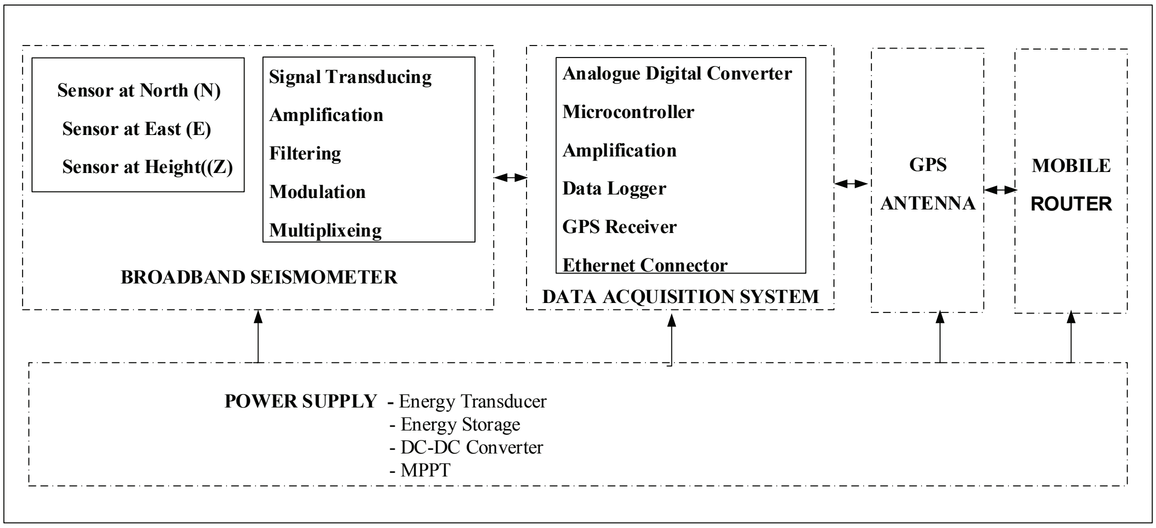

Fig. 3: Proposed Architecture of Optimized Energy Harvesting System with Seismic Instrumentation

III.II Energy Transducer

Deploying seismic instrumentation at a quiet node is necessary [29], and suitable installation of PV and thermal transducers which have no moving parts [30] are appropriate for seismic nodes. A thermoelectric transducer has a solid-state conversion, characterized by a very long lifespan and can produce electrical energy even without sunlight [31]. Table II shows the electrical characteristics of a case study at Nsukka Seismic Node. The proposed system employs a PV module as the primary source and thermoelectric as a compliment. The two sources are combined using a non-inverting operational amplifier across the DC-DC converter to power the load and energy storage.

Table II. Electrical Specifications at Nsukka Seismic Node in Nigeria

Subsystem	Nominal Voltage/Current	Mode of Operation
Seismometer	12V/200mA	Always
Digital Acquisition System	12V/200mA	Always
GPS Receiver	12V/100mA	Always
Mobile Router	12V/300mA	Hourly

III.II.I Photovoltaic Module

Photovoltaic cell consists of p-n junction diodes that convert solar energy to electrical energy and typically have an efficiency between 6% to 20% [32]. Ambient temperature and irradiance are the significant parameters that affect the outputs of a PV cell, and they are always considered during the design of a solar energy harvesting system. Fig. 4 represents an equivalent circuit of a PV cell and consists of current source I_{PV} connected in parallel to the p-n junction diode. Fig. 5 demonstrates how the cell inputs vary with irradiance and temperature. The circuit and plot define the relationships between current and voltage levels by Kirchoff's law. The generated current at the load, I_L, is based on the circuit, defined by (1) and (2) as well as the curve in Fig. 3 [33]:

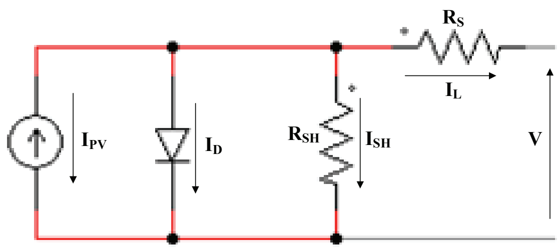

Fig. 4. Equivalent Solar Cell Circuit

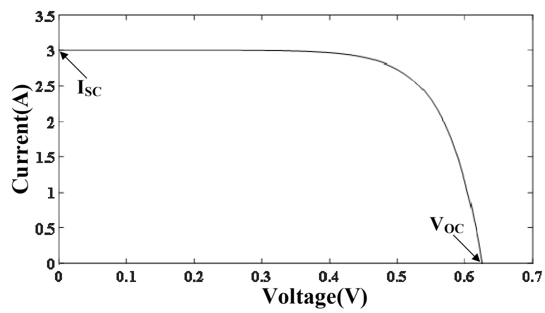

Fig 5. Simulated I-V Relationship of a Solar Cell

$$\mathbf{I_L = I_{PV} - I_D - I_{SH}} \quad (1)$$

$$\mathbf{I = I_{PV} - I_O \left[\exp\left(\frac{V+IR_S}{AV_T}\right) - 1\right] - \frac{V+IR_S}{R_{SH}}} \quad (2)$$

Where;

I_L	=	Generated Current
I_{PV}	=	Photocurrent
I_O	=	Saturation Current of the Diode
V	=	Terminal voltage
R_S	=	Series Resistance
A	=	Ideality Factor of the Diode
V_T	=	Thermal Voltage
R_{SH}	=	Shunt Resistance

III.II.I.I Effects of Ambient Temperature

Applying the model of PV cell in (2)and its equivalent circuit in Fig. 4, graphs of Fig. 6 and Fig. 7 were plotted, demonstrating current, voltage, and power relationships. The graphs describe how temperature levels influence the parameters.

