River Publishers Series in Energy Sustainability and Efficiency

RECENT ADVANCES IN ENERGY HARVESTING TECHNOLOGIES

Editors:

Shailendra Rajput
Abhishek Sharma
Vibhu Jately
Mangey Ram

River Publishers

Recent Advances in Energy Harvesting Technologies

RIVER PUBLISHERS SERIES IN ENERGY SUSTAINABILITY AND EFFICIENCY

Series Editors:

PEDRAM ASEF
Lecturer (Asst. Prof.) in Automotive Engineering, University of Hertfordshire, UK

The "River Publishers Series in Sustainability and Efficiency" is a series of comprehensive academic and professional books which focus on theory and applications in sustainable and efficient energy solutions. The books serve as a multi-disciplinary resource linking sustainable energy and society, fulfilling the rapidly growing worldwide interest in energy solutions. All fields of possible sustainable energy solutions and applications are addressed, not only from a technical point of view, but also from economic, social, political, and financial aspects. Books published in the series include research monographs, edited volumes, handbooks and textbooks. They provide professionals, researchers, educators, and advanced students in the field with an invaluable insight into the latest research and developments.

Topics covered in the series include, but are not limited to:

- Sustainable energy development and management;
- Alternate and renewable energies;
- Energy conservation;
- Energy efficiency;
- Carbon reduction;
- Environment.

For a list of other books in this series, visit www.riverpublishers.com

Recent Advances in Energy Harvesting Technologies

Editors

Shailendra Rajput
Xi'an International University, China

Abhishek Sharma
Graphic Era University, India

Vibhu Jately
University of Petroleum and Energy Studies, India

Mangey Ram
Graphic Era University, India

River Publishers

Routledge
Taylor & Francis Group
NEW YORK AND LONDON

Published 2023 by River Publishers
River Publishers
Alsbjergvej 10, 9260 Gistrup, Denmark
www.riverpublishers.com

Distributed exclusively by Routledge
605 Third Avenue, New York, NY 10017, USA
4 Park Square, Milton Park, Abingdon, Oxon OX14 4RN

Recent Advances in Energy Harvesting Technologies / by Shailendra Rajput, Abhishek Sharma, Vibhu Jately, Mangey Ram.

Routledge is an imprint of the Taylor & Francis Group, an informa business

ISBN 978-87-7022-845-9 (print)
ISBN 978-87-7022-993-7 (paperback)
ISBN 978-10-0096-283-3 (online)
ISBN 978-1-003-44038-3 (ebook master)

Contents

Preface

The growing need for energy by the human race calls for the search for sustainable resources to ensure energy security. Once the resources are identified, the effort has to be directed to harvest as much energy from these as is technologically feasible and economically viable.

Harvesting energy can be broadly divided into two levels: at the macro level and at the micro level. Technologies for harvesting energy would also need to be grouped into two corresponding groups. In the first group at the macro level, the focus primarily is on meeting the gross energy requirements of a region, state or country from the considerations of energy security as well as sustainability. Reduction of carbon emissions remains an important factor too while deciding the resources to be harvested and the technology used in the harvesting of energy. Extracting maximum power from solar, wind etc falls in this category. So do all technologies that assist in maintaining the grid stable and secure. All major energy storage devices and systems with their associated techniques fall into this group too. In fact, technologies for sustainable agriculture including irrigation and hydrological studies also fall into this category.

The second group at the micro level has a wide arrange of technologies that can help us in harvesting small amounts of energy through miniature, wearable and portable energy sensing elements like piezoelectric nano-generators (PENG), triboelectric nano-generators (TENG), nano-composite electrical generators (NEG), thermoelectric generator (TEG), etc. These mini harvesters can be used for harvesting the small amounts of energy associated with human movement, like walking, stepping, dancing, etc., that can be useful for self-powering small smart devices. The flexible and transparent harvesters made of nanocomposites can help in supplementing the battery life if not able to replace the battery altogether. Some polymer nanocomposites have shown promise for building thermoelectric coolers that can be used for transporting vaccines and serums. Because of the diffused form of small amounts of these harvesters, the role of AI and machine learning techniques can be handy in making the systems scalable and economically viable.

Inspiration for compiling this book basically came from the need felt by the editors to have in a single volume, the *Recent Advances in Energy Harvesting Technologies*. We are confident that this volume containing contributions from authors on energy harvesting technologies at the macro level in Chapters 2, 3, 4, 7 and 9 and at the technologies at the micro level in the remaining chapters will be found interesting and of value by the readers.

Editors:

Shailendra Rajput
Xi'an International University, China

Abhishek Sharma
Graphic Era University, India

Vibhu Jately
University of Petroleum and Energy Studies, India

Mangey Ram
Graphic Era University, India

Acknowledgement

The editor acknowledges River publishers for this opportunity and professional support. My special thanks to Ms Philippa Jefferies, River publishers for the excellent support, she provided us to complete this book.

Thanks to the chapter authors and reviewers for their availability for this work.

List of Figures

List of Tables

List of Contributors

Ashok, Prashasti, *Department of Geology, Institute of Earth Sciences, India*

Azzopardi, Brian, *MCAST Energy Research Group (MCAST Energy), Institute of Engineering and Transport, Malta College of Arts, Science and Technology (MCAST), Malta*

Bisht, Neeraj, *Department of Mechanical Engineering, College of Technology, GBPUAT, India*

Chauhan, Sakshi, *Department of Mechanical Engineering, College of Technology, GBPUAT, India*

Chinthamalla, Ramulu, *EE Department, National Institute of Technology, India*

Dutt, Sunil, *Department of Chemistry, Government Post Graduate College, India*

Gopikishan Sabavath, *Faculty of Science, Department of Physics, University of Allahabad, India*

Gorfad, Vijaykumar, *Department of Aerospace Engineering, MIT School of Engineering, MIT ADT University, India*

Hong Lim, Wei, *Faculty of Engineering, Technology and Built Environment, UCSI University, Malaysia*

Hu, Xinghao, *Institute of Intelligent Flexible Mechatronics, Jiangsu University, China*

Jadhav, Vishwanath, *Department of R&D (NPD), Deep Plast Industries, India*

Jately, Vibhu, *Department of Electrical and Electronics Engineering, University of Petroleum and Energy Studies, India*

Joshi, Jyoti, *Department of Computer Science and Engineering, Graphic Era Hill University, India*

Krishna Mathi, Dileep, *EEE Department, Vidya Jyothi Institute of Technology, India*

Kumar Bajaj, Dinesh, *MIT-ADT University, India*

Kumar Srivastava, Ankit, *Department of Physics, Indrashil University, India*

Kumar Verma, Sushil, *Department of Chemical Engineering, Indian Institute of Technology Guwahati, India*

Pal Singh, Surendra, *Surveying Engineering Department, Wollega University, Ethiopia*

Sahoo, Devabrata, *Department of Aerospace Engineering, MIT School of Engineering, MIT ADT University, India*

Saxena, Swati, *Department of Physics, Sardar Vallabhbhai National Institute of Technology, India*

Sharma, Abhishek, *Department of Computer Science and Engineering, Graphic Era Deemed to be University, Dehradun, India*

Siddharth, Pandi, *MIT-ADT University, India*

Sonika, *Department of Physics, Rajiv Gandhi University, Doimukh, Itanagar, India*

Tashale Amanu, **Marga,** *Surveying Engineering Department, Wollega University, Ethiopia*

List of Abbreviations

ABC	Artificial bee colony
AI	Artificial intelligence
ANN	artificial neural network
AR	Augmented reality
CANN	cluster-ANN
CGSVM	Coarse-Gaussian support vector machine
CNN	Convolution Neural Network
CNTs	Carbon nanotubes
ELM	Extreme learning machine
EU	European Union
EVs	Electric vehicles
FOA	Firefly optimization algorithm
GMPP	Global MPP
GP	Global peak
HBB-BC	Hybrid big bang-big crunch
IGSA	Improved version of the gravitational search algorithm
ILC	Iterative learning controller
INC	Incremental conductance
IoT	Internet of Things
I–V	Current versus voltage
ML	Machine learning
MLR	Multiple linear regression
MPP	Maximum power point
MPPT	Maximum power point tracking
P&O	Perturb and observe
P-ANN	Periodic-ANN
PSC	Partial shading conditions
PV	Photovoltaic
P−V	Power versus voltage
RNN	Recurrent neural network
SAE	Stacked auto-encoder

SI	Swarm intelligence
SOA	Seeker optimization algorithm
SVM	Support vector machine
T-ANN	Threshold-ANN
UI	User interface
UIC	Uniform irradiance conditions
VR	Virtual reality

1

AI in Energy Harvesting

Vijaykumar Gorfad[1], Devabrata Sahoo[1], and Xinghao Hu[2]

[1]Department of Aerospace Engineering, MIT School of Engineering, MIT ADT University, India
[2]Institute of Intelligent Flexible Mechatronics, Jiangsu University, China
E-mail: gorfadvijay@gmail.com; devabrata.sahoo@mituniversity.edu.in; huxh@ujs.edu.cn

Abstract

Humankind consumes different forms of energy for life and growth. Electric energy is one of them. Demand for electric energy keeps growing as the application area of electric energy keeps increasing day by day. To meet this huge demand and to save natural recourses, there is research going on to generate electrical energy from renewable energy resources like solar energy, wind energy, etc. Energy harvesting technology is an emerging area that gives the opportunity to increase the efficiency of reusable energy generation by using recent technology like artificial intelligence, machine learning, the Internet of Things, etc. The dissipated energies like electromagnetic waves, heat energy and vibrations are converted to electric energy. Artificial intelligence can be deployed along with different sensors like piezoelectric sensors for energy harvesting. This harvested energy can effectively be useful in different sectors like automobiles, domestic and industrial applications, etc. This book chapter summarizes the characteristics of energy harvesting with the help of AI/ML, recent developments in this area and major challenges, along with the future scope of development. Application of existing artificial intelligence technology in the field of energy harvesting is explained and the possible use of existing state-of-the-art AI/ML technologies for prediction and increase the efficiency of energy harvesting technology is also suggested in the present book chapter.

Keywords: Energy Harvesting; AI/ML; Piezoelectric Energy Harvester; Electro-magnetic Energy Harvester; Triboelectric energy harvester (TENG).

1.1 Introduction

There is unlimited energy available in nature surrounding us. A small amount of this energy can be harvested and used as electrical energy. This energy harvested from nature plays important role in achieving sustainable development goals. Nowadays, with the increasing use of technology, the requirement for energy is further increasing. To fulfil these energy requirements, effective implementation of energy harvesting became the need of the day. Energy harvesting is mainly dealing with photovoltaics in the visible light range. The process of energy harvesting can be classified mainly into four processes: energy harvesting from the environment, conversion of this energy into electric energy, power conservation and power management. Figure 1.1 shows this process in detail.

Solar cells are one of the most widely used technologies for energy harvesting for a long time. Apart from sunlight, researchers are also focusing on the stable output from indoor light whose spectrum is spread in the narrow bend of the visible light. There are different types of solar cells used for energy harvesting, there is a need to have a standard process to evaluate energy harvesting characteristics of the solar cells to implement those technologies in society and carry out more research and development activities on energy harvesting.

Solar power technology is described in various research articles and in high-level review papers by a number of researchers. This chapter is mainly focused on three techniques for collecting vibration, radio waves and thermoelectric energy. The parameters mainly needed for power harvesting devices applied to Internet of Things instruments are tiny and high-performance. Also, environmental resistance and functional dependability requirements depend on the application environment, execution type and economical involvement. As depicted in Figure 1.1, the energy harvesting technology is assumed to be applied to IoT fields such as clearing the information and transmission of sensor data and excludes geothermal, wave and wind power generation as well as large-scale environmental energy harvesters.

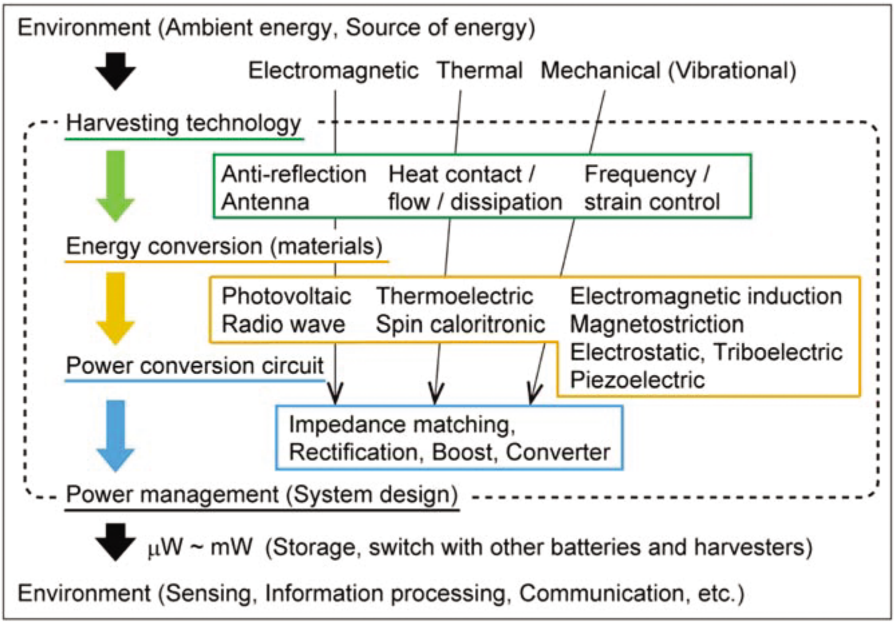


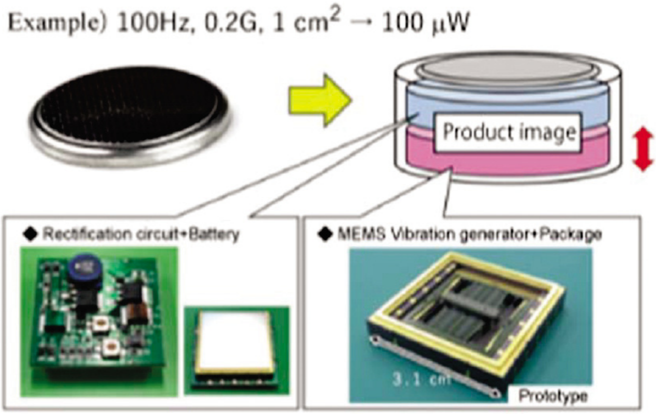
Figure 1.1 Energy harvesting process [1].

1.2 Energy from Mechanical Vibrations

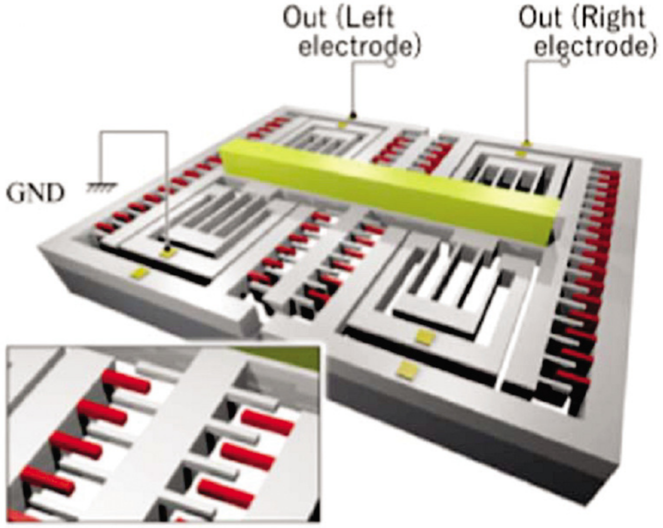
Mechanical vibrations can be used as a source of energy to be harvested. The vibration energy harvester senses the mechanical vibration in the surroundings and converts this vibration energy into electrical energy which can be used for remote or wireless applications. As this energy is of low level it can be used for electronic devices such as sensors whose energy requirement is low specifically in terms of mW. Vibrational energy can be harvested using the following three methods:

1. electromagnetic,
2. electrostatic and
3. piezoelectric.

In the **electromagnetic method** of vibrational energy harvesting, electromagnetic induction and inverse magnetostrictive effects are used. In this method, permanent magnets are used to apply the bias magnetic field to control the magnetisation state of the magnetostrictive material. Afterward, the variation in magnetic flux is achieved by using a strain. This variable magnetic flux is converted into electric energy with the help of coils. Electret



(a) Button cell-type MEMS vibrational energy collector.



(b) Button cell-type MEMS vibrational generator and package.

Figure 1.2 MEMS vibrational energy harvester of button cell type [1].

vibrational energy harvesting with the help of MEMS and triboelectric energy harvesting comes under the **electrostatic method** of vibrational energy harvesting. In this method, the electric energy is generated with the help of fluctuating electrostatic capacitance. The fluctuations in the electrostatic capacitance are produced with the help of the vibrations of the electrode of a capacitor. Piezoelectric energy is generated when piezoelectric materials come in contact with the vibrations. When mechanical stress or strain is applied to the dielectric surface charge produced, this effect is known as the piezoelectric effect. The **piezoelectric method** uses this phenomenon to harvest energy from the vibrations. The performance of all three methods depends on the type of vibrations and the frequencies of the vibrations. These harvesters can work for the vibration of up to 200 Hz. If we take the example of vibrations of the human body or some of the infrastructures such as buildings or bridges, the frequency of these vibrations is approximately 2–3 Hz with an acceleration of approximately 10 m/s^2. Also, the vibration in the real condition is random in nature so as does the frequency and the accelerations. The performance of these energy harvesters is mainly depended upon the characteristics of these harvesters, such as output power, impedance and frequency response. The designs of the vibrational energy harvesters are, therefore mainly focused on impedance matching and energy conversion rate by avoiding the resonant conditions. Current research is focused on the development of harvesters to efficiently generate electric energy from MEMS which are being used for smaller vibrations such as with an acceleration of 0.98 m/s^2 and frequency of less than 100 Hz with the help of MEMS. Figure 1.2 shows a schematic diagram of a button cell-type MEMS vibrational energy collector. When the electret of one of the opposing comb electrode pairs is charged, the current is produced by electrostatic induction which produces vibrations in the electrodes. The comb electrodes make the device bulkier as the effective area is increased due to its structure. To overcome these problems, the use of advanced MEMS is essential at this point of time. CMOS integrated circuits are used to make voltage booster rectifiers which can give an output voltage of approximately 3.3 V. This low output of the rectifier helps to increase the frequency band by approximately 10 times in comparison to p-n rectifiers.