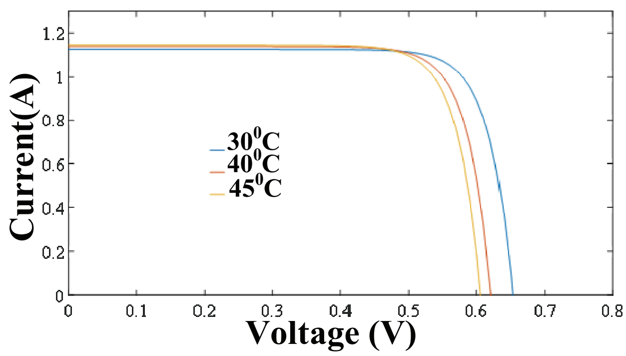

Fig 6. A Plot of I-V Characteristics of varying Ambient Temperature

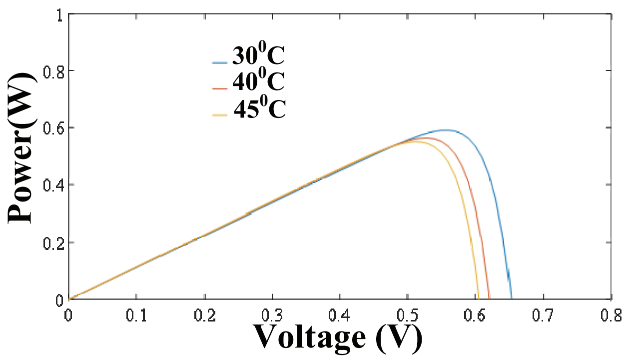

Fig 7. A Plot of P-V Characteristics of varying Ambient Temperature

The open-circuit voltage, V_{OC} being one of the key parameters of a PV cell, is the maximum voltage available for the load when the current flow does not exist, as shown in Fig. 5 earlier. Fig. 7 demonstrates the linear relationship between temperature effects and the V_{OC}, and its highest value was measured at the lowest temperature of 0^0C at 0.56V:

$$V_{OC} = \frac{KT}{q}\ln\left(\frac{I_s}{I_O} + 1\right) \quad at \quad I = 0 \quad (3)$$

The temperature effects on V_{OC} is given by (3), while the recombination of the carriers in the PV cell depends on I_O as well as the irradiance. The thermal voltage, V_T caused inefficiency of the PV cell, and the expression is as shown in (4). The saturated current, I_O is a fraction of the reverse current in the diode, which estimates the characteristics of the diode, as shown in (2). Then (4) equally implies the thermal voltage is directly proportional to temperature T. The behaviours of (2) and (4) indicate the voltage is mostly affected by temperature negatively, and it influences the terminal voltage swiftly:

$$\mathbf{V_T = \frac{KT}{q}} \quad (4)$$

Fig. 5 shows the graphical representation of the short circuit current, I_{SC}, showing the highest value of PV cell current against voltage as zero, assuming the series resistance R_s is neglected in (2) to obtain (5). In Fig. 6, I_{SC} slightly changed when compared to V_{OC} behaviour with temperature variations. The highest measurement was at 0.71196A at a temperature of 60^0C and the lowest at 0.69816 at 0^0C:

$$\mathbf{I_{SC} = I_{PV}} \quad (5)$$

Fig. 7 clearly shows the direct dependence of P_{MAX} on the ambient temperature. It demonstrated the performance of the PV cell measurements from Table III, decreasing from 0.281315W to 0.169977W as the temperature levels increased from 0^0C to 60^0C. Hence, efficiency is directly affected by temperature shown in Fig. 8 to Fig. 10.

Table III. Simulated Measurements of PV cell at fixed Ambient Irradiance

Temperature	I_{MAX}(Amps)	V_{MAX}(Volts)	P_{MAX}(Watts)
0	0.69816	0.56	0.28
10	0.70046	0.53	0.261817
20	0.70276	0.5	0.24346
30	0.70506	0.48	0.224837
40	0.70736	0.45	0.206325
50	0.70966	0.42	0.187845
60	0.71196	0.39	0.169977

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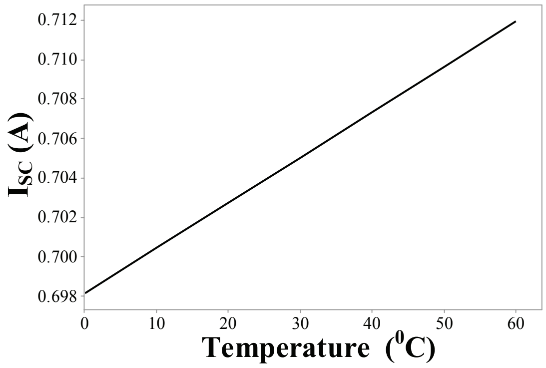

Fig 8. A Plot of Temperature effects on I_{SC} with fixed Ambient Irradiance

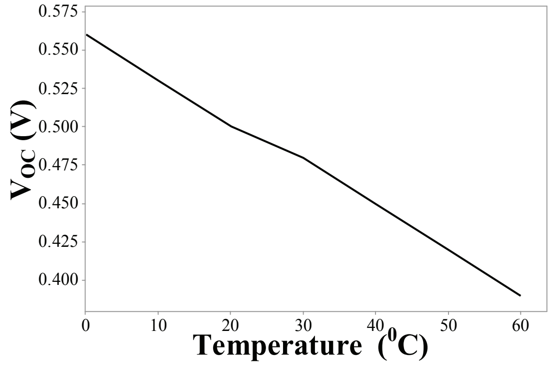

Fig 9. A Plot of Temperature effects on V_{OC} with fixed Ambient Irradiance

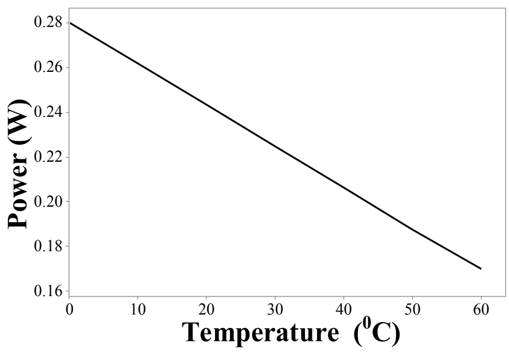

Fig 10. A Plot of Generated Power with varying temperature

III.II.II Thermoelectric Transducer

A thermoelectric transducer converts thermal heat to electrical energy due to the thermal gradient between two junctions, utilizing Seebeck effects [34]. The equivalent circuit of its element is modelled with a voltage source in series with internal resistance R_{TH}, as shown in Fig. 10 [35]. The source voltage, V_{TH} is calculated as open-circuit voltage V_{OC}, which is directly proportional to the thermal gradient, as exhibited in Fig. 11(a) with linear characteristics. The voltage across the terminal of the two junctions is defined as:

$$\mathbf{V_{TH} = \propto_{p-n} \Delta T * \frac{R_O}{R_O+R_{in}}} \quad (6)$$

$$\mathbf{P_O = \left(\frac{\propto_{p-n}\Delta T}{R_O+R_{in}}\right)^2 * R_O} \quad (7)$$

Where;

α_{p-n}	=	Seebeck Coefficient between p-type and n-type materials
R_{TH}	=	Internal Resistance
R_O	=	Load Impedance
ΔT	=	Thermal Gradient between the two junctions
P_O	=	Generated power at the load

Most frequently, modeling of a thermoelectric transducer is performed under constant thermal gradient ΔT [36]. The effects of internal resistance R_{TH} of the transducer are ignored, and it is modelled with a fixed voltage source connected in series to internal resistance and implement (6) and generate power as (7) [35].

Fig. 11(b) and Table IV have simply demonstrated the voltage magnitude being linearly dependent on the thermal gradient and varies with the ambient temperature. Based on the results, the V_{MPP} is almost half of the V_{OC} simply because of the linear characteristics of the plots. The linearity implies tracking MPP will be less tricky than PV cell.

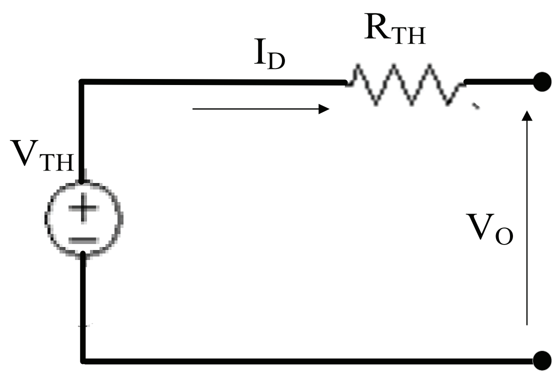

Fig 11(a). Basic Equivalent Circuit of Thermoelectric Transducer

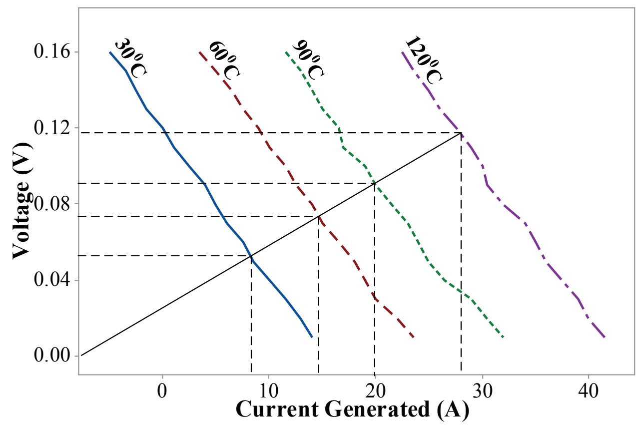

Fig 11(b). A Plot of V-I at varying Thermal Gradient

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Table IV. Performance of the various Thermal Gradient

Thermal Gradient, ΔT	V_{MPP} (V)	P_{MPP} (W)
30^0C	0.05	8
60^0C	0.07	15
90^0C	0.088	20
120^0C	0.118	28

III.II.III Hybrid Energy Transducer

The proposed design intends to use the phenomena of a photovoltaic and thermoelectric system. Their outputs are DC source, and the nominal voltage of a remote seismic node is 12VDC. In the proposed design, since the output voltage of the thermoelectric transducer is low, less than 1VDC, and hardly exceeding 1.5VDC for remote environments [37]. Hybrid circuit of non-inverting Op-Amp adder, as shown in Fig. 12, the output of the PV module is employed to bias the amplifier as the primary energy source, and the thermoelectric module is applied to the non-inverting terminal.