1.3 Fundamentals of Vibrational Energy Harvesting

The vibration energy harvesting system works on the basis of a seismic mass's resonance operation which electromechanically converts kinetic energy into electric energy. Only in a limited natural frequency bandwidth of the resonant frequency machine can the vibration energy harvester operate effectively. The resonance mechanism is an essential component of any vibration energy harvesting mechanism. The seismic mass oscillations within the mechanism get converted according to the physical principle of electromechanical transformation. Vibration energy harvesting system typically employs piezoelectric, electrostatic, or electro-magnetic conversion principles. Several techniques, such as spring non-linearity, can be used to extend the operating frequency's narrow bandwidth. Another critical parameter of the vibration energy harvester is the quality factor of the resonance mechanism. In resonant mode, the maximum amplitude of the relative motion of the resonant mechanism is estimated by the quality factor, which determines the collected power. The electromagnetic vibration energy converter explained here is having a magnetic circuit and a fixed air coil.

Figure 1.3 depicts the energy harvesting system developed by Hadas and his team. When this system is excited by vibration, the resonance mechanism's design causes vibrations in the magnetic circuit which is having a permanent magnet around the fixed coil. The oscillatory movement of the magnetic field induces a voltage in the coil due to Faraday's law. The use of harvested power in an electrical load results in energy dissipation. This means that an electrical load connected to the circuit will produce an electric current. According to Faraday's law, the oscillating motion of a magnetic field induces a voltage in the coil. Consumption of power collected from electrical loads causes energy loss. This means that the connected electrical load provides a current to the electrical circuit, producing feedback proportional to the electrical energy collected in the resonant circuit. The vibration energy rapidly decreases as the electric energy is harvested and with this, the amplitude of the vibration also reduces in the resonance circuit. This results in an induced voltage that is much lower than that of an open electrical circuit.

Vibration energy harvesting systems produce maximum power at the time of equivalent mechanical and electrical damping. This phenomenon is popular and has been inferred in several instances (Williams and Yates

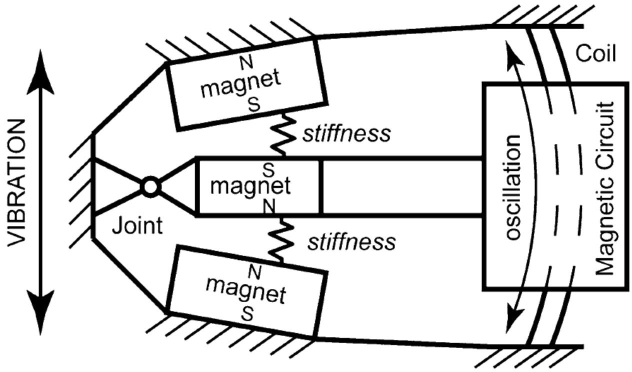


Figure 1.3 Springless electromagnetic vibration energy harvester [2].

1996; Hadas et al. 2010a). This fact must be taken into account whenever a vibrational energy harvesting model is developed, after which an optimal vibrational energy harvesting system is developed. Though the system can be again optimised to minimise volume and weight, or it can be optimised for maximum power output. The main factors of these studies are the quality factors and mass of the resonant mechanism, the geometry, the parameters of the electromagnetic transducer, the electrical load, the materials and technology used, etc. Hadas et al developed the vibration energy harvester under the European project WISE, which was again modified to maximise vibration sensitivity and the efficiency of the system in terms of power output. This device works on the electromagnetic principle of conversion of mechanical to electrical energy. This system converts electromagnetic energy into electric energy [2]. Optimisation is carried out for maximum power output and to minimise the volume and weight of the device. Artificial intelligence methods can be used to optimise the parameters of the harvester device. The authors applied AI techniques to optimise the mechanical, electrical and electromagnetic permeates of the harvester device.

1.4 Piezoelectric and Triboelectric Nanogenerators

Piezoelectric nanogenerators (PENG) and triboelectric nanogenerators (TENG) are energy harvesting technologies that harvest energy from environments using piezoelectric and triboelectric effects, respectively. In the last 10 years, both of these technologies are growing rapidly and they have reignited the interest among researchers towards green energy and energy harvesting. At a time of the considerable power shortage and remarkable ecological downturn caused by conventional fossil fuel consumption, it becomes important to restructure the energy generation system from an unreproducible conventional energy generation method to ecologically sound reproducible energy harvesting technologies such as PENG and TENG. PENG and TENG are to outperform traditional power solutions because of their efficiency, potential for producing power from different natural scenarios like body movements, fluctuating temperatures, structural oscillations, etc., and out-of-the-box electromechanical characteristics.

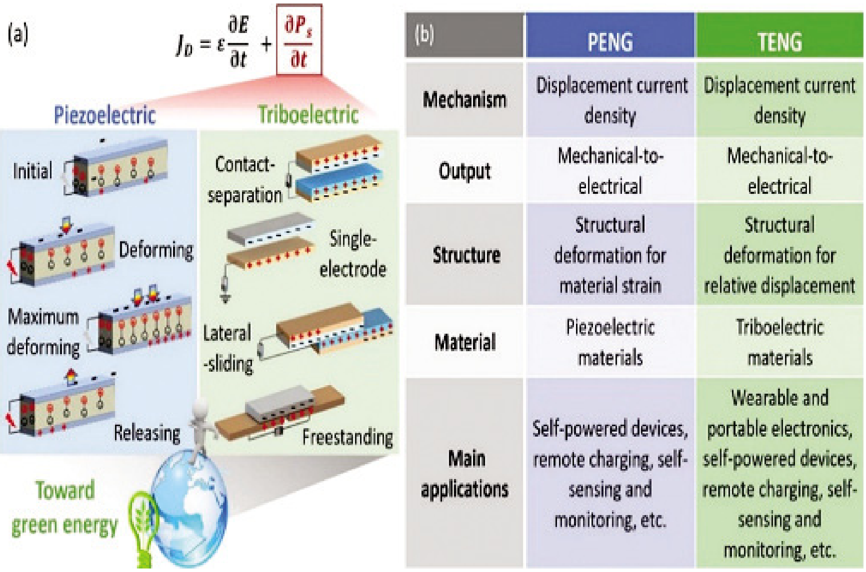
Because of the characteristics of piezoelectric and triboelectric materials, the structural and material elements play an important role in these energy harvesting technologies; so it is important to logically design the structure and artificial materials for getting the improved electrical properties that are generally absent in the conventional structures or conventional materials. As a result, a new research focus has been shifted to the design, characterisation and use of PENGs and TENGs to get the desired electrical performance which results in a wide interdisciplinary research area that includes power, electricity, structural analysis, materials science and multi-scale commerce, manufacturing and multi-functional applications. Energy harvesting devices are reported for use in a variety of usage apart from energy harvesting that includes new equipment and methods in engineering and biomedical fields. Due to the exponential growth of the recent information era, efficient power supplies and a wide range of energy solutions are urgently needed to charge different advanced commercial and information technologies like smart sensors and monitors, recognition and computing in high-tech cities. However, these energy harvesters are currently struggling to provide clean energy solutions in a more portable, dependable and eco-friendly way. As a result, research efforts have emerged to design, predict as well as optimise the performance of these devices using artificial intelligence (AI). AI, an intelligent machine that tries to imitate human perception, has been widely used as a supportive model for solving difficult engineering problems which conventional approaches cannot solve. Artificial intelligence has received considerable attention in the present time because of the inefficiency of conventional models developed using the first principles of physics. AI technologies improve computers' ability to solve problems by copying complicated bioactivities like learning, rational thinking and auto-correction. Early attempts identified artificial intelligence and its derivatives as an effective approach to solving the problems of designing, predicting and optimising structures and materials in energy harvesting techniques. Unlike conventional statistical methods, AI methods can capture precise operational relationships between input parameters like environmental conditions and exogenous variables like electrical energy in absence of prior assumptions of any relationships. The benefits of AI over conventional methods in PENG and TENG are primarily due to the characteristics that promote computational efficiency in designing new structures and discovering materials. Using AI to mine, process and analyse data has improved the precision and effectiveness of the modified structural design and piezoelectric and triboelectric material research in energy harvesting devices. As a result, the present model for deploying AI in harvesting devices has emerged. Although AIPENG and AITEN offer advanced mechanical and electrical performance, an overview of bright topics has not yet been explored.