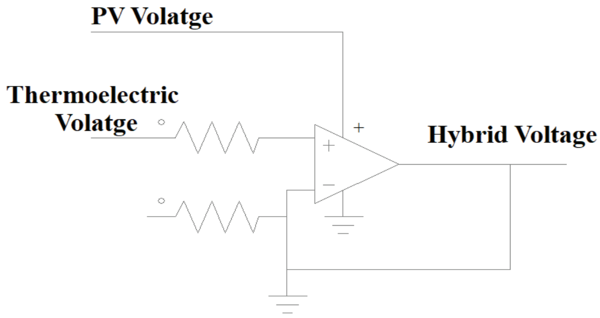

Fig 12. Hybrid Transducer with Inputs from PV and Thermoelectric Modules

The aggregate current levels of PV and thermoelectric modules are expressed in (8) to increase the total current generated [38]. The total power harvested of the two transducers is also expressed in (9) [38] as:

$$\boldsymbol{I_{hybrid} = I_{PV} + I_{TH}} \quad \textbf{(8)}$$

$$\boldsymbol{P_{hybrid} = P_{PV} + P_{TH}} \quad \textbf{(9)}$$

I_{hybrid}	=	Hybrid Current
I_{pv}	=	PV Current
I_{TH}	=	Thermoelectric Current
P_{hybrid}	=	Hybrid Generated Power
P_{pv}	=	PV Generated Power
P_{TH}	=	Thermoelectric Generated Power

III.III.I Buck DC-DC Converter for the Hybrid Energy Harvesting System

Fig 13 shows a buck DC-DC converter that converts the outputs from the PV module to the desired 12VDC across the remote seismic node. It is used to charge the battery and energize the load simultaneously.

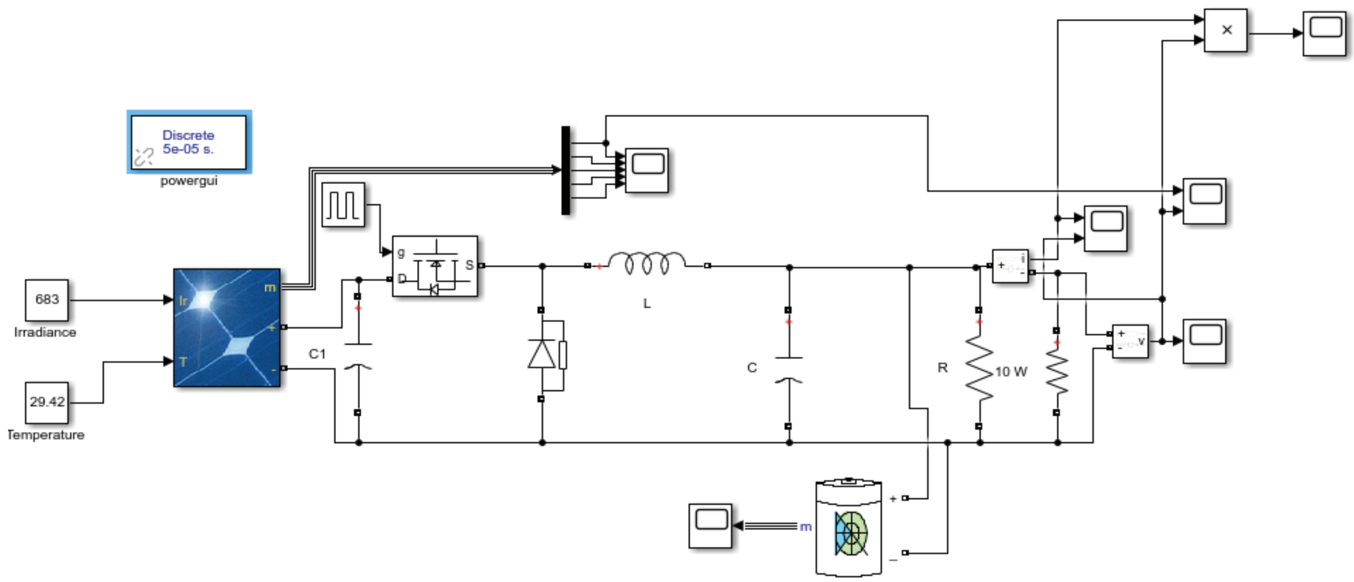

Fig 13. Buck Converter Circuit

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IV. RESULTS AND DISCUSSIONS

Reviewing the related work shows abundant studies of energy harvesting system aimed at improving the efficiency and simultaneously adding more electrical energy at remote modes. In the case study, a 120W solar module is installed, and Fig. 14 represents the typical daily generated power. It employs a linear mode of DC regulation, which delivers inefficient, disproportionate, and expensive to run on a long-term basis.

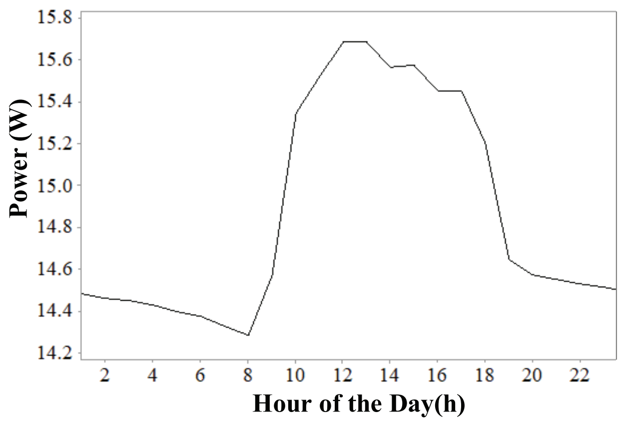

Fig 14. Generated Power by the Case Study with the PV Module

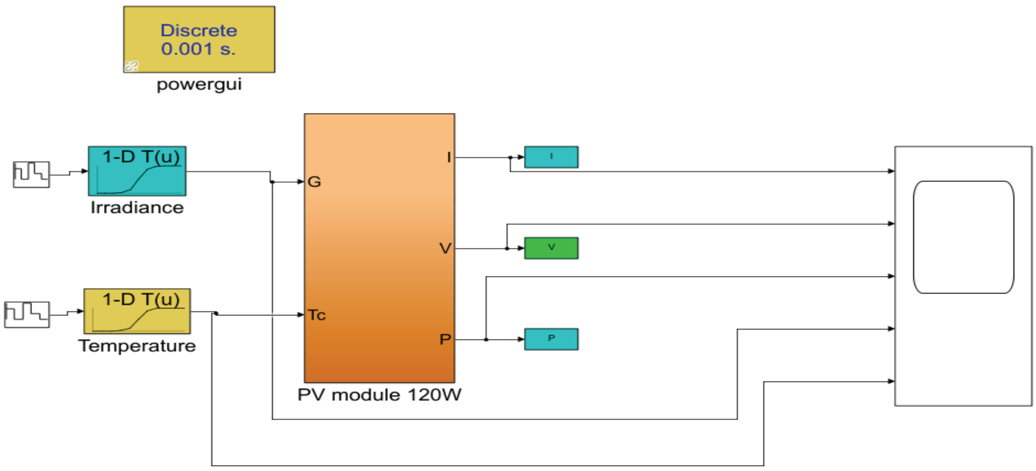

Fig 15. Simulated Circuit of the existing Energy Harvesting System at a Remote Seismic Node

Fig. 15 shows a simulated circuit in Simulink utilizing similar electrical characteristics and ambient irradiance and temperature measurements obtained from a weather station operated by Centre for Atmospheric Research, Anyigba, Nigeria. Fig. 16 demonstrated that relatively higher generated power could be delivered in the case study.

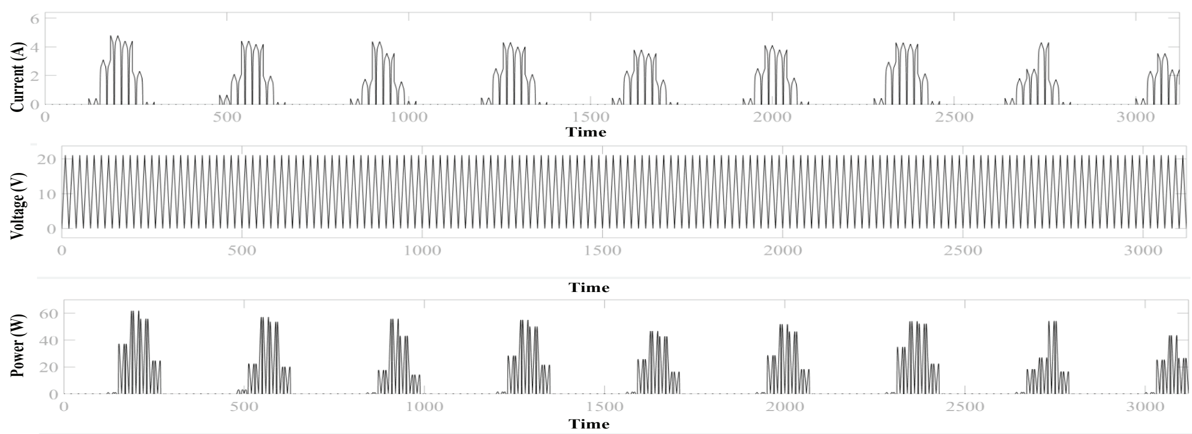

Fig 16. Simulated Current, Voltage, and Power supplied to the node

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For the optimal duty cycles across the DC-DC converter, the neural network model will be interfaced with the converter to predict duty cycles from the corresponding ambient irradiance and temperature levels. Perturb and Observe(P&O) algorithm was used to generate V_{MAX} and duty cycle as the output measurements of historical data. The corresponding ambient irradiance and temperature measurements were used as the inputs measurements. The historical data were trained by a neural network model to predict duty cycles across the buck converter each time a set of irradiance and temperature hit the PV module. This model could predict accurately for both trained and untrained data, and it does require no voltage or current sensors to sense both voltage and current measurements. Meanwhile, Fig. 17 shows the P&O MPPT implemented circuit and to produce the V_{MAX} measurements and the computed duty cycles. Fig. 18 describes the proposed circuit implementing the neural network MPPT in Simulink, and Fig. 19 is the plot showing V_{MAX} measurements of the circuit. The circuit takes 0.00005s to stabilize to deliver the V_{MAX} levels, maximum power of 90W, and efficiency of 75%, with ambient irradiance levels from 0 to 683.6. Fig. 20 and Fig. 21 represent the load voltage and current, respectively. They are relatively stable despite the irregularities of the ambient inputs across the PV module. While the generated power without and with MPPT is shown in Fig. 14 and Fig. 22, respectively, obviously indicating, MPPT optimally track the maximum possible power.