1.5 Electro-mechanical Energy Harvesting

Mechanical to electrical energy harvesting is designed to produce the electricity from the environment in an eco-friendly, inexpensive, reproducible, dependable and greener way. In addition to the popular electromagnetic generators, various techniques have been designed to collect all sorts of energy like solar, nuclear, thermal, chemical, magnetic, etc. Mechanical energy is usually wasted due to its low amplitude, low frequency, low energy density and diffusion form. As a new green energy solution, piezoelectric and triboelectric nano harvesters are developed to harvest energy from mechanical energy sources which are constant, unconventional, easily procurable and extensive. PENGs and TENGs are piezoelectric and friction materials with an easy design that can be activated by mechanical excitation and produce power more efficiently. Mechanical–electrical energy harvesting is designed to harvest cheaper, renewable, green, energy from the environment. In addition to the popular electromagnetic generators, other methods like PENG and TENG were developed primarily based on the output current in Maxwell's theory of displacement current. Debuting in 2006, PENG uses the piezoelectric effect to convert strains or stresses caused by mechanical excitation into electrical energy. First reported in 2012, TENG uses the triboelectric effect to convert the combined effects of contact charging and electrostatic induction into electrical energy. Compared to their counterparts in the energy harvesting technology suite, PENG and TENG have demonstrated advantages, ranging from the conceptual economics of environmental power generation to the manufacturing and applicability of self-powered units on multiple scales.

Figure 1.4 (a) shows the fundamentals of the piezoelectric and triboelectric effects. The piezoelectric effect of PENG can be displayed in a metal–insulator–metal sandwich structure comprising an insulating piezoelectric sheet in-between two sheets of the metal electrode. Initially, positive and negative ions are superimposed, so there is no polarisation in the piezoelectric material. This reduces the volume of the piezoelectric material and creates negative stresses as a result of the deformation. The positive and negative ions separate to create an electric dipole and the electric dipole moment changes, creating a piezoelectric potential in-between the electrodes.

By attaching the electrodes to an outer excitation, the piezoelectric charge causes electrons to flow into an external circuit, partially shielding the potential and attaining a new equilibrium. This is how energy is harvested from mechanical vibrations. The maximum compression state with the maximum polarisation density is achieved when the two conductive electrodes



(b)	PENG	TENG
Mechanism	Displacement current density	Displacement current density
Output	Mechanical-to-electrical	Mechanical-to-electrical
Structure	Structural deformation for material strain	Structural deformation for relative displacement
Material	Piezoelectric materials	Triboelectric materials
Main applications	Self-powered devices, remote charging, self-sensing and monitoring, etc.	Wearable and portable electronics, self-powered devices, remote charging, self-sensing and monitoring, etc.

Figure 1.4 Comparisons of PENG and TENG [3].

come into full contact by means of deformation. Finally, when the external force is released from the shunt, the electrons return to a new equilibrium state. The triboelectric effect of a heating element is depending on the joint effect of contact charging and electrostatic induction. This nano harvester is considered as a multi-purpose mechanical energy harvesting technology that efficiently converts external mechanical energy into electrical energy. In general, the more two triboelectric materials are separated; the more electric charge can move along the triboelectric series, thus generating higher power. The triboelectric effect is widespread in a variety of materials, but triboelectric materials have a significant impact on charging efficiency and final power. Therefore, it is very important to choose a triboelectric material for the heating element. The selection of a set of triboelectric materials with opposite triboelectric polarities is the key to getting increased power. The mechanism, output, structure, material and applications of PENG and TENG are compared in Figure 1.4 (b). Depending on the bias current density mechanism, the PENG and TENG generate an electrical output from a mechanical input power source. Due to fundamental differences, PENG structures are usually designed to activate piezoelectric materials by material deformation whereas TENGs activate triboelectric materials by relative displacement. Thus, PENG and TENG have developed microstructures engineered to get unusual electromechanical behaviours in terms of design, such as PENGs reinforced with mechanical Meta materials, TENGs reinforced with spring or pivot structures, etc. In addition, PENG and TENG have been reported to provide a decisive increase in the energy density generated using functional materials in terms of material properties such as PZT-based compositions.

1.6 Piezoelectric Energy Harvesters

As per the piezoelectric effect, EEG generates electricity due to deformation due to external excitation. An electric dipole is created when an electric charge builds up due to strain stress at both ends of a piezoelectric material. The positive ion displacement of the anion leads to a piezoelectric potential. According to existing research, piezoelectric energy harvesting is an energy harvesting technology that can convert the mechanical energy of various scales into electrical energy. Various types of piezoelectric materials are developed as piezoelectric energy harvesters, which can be divided into piezoelectric ceramics and piezoelectric polymers. Piezoelectric ceramics are the semiconductor nanomaterials, lead-based ceramics and lead-free ceramics and piezoelectric polymers generally refer to organic polymers such as polyvinylidene fluoride (PVDF) and inorganic polymers. Piezoceramics are chemically inert, resistant to moisture and have elevated electromechanical conversion efficiencies, but their harsh properties make them insufficient for flexible device applications. In contrast, piezoelectric polymers have a little piezoelectric effect but are much more flexible. Research is done to explore the major properties of designing, predicting and optimising PENGs in response to various external influences, such as body movements or environmental influences. Figure 1.5 shows the existing PENG techniques.

Figure 1.5 (a) shows a MoS_2 piezoelectric energy harvester monolayer passivated with sulphur vacancy. Sulphur vacancies are passivated using a sulphur treatment on the original MoS_2 surface to expand the output peak current to 100 pA and voltage to 22 mV of a sulphur-treated MoS_2 piezoelectric energy harvester nano sheet monolayer. Sulphur treatment increased the maximum output by almost a factor of 10. The obtained data indicate that sulphur treatment can stop the screening effect and decreases the number of free charge carrier PENGs due to sulphur passivation. Figure 1.5 (b) shows a skin-like, battery-free piezoresistive sensor that can be conformal to human skin. The sensor was developed from four material groups, composed of (1) a multilayer NFC chip package, a loop antenna and a silicon pressure sensor, (2) a polyimide thin film as an electrical insulator and (3) a top and base.

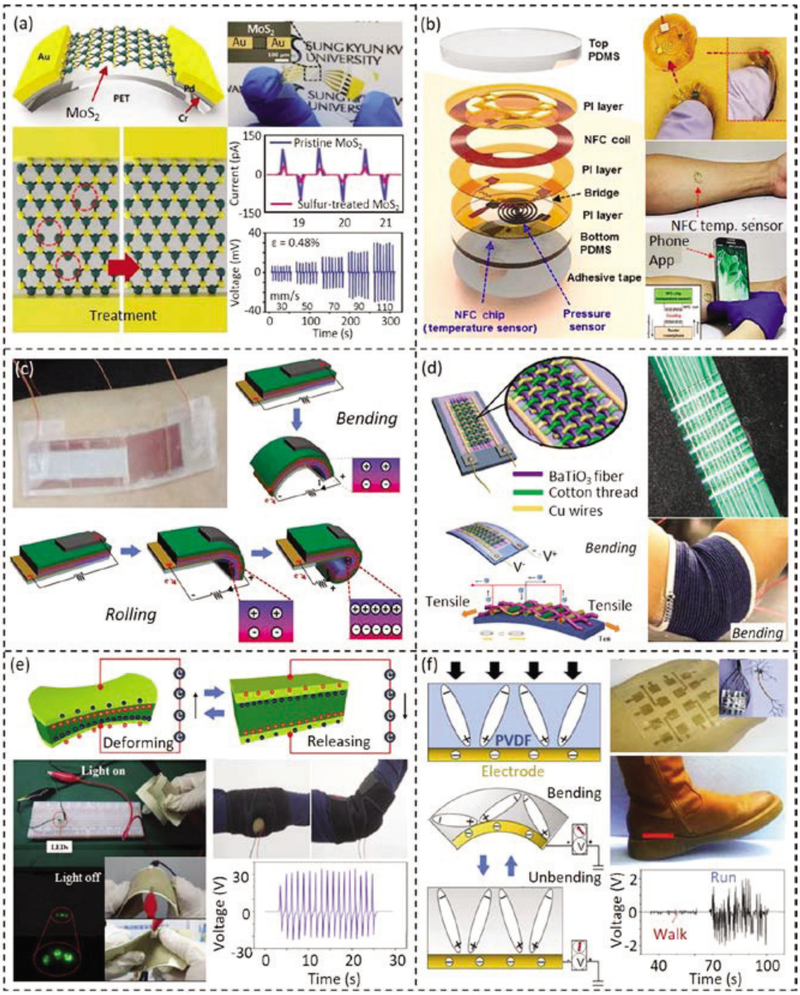


Figure 1.5 Existing piezoelectric energy harvesters [3]. (a) MoS2 piezoelectric energy harvester monolayer passivated with sulphur vacancy. (b) Battery-free piezoresistive sensor. (c) Solution-treated piezoelectric energy harvester. (d) 2D fabric PENG using PVC BaTiO3 nanowire hybrid piezoelectric fibres. (e) High tensile PZT-based PENG. (f) Electrode PENG with PVDF nano fibbers.