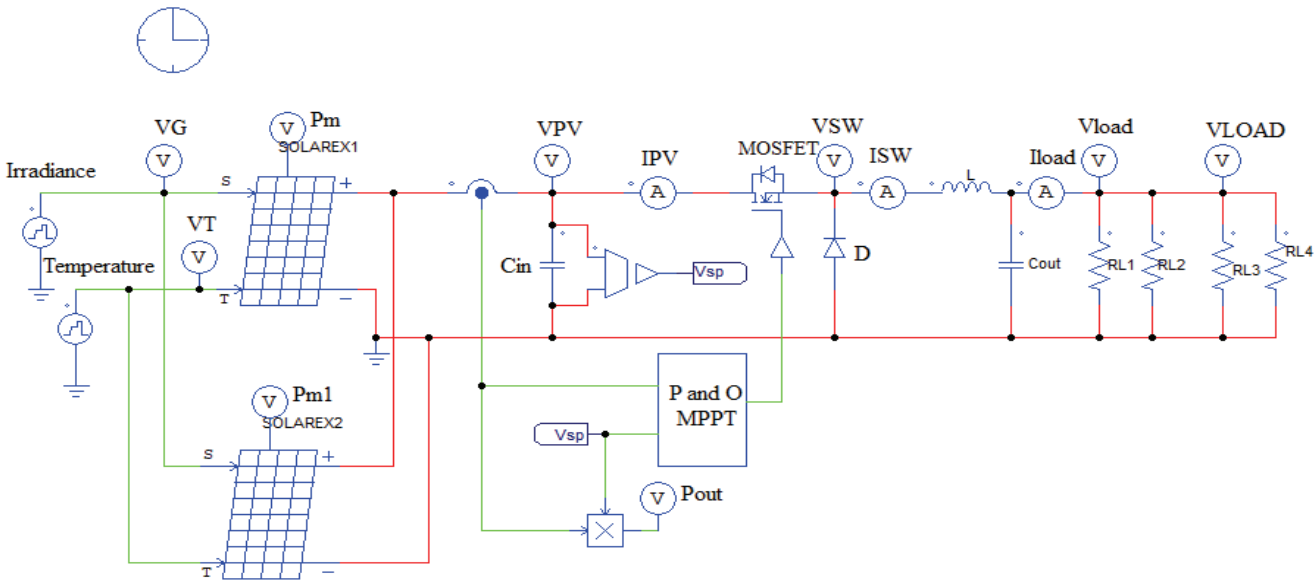

Fig 17. Buck Converter with Perturb and Observe MPPT Algorithm Circuit

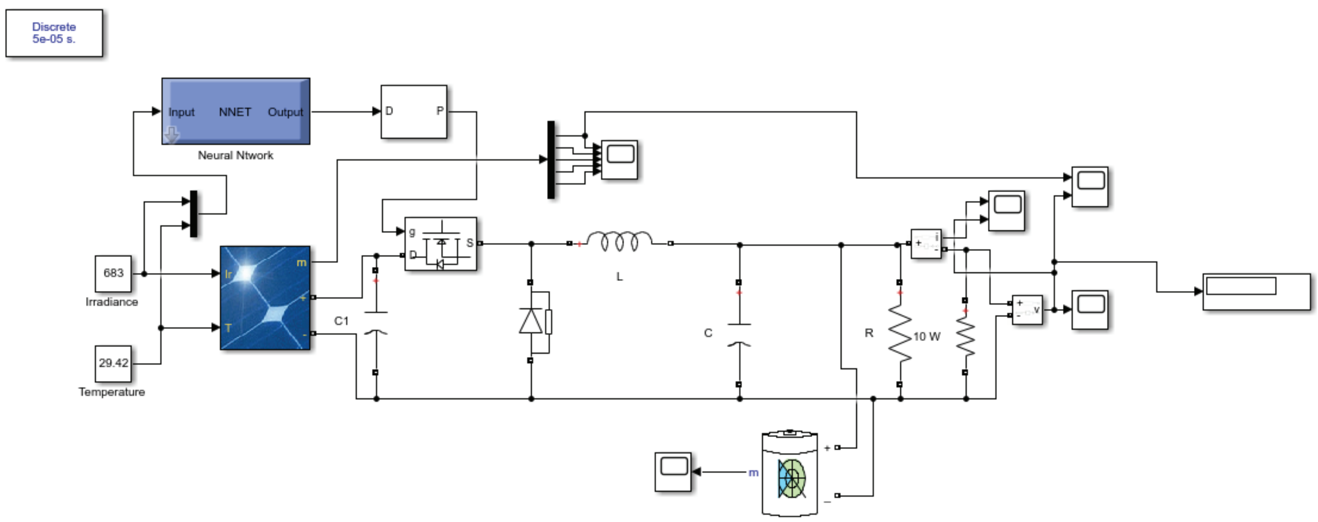

Fig 18. Proposed Circuit for the Remote Seismic Node

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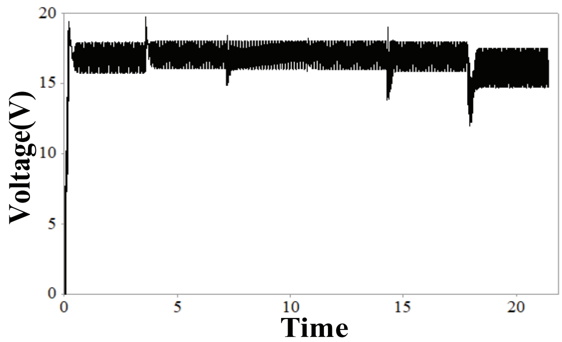