Polydimethylsiloxane as summarisation and (4) bio-friendly skin glue. The test results displayed the capabilities of the skin-mounted sensor by using a smart device to read data from a short distance. It is concluded that sensors may have promising value in monitoring circadian cycles and reducing risk.

Figure 1.5 (c) depicts solution-treated piezoelectric energy harvester flexible thin films by using drenched ZnO ink as a thin layer. Electrical energy is produced by the mechanical deformation of the elastic thin film during the rolling and bending process. It was reported that the ZnO PENG thin film showed high elasticity and mechanical fatigue resistance. a solution-treated p-type polymer blend and a perforated transport layer are placed to increase the power output. Figure 1.5 (d) shows a 2D fabric PENG using PVC BaTiO3 nanowire hybrid piezoelectric fibres. The piezoelectric properties of PVC BaTiO3 nanowires were enhanced by inorganic active BaTiO3 nanowires. The reported PENG was applied to an arm-actuated elbow pad, resulting in high performance and the ability to be used as a wearable power supply. Figure 1.5 (e) shows a high tensile PZT-based PENG that achieved an output power density of about 81 μW/cm^3. PZT particles are added to a solid silicone rubber with the help of the blending method. Therefore, the part of PZT in the composite rose from elongation of 30–92% by weight. This nano harvester is then connected to the human body to collect kinetic energy in multiple deformation modes. Figure 1.5 (f) depicts a single-electrode PENG with PVDF nano fibbers capable of performing pressure measurements with cold/heat integration with a single device. The piezoelectric signal is received as a square wave signal while the thermal sensor signal appears as a pulsed signal.

1.7 Triboelectric Energy Harvester (TENG)

According to the triboelectric effect, a heating element that generates energy from electric charges after contacting various triboelectric materials by friction has been developed. particularly, when two triboelectric materials are misshaped and brought into contact by an external excitation, an electrostatic charge is induced on the contact surface by the triboelectric effect. When these materials in contact are separated, more electric potentials are created between the electrostatic charges, moving the charges on the conductive material side by side. Utilising the triboelectric effect, TENG is used in multi-scale energy harvesting applications because of the properties such as environmental friendliness, more efficiency, less weight, cheapness and ease of availability. TENGs are generally classified into four categories of usage, like triboelectric modes of vertical contact separation, lateral slip, single electrode and freestanding triboelectric layers, making them versatile and versatile applications in various work conditions such as wastewater treatment, wireless communication, etc. Its possible application may be

Textiles, Human Movement, Human-Machine Interface (HMI), Vibration, Wind, Flowing Water, etc.

Figure 1.6 (a) shows a PETN-based micro-motion sensor operating through the fusion of triboelectricity and electrostatic induction. This elastic

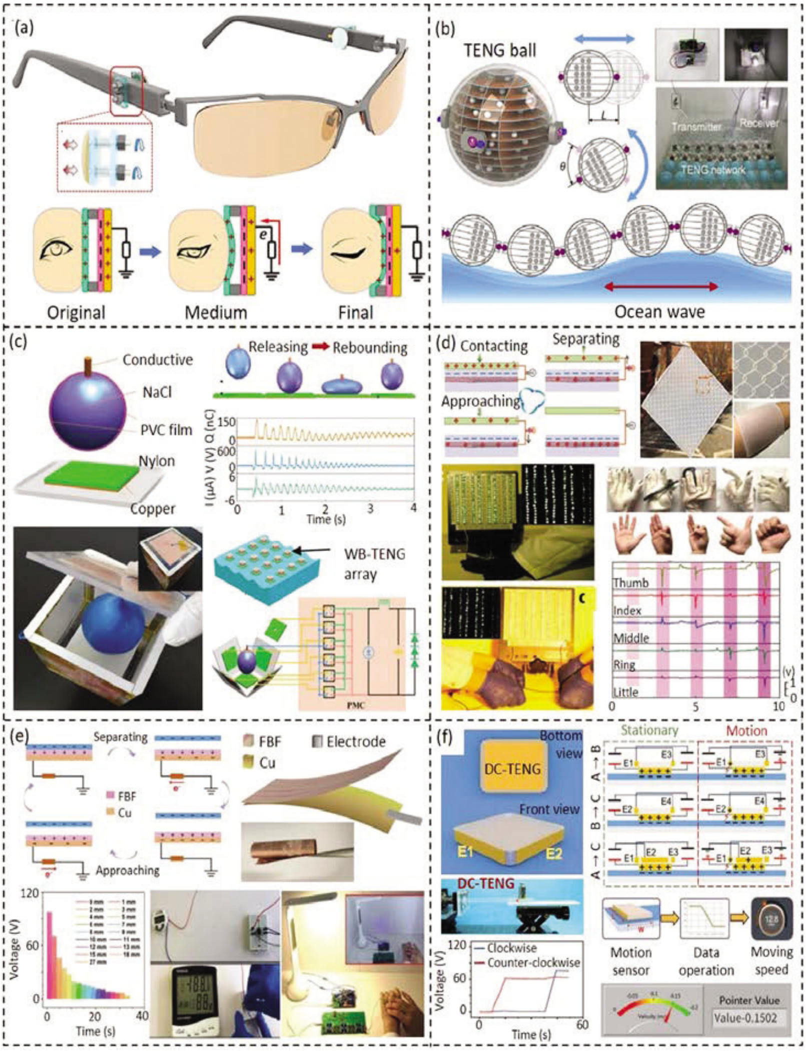


Figure 1.6 Existing TENG [3]. (a) PETN-based micro-motion sensors, (b) TENG for energy generation from water waves, (c) multiple-frequency TENG, (d) Flexible and Waterproof Skin-Inspired Piezoelectric Nanogenerator (PENG), (e) Adaptable, Exceptionally Flexible, and Highly Sensitive Triboelectric Nanogenerator (TENG) using Fish Bladder Films, (f) Self-sustained Triboelectric Vector Sensors using Direct Current TENG for Motion Parameters measurements.

and see-through sensor composed of an indium tin oxide electrode and two opposing friction materials successfully detected blinking motion by a strong signal level of about 750 mV. The sensor was attached to the goggles and applied to two real-time mechanosensory HMIs are highly sensitive, stable, economical and simple in operating. TENG-based micro-motion sensors were a smart measurement technology available on HMI. The macroscopic auto-assembly network composed of the entrapped TENG for energy generation from water waves is depicted in Figure 1.6 (b). Based on the self-adaptive magnetic joints of the encapsulated TENG, the network demonstrated self-assembly, self-healing and easy reconfiguration. The three-dimensional electrode structures are created to improve the TENG unit's output. Figure 1.6 (c) shows a multiple-frequency TENG based on a water balloon for energy harvesting in any direction of a water wave. Because of the excellent mechanical properties of the water balloon, the TENG achieved multiple frequency response using low-frequency external mechanical simulations for generating high-frequency electrical of the instant short circuit output. In this method approximately the maximum instantaneous short-circuit current measured by the authors was 147 A, with an open-circuit high voltage.

1.8 Artificial Intelligent in Energy Harvesting

The foremost artificial intelligent technologies at present used in the energy harvesting sector are dealing with auto-gain of the information based on existing data, recognising invisible relationships in the inputs and outputs, and helping decision-making. The application of artificial intelligent for energy harvesting can be divided into information gathering and expression, algorithm definition and model construction as depicted in Figure 1.7 (a).

AI technologies are required to be trained for information gathering and plotting using available data of energy harvesting. Therefore, it is of utmost importance to maintain effective and sufficient data collection. In energy harvesting maintaining the capacity and efficiency of the data pool is critical as data collection and presentation will require training AI methods on existing energy harvesting data. For example, energy harvesting due to body motion is subjected to millions of periodic loads over a 24-hour period, typically resulting in 30% data loss which is the noise in data. Therefore, pre-processing of the initial information is required to be performed to understand missing or incorrect data during data collection.

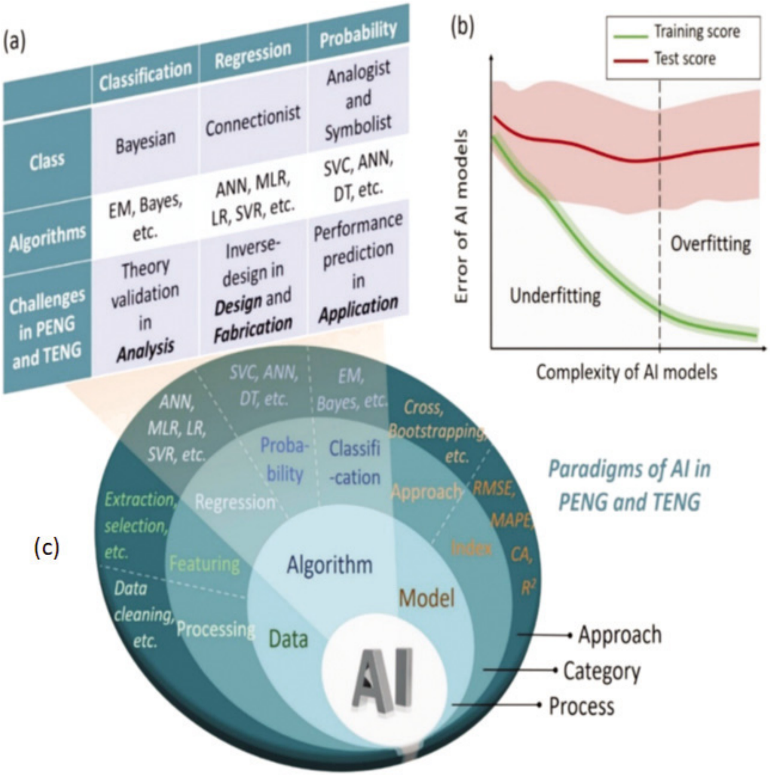


Figure 1.7 Artificial intelligence in energy harvesting [3]. (a) Artificial intelligent for energy harvesting. (b) The interrelation between the difficulties and errors of the AI model. (c) Artificial intelligence in energy harvesting.

Recognising and fixing these bugs is important to reduce the chance of an AI model being misguided. The large set of information in energy harvesting is so critical to the precision and effectiveness of AI models. For example, the voltage produced is recorded in the time domain. However, the output must be transformed into the frequency domain for more analysis. Like human intelligence, AI algorithms are far more efficient than remaining on some specific row information types. Transforming this data into a format appropriate for AI models requires functional characterisation or development. Converting the information into a suitable arrangement for AI models, characteristic study, or characteristic engineering is required to be carried out.

When defining an algorithm, it is necessary to define a specific algorithm for training a dataset after collecting and presenting the data. A wide pool of

AI algorithms can be run to construct the predictive energy harvesting models like supervised machine learning (ML) models utilised in forecasting energy generation depending on individual data sets that require categorisation of the data set or continuous data sets that require data regression. There can be simple and rigid or flexible and complex AI predictive models for energy harvesting. AI constructs the algorithms to increase model performance depending on big data by mimicking human learning abilities and gaining experience through thinking. Data is a key parameter in AI models, but big data is of no use until a computer can draw conclusions or knowledge. AI usually uses some assumptions and implements them in the model to effectively capture missing data. A normal AI paradigm may be described as the use of different methods to determine unique acts and relationships between resultant data and invisible patterns or features of materials and structures. In PENG and TENG, a grouping of algorithms can be used, inter alia, for analytical problems, regression algorithms for design and manufacturing problems and probabilistic algorithms for applied problems. During model construction, the models need to be evaluated, validated and optimised to obtain the best AI model for energy harvesting. The precision of the AI model can be tested using the cross-validation method if the inputs used for training and validation can represent the total data set, but problems can arise when the data set is smaller. Appropriate acts should be applied for testing the applicability of AI models. Different indicators (such as RMSE, MAPE, CA, R2, etc.) are suggested to test and analyse the projection errors of AI models. Model bias and difference are largely regarded as the main causes of model error in energy collection. Model bias refers to errors due to improper assumptions in an algorithm, resulting in a lack of a fundamental relationship between the input raw data and energy efficiency predictions. Model variance describes the sensitivity to small variations in the input raw data, such as data noise, computational uncertainty and measurement constraints. Relatively high bias or high variance usually degrades the performance of AI models. Figure 1.7 (b) shows the interrelation between the difficulties and errors of the AI model. High bias is considered underfitting, which happens at a time when an AI model is rigid enough to account for the difficult relationship between the input raw data (e.g., the power harvesting voltage observed in an experiment) and its predictive function (e.g., the forecasted voltage). The large variation is taken as overfitting that takes place when the AImodel is more complicated like increasing input variables.

Figure 1.8 (a) explains a typical structure of an artificial neural network (ANN) composed of multiple abstract brain neurons and data processing connections. Nodes represent a particular output performance and the relationship between nodes is the weights of the transform signal (i.e., the memory of the ANN model). As a result, the output of an ANN is strongly influenced by the weights, features and relationships of the model. ANN is used in AI algorithms in energy harvesting methods because of its high nonlinear approximation ability. Figure 1.8 (b) shows the structure of a support vector machine (SVM) that classifies input data using supervised learning. The nature of SVM as a generalised classifier is to determine a support vector for the formation of an optimal classification hyperplane on the training information volume. SVM uses a hinge loss function to estimate factual risk and therefore improves model soundness and slenderness. Figure 1.8 (c) shows the structure of an extreme learning machine (ELM) as a learning algorithm for a feed-forward neural network having one invisible surface. ELM can randomly generate network parameters. For example, the threshold of the hidden layer or the weight of the neural connection. Overall, high grasping power and adequate simplification capacity are observed in ELM which makes it more suitable for use in energy harvesters.

The mechanisms of the ELM as the training algorithm for the feed-forward neural network with one invisible surface are depicted in Figure 1.8 (c). ELM can generate the network parameters in a random manner.

ELM is widely used in PENG and TENG because of its quick learning capabilities and generalisation capability. Figure 1.8 (d) depicts a deep neural network algorithm known as a stacked auto-encoder (SAE). It is important to note that coding gives unpredictable changes between the input and invisible layers, whereas decrypting gives changes between the hidden and reconstruction layers. SAE can restructure the input data with acceptable error ranges by encryption and decryption process. Figure 1.8 (g) depicts classic AI methods and structures for PENG and TENG. In the design and analysis phase, the nanogenerator is characterised to obtain input data regarding structural design, material properties, geometric properties and external excitation. PENG and TENG inputs are generated by raw data processing. In particular, AI is utilised as a tool to study triboelectric mechanisms in heating elements. A lot of theoretical models are used in past to analyse triboelectric effects, such as the V–Q–X model for TENG in proximity division separation or skidding mode. But these theoretical models were mainly based on some assumptions such as proximity-sharing structures, linear or skidding structures, etc., to simplify them. It is tough to consider the theoretical location of heating elements in practical applications. Or else it becomes complicated. Using AI to analyse a large number of data and establish complicated relationships between inputs and outputs can greatly expand theoretical models of triboelectric mechanisms.

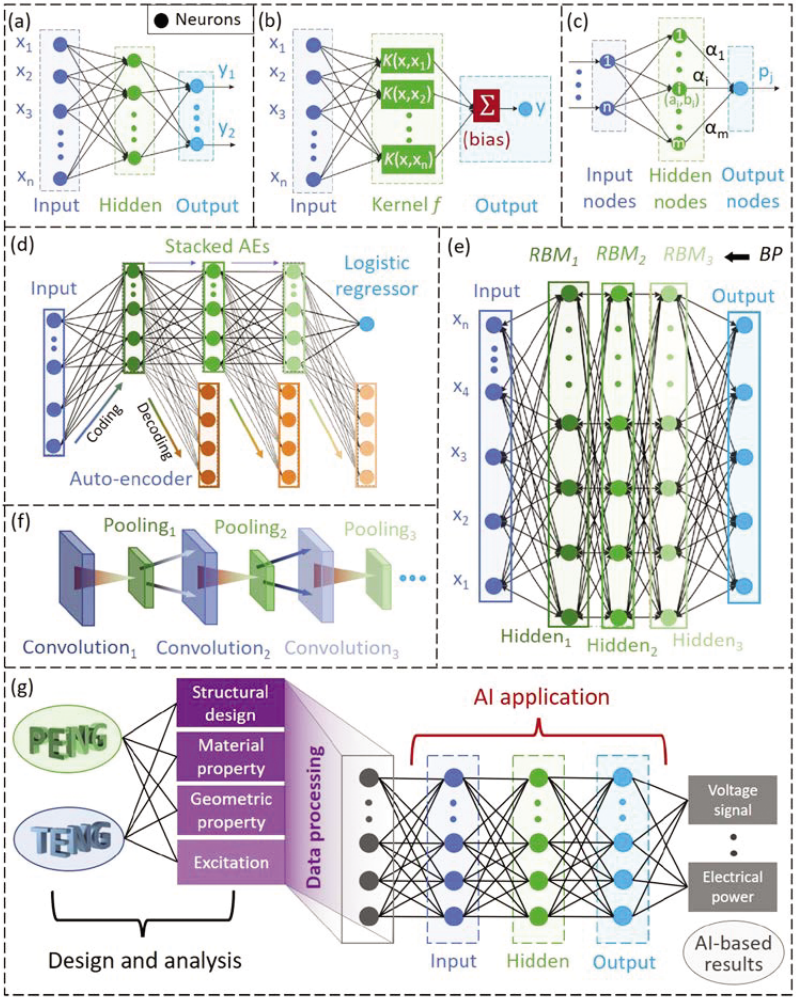


Figure 1.8 Artificial intelligent structure for PENG and TENG [3]. (a) Artificial neural network (ANN). (b) Support vector machine (SVM). (c) Extreme learning machine (ELM). (d) Stacked auto-encoder (SAE). (e) Deep belief network (DBN). (f) Conventional neural network (CNN). (g) Typical procedures and structures of AI-based PENG and TENG.