Fig 19. Simulated V_{MAX} Plot by the proposed circuit

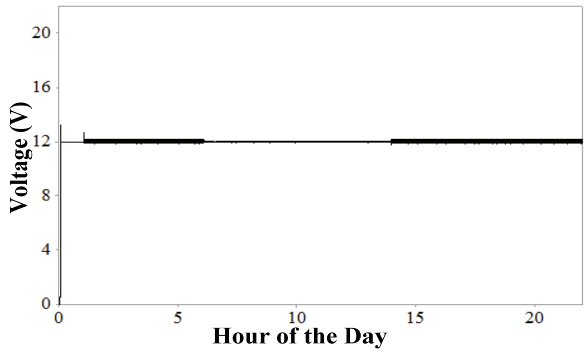

Fig 20. Simulated Load Voltage by the Proposed Circuit

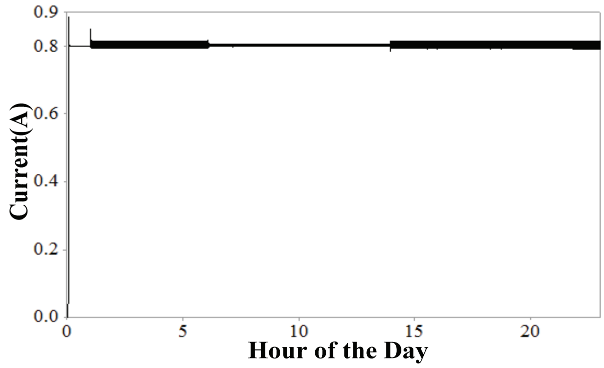

Fig 21. Simulated Load Current by the Proposed Circuit

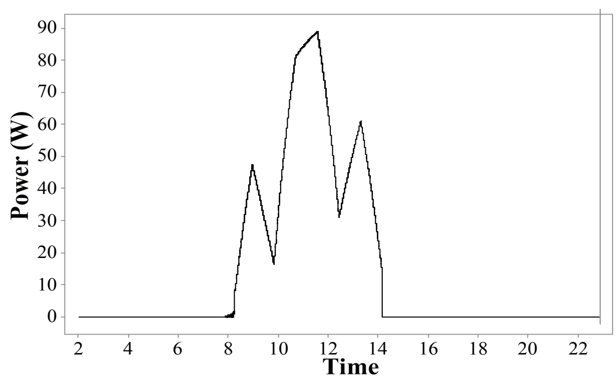

Fig 22. Simulated Generated Power with MPPT Algorithm

V. CONCLUSIONS

The hybrid energy harvesting system based on theoretical studies of the photovoltaic and thermoelectric techniques has been simulated to power remote seismic nodes. The efficiency of 75% was attained with relatively lower ambient irradiance levels. Although the thermoelectric and PV modules have been demonstrated separately but analytically, it is shown that more electrical energy is added when it serves as a compliment, with the PV as the primary source. The PV module measurements at the case study were simulated because it is the primary ambient source, and its output would be used to bias the thermoelectric module. Neural network MPPT and buck converter were executed, and delivered an optimal energy harvesting system. The essence of the study is to develop a simple, sufficient, and affordable energy harvesting system at the remote seismic node for a long-term seismic database without discontinuities.

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REFERENCES

[1] J. J. Andres, C. Soto and J. Verdugo, "Seismic Analysis Without Seismic Data. The relevance of ground observation for seismic interpretation," in *9TH International Symposium on Rockbursts and Seismicity in Mins*, Satiago, 2017.

[2] C. Li, W. Xue-jun, M. Tao, W. Tie-cheng, Y. Li and Y. Wei, "Research on petroleum seismic data resource quality management methods," in *2010 The 2nd Conference on Environmental Science and Information Application Technology*, Wuhan, 2010.

[3] A. M. Siddiqui, M. L. and Q. Ni, "Energy Efficiency Optimization with Energy Harvesting using Harvest-Use Approach," in *2015 IEEE International Conference on Communication Workshop (ICCW)*, London, 2015.

[4] M. Ashraf and N. Masoumi, "High efficiency boost converter with variable output voltage using aself-reference comparator,"," *International Journal of Electronics and Communications,* vol. 68, no. 2014, pp. 1058-1064, 2014.

[5] C. Lu, V. Raghunathan and K. Roy, "Micro-Scale Energy Harvesting," in *Circuits And Systems.*.

[6] L. C. Chuan, H. Wahid, H. A. Rahim and R. A. Rahim, "A Review of Thermoelectric Energy Harvester and Its Power Management Approach," *Electronic Applications,* vol. 73, no. 2015, 2015.

[7] J. Jessen, M. Venzke and V. Turau, "Design Considerations for a Universal Smart Energy Module for Energy Harvesting in Wireless Sensor Networks," in *Ninth International Workshop on Intelligent Solutions in Embedded Systems* , Regensburg, 2011.

[8] A. Leoni, I. Ulisse, L. Pantoli, V. Errico, M. Ricci, G. Orengo, F. Giannini and G. Saggio, "Energy harvesting optimization for built-in power replacement of electronic multisensory architecture," *International Journal of Electronics and Communications,* vol. 107, no. 2019, pp. 170-179, 2019.

[9] J. Havskov, L. Ottemoller, A. Trnkoczy and P. Bormann, Seismic Networks, GFZ.NMSOP, 2011.

[10] A. P. Chandrakasan, S. Sheng and R. W. Brodersen, "Low-Power CMOS Digital Design," *IEEE Journal of Solid-State Circuits,* vol. 27, no. 4, pp. 473 - 484, 1992.

[11] A. Chandrakasan, R. Amirtharajah, J. Goodman and W. Rabiner, "Trends in Low Power Digital Signal Processing," in *IEEE International Symposium on Circuits and Systems (ISCAS)*, Monterey, 1998.

[12] A. Montecucco and A. R. Knox, "Maximum Power Point Tracking Converter Based on the Open-Circuit Voltage Method for Thermoelectric Generators," *IEEE Transactions on Power Electronics,* vol. 30, no. 2, pp. 828 - 839, 2015.

[13] J. S. Kumari and C. S. Bab, "Comparison of Maximum Power Point Tracking Algorithms for Photovoltaic System," *International Journal of Advances in Engineering & Technology, Nov 2011,* vol. 1, no. 5, pp. 133-148, 2011.

[14] K. Suzuki and M. Deng, "Operator-based MPPT control system for thermoelectric generation by measuring theopen-circuit voltage," in *Proceedings of the 2016 International Conference on Advanced Mechatronic Systems*, Melbourne, 2016.