1.9 Artificial Intelligent in Energy Harvesters

Energy collection and measurement are the two main functions of PENG and TENG, providing a wide scope of use for smart techniques in engineering and life sciences applications. An intelligent system mainly consists of three steps, which include information gathering, information sharing and data analysis. Because of its character as a tool for data analysis, AI is mostly classified as level 3 and has become increasingly important in data processing and analysis. The use of AI in PENG and TENG, in particular, includes (1) big data analysis and sensor processing, (2) nanogenerator design and improvement depending on the requirements and (3) AI algorithm modification and optimisation based on data analysis requirements. At present, AI is largely used to analyse data from sensors, such as grouping and filtering big chunks of information gathered by sensors in PENG or TENG for smart sports devices. Figure 1.9 (a) shows a conceptual iteration in combination with artificial intelligence to forecast the electrical properties of a rotating heating element. The input parameters of the model are the number of components, the rotational speed, the distance between the friction surfaces and the output variables. The AI-enabled prognostication model was constructed to describe the rotary TENG outcomes in the form of kinematics and spatial constraints. Figure 1.9 (b) depicts the TENG-enabled falling juncture allocated numerical scheme and the edge ball judgment system, both of which use AI for data analytics. The wood-based TENG (W-TENG) was suggested as an intelligent table tennis device, and the falling point system is designed by assessing real-time information collection and transforming it into quantitative. Machine learning is used to collect handwriting as input with the help of a TENG tablet and process the information for pattern identification. A multiclass classification model was prepared with the help of an SVM-based flowchart for decision making and the input information was utilised to educate the machine learning model. Figure 1.9 (d) shows a super hydrophobic triboelectric gesture recognition glove. Machine learning has been applied for real-time gesture recognition, and virtual reality (VR) and augmented reality (AR) controls have been implemented. Convolution neural network (CNN) models have been constructed to identify actions and expressions and give appropriate commands via wireless communication. The self-powered HMI shown in Figure 1.9 (e) used TENG for monitoring handwriting in the tapping and sliding modes. CNN was specifically designed with three layers: the input layer, which fed the input data into the neurons; the hidden layer, which included the convolution layer and the linearization

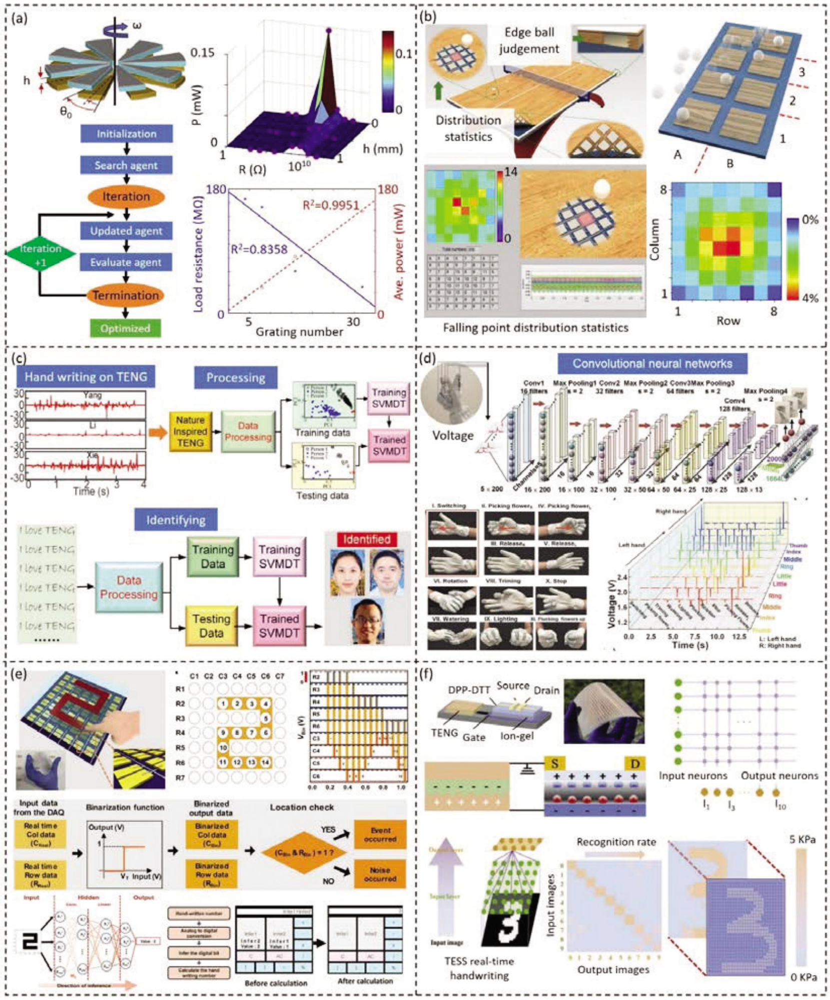


Figure 1.9 Recent AI for PENG and TENG [3]. (a) Theoretical modeling combined with AI to predict the electrical performance of the rotary TENG. (b) TENG-enabled falling point distribution statistical system and edge ball judgment system that use AI for data analytics. (c) Smart self-powered handwriting pad based on the textured TENG. (d) Superhydrophobic triboelectric gloves for gesture recognition. (e) Self-powered HMI that use TENG to monitor handwriting in the tapping and sliding modes. (f) Artificial sensory memory developed based on the TENG matrix.

layer to take out the characteristics of the input and the output layer, which displayed the results.

1.10 Philosophy of AI in Energy Harvesting

AI has received a great deal of research attention in energy harvesting in recent years, primarily because of the incapability of physics-based model mode with the help of first principles. in comparison to the conventional modelling ways that basically use physical principles to learn and forecast a particular response, AI has the ability to understand and manipulate higher-dimensional feature spaces. Depending on the goals and usage, energy-harvesting AI can be classified into technologies like AI algorithms and utilities (i.e., AI-enabled features).

Conventional modelling was mainly based on machine learning algorithms and the new approach includes features such as inference, programming, artificial life, computational development and hindrance satisfaction. A paradigm that applies artificial intelligence with energy harvesting technology. Energy harvesting technology can be divided into three steps, (1) code acceleration apparatus to decrease the economical involvement for the analysis of passive models, (2) creating experimental methods when passive models are not feasible and (3) procuring categorisation equipment. Applications of AI technology in energy harvesting primarily include four layers as depicted in Figure 1.10:

1. the environment layer,
2. hardware layer,
3. software layer and
4. application layer.

At the environment layer, most relations are of low frequency and low amplitude, so artificial intelligence helps control and utilise external activities for energy harvesters. The use of artificial intelligence to adjust and boost the external conditions of this layer to activate piezoelectric and triboelectric materials and generate electricity more effectively. At the hardware level, artificial intelligence helps design and optimise the energy harvester's physical networks and end devices. Hardware is required for the physical network to provide the produced data and to match the inputs and outputs in relation to the structure and materials of the energy harvester. To improve the efficiency and voltage analysis, the generated data must be rectified by signal pre-processing, mining and amplification. The Internet of Things (IoT), or an intelligent cloud can be used for the communication of the data through the wireless gateway, along with this, the data must be converted by another device software like a user interface (UI), man–machine interference, user interference, or modified cloud interface design. At the application

AI in Energy Harvesting

Sharma, A. , Sharma, A. , Dasgotra, A. , Jately, V. , Ram, M. , Rajput, S. , Averbukh, A. & Azzopardi, B. (2021). Opposition-based tunicate swarm algorithm for parameter optimization of solar cells. *IEEE Access* , 9, 125590–125602.

Sharma, A. , Sharma, A. , Pandey, J. K. , & Ram, M. (2022). *Swarm Intelligence: Foundation, Principles, and Engineering Applications* . CRC Press.

Pengcheng, Jiao , "Emerging artificial intelligence in piezoelectric and triboelectric nanogenerators" Nano Energy 88 (2021) 106227.