[15] Q. Brogan and D. S. Ha, "A Single Stage Boost Converter for Body Heat Energy Harvesting with Maximum Power Point Tracking and Output Voltage Regulation," in *IEEE International Symposium on Circuits and Systems (ISCAS)*, Sapporo,, 2019.

[16] Z. M. Zakariya M. Dalala, "Energy Harvesting Using Thermoelectric Generators," in *2016 IEEE International Energy Conference (ENERGYCON)*, Leuven, 2016.

[17] A. Andrea Montecucco, J. Siviterand and A. R. Knox, "Simple, Fast and Accurate Maximum Power Point Tracking Converter for Thermoelectric Generators," in *IEEE Energy Conversion Congress and Exposition (ECCE)*, Raleigh, 2012.

[18] K. Keita Taeda, N. Shiina, K. k. and H. Koizumi, "A Thermoelectric Energy Harvesting System with Bridgeless Boost/Buck-Boost Rectifier," in *IECON 2017 - 43rd Annual Conference of the IEEE Industrial Electronics Society*, Beijing,, 2017.

[19] H. Zontag, "Commercially available PVT products," Internet Publication, 2006.

[20] Y. Tripanagnostopoulos, "Aspects and improvements of Hybrid Photovoltaic/Thermal Solar Energy Systems," *Solar Energy ,* vol. 81, no. 2006, p. 1117–1131, 2007.

[21] H. Zontag, "Flat-plate PV-thermal Collectors and Systems: a Review.," *Renew. Sust. Energy Rev. 12, ,* vol. 12, no. 2008, p. 891–959, 2008.

[22] Y. Nishijma, R. Komatsu, ,. T. Yamamura, A. Balcytis, G. Seniutinas and S. Juodkazis, "Design concept of a hybrid photovoltaic/thermal conversion cell for mid-infrared light energy harvester," *Optical Materials Express,* vol. 7, no. 10, 2017.

[23] S. P. Thennarasu, V. Vasanthakumar, R. N. Vasanthakumar, G. Vijay and M. Manimaran, "Increasing the Efficiency of the Solar Panel Using Thermoelectric ModuleLE," *International Journal of Advance Research and Innovative Ideas in Education,* vol. 4, no. 2, 2018.

[24] G. Sherkar and A. Akkewar, "To Analysis and Improvement of System Efficiency by Using Thermoelectric Device," *International Journal of Research in Advent Technology (E-ISSN: 2321-9637) Special Issue,* vol. 2015, no. 2321-9637, 2015.

[25] S. S. Ahadi, H. R. Hoseini and R. Faez, "Using of Thermoelectric Devices in Photovoltaic Cells in order to increase Efficiency," *Indian Journal of Scientific Research,* vol. 2, no. 1, pp. 20-26, 2014.

[26] K. Kalpana, V. Muthumeena, S. Farhana and M. Sriranjan, "Thermoelectric Generator and PV Panel Integrated HybridEnergy Harvesting System," *International Journal for Modern Trends in Science and Technology,* Vols. 173-177, no. 05, p. 05, 2017.

[27] I. Doms, P. Merken, P. Van, C. Hoof and K. U. Leuven, "Comparison of DC-DC-converter Architectures of Power Management Circuits for Thermoelectric Generators," in *IEEE 2007 European Conference on Power Electronics and Applications*, Aalborg, 2007.

[28] M. Abdulfattah, A. Mohledin, A. Emira and E. Sanchez-Sinencio, "A low-voltage charge pump for micro scale thermal energy harvesting," in *2011 IEEE International Symposium on Industrial Electronics*, Gdansk, 2011.

[29] S. I. Kaka, "Seismic noise study for a new seismic station," *Advances in Geosciences,* vol. 34, no. 2013, pp. 29-32, 2013.

[30] C. MacLennan, "Solar PV & Solar Therma," AES Ltd, Kincraig, 2012.

[31] P. Dziurdzia, "Modeling and Simulation of Thermoelectric Energy Harvesting Processes," in *Sustainable Energy Harvesting Technologies – Past, Present and Future*, pp. 109-128.

[32] B. V. Chikate and Y. A. Sadawarte, "The Factors Affecting the Performance of Solar Cell," *International*

Journal of Computer Applications, vol. 2015, no. 2015, pp. 1-5, 2015.

[33] S. Pindado and J. Cubas, "Simple mathematical approach to solar cell/panel behavior based on datasheet information," *Renewable Energy,* vol. 103, no. 2017, pp. 729-739, 2017.

[34] A. Montecucco and A. Knox, "Maximum Power Point Tracking Converter Based on the Open-Circuit Voltage Method for Thermoelectric Generators," *IEEE TRANSACTIONS ON POWER ELECTRONICS,* vol. 30, no. 2, pp. 828-839, 2015.

[35] S. Siouane, S. Jovanovi and P. Poure, "Equivalent Electrical Circuits of Thermoelectric Generators under Different Operating Conditions," *MDPI Energies,* Vols. 10, , no. 386, pp. 1-15, 2017.

[36] K. Yazawa and A. Shakouri, "Cost-efficiency trade-off and the design of thermoelectric power generators," *Environmental Science and Technology,* vol. 45, no. 17, p. 7548–7553, 2011.

[37] C. Knight and J. Davidson, "Thermoelectric Energy Harvesting as a Wireless Sensor Node Power Source," Commonwealth Scientific and Industrial Research Organisation, Newcastle.

[38] Y. K. Tan and S. K. Panda, "Energy Harvesting From Hybrid Indoor Ambient Light and Thermal Energy Sources for Enhanced Performance of Wireless Sensor Nodes," *IEEE Transactions on Industrial Electronics,* vol. 9, no. 1, p. 58, 2011.