Z. L. Wang , J. H. Song , Piezoelectric nanogenerators based on zinc oxide nanowire arrays, Science 312 (5771) (2006) 242–246.

A. Yu , P. Jiang , Z. L. Wang , Nanogenerator as self-powered vibration sensor, Nano Energy 1 (3) (2012) 418–423.

H. Akinaga , H. Fujita , M. Mizuguchi , and T. Mori , Sci. Technol. Adv.Mater. 19, 543 (2018).

S. Y. Chung , S. Kim , J. H. Lee , K. Kim , S. W. Kim , C. Y. Kang , S. J. Yoon , Y. S. Kim , All-solution-processed flexible thin film piezoelectric nanogenerator, Adv. Mater. 24 (2012) 6022–6027.

S. H. Baek , M. S. Rzchowski , V. A. Aksyuk , Giant piezoelectricity in PMN-PT thin Films: Beyond PZT, MRS Bull. 37 (2012) 1022–1029.

P. Jiao , H. Hasni , N. Lajnef , A. H. Alavi , Mechanical metamaterial piezoelectric nanogenerator (MM-PENG): design principle, modeling and performance, Mater. Des. 187 (2020), 108214.

Y. B. Lee , J. K. Han , S. Noothongkaew , S. K. Kim , W. Song , S. Myung , S. S. Lee , J. Lim , S. D. Bu , K. S. An , toward arbitrary direction energy harvesting through flexible piezoelectric nanogenerators using perovskite PbTiO3 nanotube arrays, Adv. Mater. 29 (6) (2017), 1604500.

D. Yao , H. Cui , R. Hensleigh , P. Smith , S. Alford , D. Bernero , S. Bush , K. Mann , H. F. Wu , M. C. Chin-Nieh , G. Youmans , X. Zheng , Achieving the upper bound of piezoelectric response in tunable, wearable 3D printed nanocomposites, Adv. Funct. Mater. 29 (42) (2019) 1–11.

B. Wu , H. Wu , J. Wu , D. Xiao , J. Zhu , S. J. Pennycook , Giant piezoelectricity and high curie temperature in nanostructured alkali niobate lead-free piezoceramics through phase coexistence, J. Am. Chem. Soc. 138 (47) (2016) 15459–15464.

L. Dong , C. Wen , Y. Liu , Z. Xu , Piezoelectric buckled beam array on a pacemaker lead for energy harvesting, Adv. Mater. Technol. 4 (1) (2019), 1800335.

S. K. Ghosh , D. Mandal , High-performance bio-piezoelectric nanogenerator made with fish scale, Appl. Phys. Lett. 109 (2016), 103701.

L. Jiang , Y. Yang , R. Chen , G. Lu , R. Li , L. Di , M. Krailo , K. K. Shung , J. Zhu , Y. Chen , Q. Zhou , Flexible piezoelectric ultrasonic energy harvester array for bio-implantable wireless generator, Nano Energy 56 (2019) 216–224.

W. S. Jung , M. J. Lee , M. G. Kang , H. G. Moon , S. J. Yoon , S. H. Baek , C. Y. Kang , Powerful curved piezoelectric generator for wearable applications, Nano Energy 13 (2015) 174–181.

X. Niu , W. Jia , S. Qian , J. Zhu , J. Zhang , X. Hou , J. Mu , W. Geng , J. Cho , J. He , X. Chou , High-performance PZT-based stretchable piezoelectric nanogenerator, ACS Sust. Chem. Eng. 7 (2018), 979–958.

A. Mellit , S. A. Kalogirou , Artificial intelligence techniques for photovoltaic applications: a review, Prog. Energy Combust. Sci. 34 (5) (2008) 574–632.

Y. Reich , S. V. Barai , Evaluating machine learning models for engineering problems, Artif. Intell. Eng. 13 (3) (1999) 257–272.

B. Sanchez-Lengeling , A. Aspuru-Guzik , Inverse molecular design using machine learning: generative models for matter engineering, Science 361 (6400) (2018) 360–365.

Y. Reich , Machine learning techniques for civil engineering problems, Computer -Aided Civ. Infrastructure. Eng. 12 (4) (2002) 295–310.

D. M. Dimiduk , E. A. Holm , S. R. Niezgoda , Perspectives on the impact of machine learning, deep learning, and artificial intelligence on materials, processes, and structures engineering, Integr. Mater. Manuf. Innov. 7 (2018) 157–172.

S. M. Zahraee , M. K. Assadi , R. Saidur , Application of artificial intelligence methods for hybrid energy system optimization, Renew. Sustain. Energy Rev. 66 (2016) 617–630.

Z. Wang , R. S. Srinivasan , A review of artificial intelligence-based building energy use prediction: contrasting the capabilities of single and ensemble prediction models, Renew. Sustain. Energy Rev. 75 (2017) 796–808.

Y. Zhou , M. Shen , X. Cui , Y. Shao , L. Li , Y. Zhang , Triboelectric nanogenerator based sel-powered sensor for artificial intelligence, Nano Energy 84 (2021), 105887.

Application of the ANN Method in Water Energy Harvesting

Rakesh T. , Tanweer, Desmukh S. , “Application of Artificial Neural Network in Hydrology-A Review”, International Journal of Engineering Research & Technology (IJERT) ISSN: 2278-0181 IJERTV4IS060247 www.ijert.org (This work is licensed under a Creative Commons Attribution 4.0 International License.) Vol. 4 Issue 06, June-2015.

Kumar P. S. , Praveen T. V. & Prasad M. A. “Artificial Neural Network Model for Rainfall-Runoff” International Journal of Hybrid Information Technology, Vol.9, No.3 (2016), pp. 263-272, 2016.

Zadeh L. A. , “Fuzzy Logic, Neural Networks and Soft Computing,” Communication of the ACM, Vol. 37, Issue.3, pp. 77-84, 1994.

Sivanandam S. N. , Deepa S. N. , “Principles of Soft Computing”, Second Edition, Published by Wiley India, New Delhi, 2011.

Rosenblatt R. , “Principle of Neurodynamics”, Spartan Books, New York, pp 23-35, 1962.

Minsky M. and Papert S. , “Perceptrons: An Introduction to Computational Geometry”, MIT Press, Cambridge, Mass., pp 43-80, 1996.

Jain A. K. and Mao J. , “Neural Networks and Pattern Recognition in Computational Intelligence: Imitating Life”, IEEE Press, Piscataway, pp.194-212, 1994.

Haykin S. , “Neural Networks: A Comprehensive Foundation”, MacMil-lan College Publishing Co., New-York, pp.115-133, 1994.

S. Rajput , E. Bender , M. Averbukh , Simplified algorithm for assessment equivalent circuit parameters of induction motors, IET Electric Power Applications, 14 (2020) 426-432.

Karunanithi N. , Grenney W. J. , Whitley D. , and Bovee K. , “Neural networks for river flow prediction”, J. Comp. in Civ. Engrg., ASCE, 8(2), 201–220, 1994.

Markus M. , Salas J. D. , and Shin H.-K. , “Predicting stream flows based on neural networks”, Proc., 1st Int. Conf. on Water Resour. Engrg., ASCE, New York, 1641–1646, 1995.

Senthil Kumar A. R. , Sudheer P. K. , Jain S. K. , and Agarwal P. K. , “Rainfall-runoff modelling using artificial neural networks: comparison of network types”, Hydrological Processes, John Wiley & Sons, Vol. 19, PP 1277–1291, 2005.

Maier H. R. , and Dandy G. C. , “The use of artificial neural networks for the prediction of water quality parameters”, Water Resources Res., 32(4), 1013, 1996.

S. Rajput , E. Farber , M. Averbukh , Optimal Selection of Asynchronous Motor-Gearhead Couple Fed by VFD for Electrified Vehicle Propulsion, Energies, 14 (2021) 4346.

S. Mengesha , S. Rajput , S. Lineykin , M. Averbukh , The effects of cog-ging torque reduction in axial flux machines, Micromachines, 12 (2021) 323.

Nayak P. C. , Sudheer P. K. , and Jain S. K. , “Rainfall-runoff modelling through the hybrid intelligent system”, Volume 43, Issue 7, First published: 13 July 2007 https://doi.org/10.1029/2006WR004930.

Nourani V. , Baghanam A. H. , Adamowski J. , Kisi O., “Applications of hybrid wavelet–Artificial Intelligence models in hydrology: A review”, Journal of Hydrology, Volume 514, 6 June 2014, Pages 358-377, 2014.

Zhang G. P. , Fenicia F. , Rientjes T. H. M. , Reggiani P. , Savenije H. H. G. , “Modeling runoff generation in the Geer river basin with improved model parameterizations to the REW approach”, Volume 30, Issues 4–5, Pages 285-296, 2005, Physics and Chemistry of the Earth, Parts A/B/C

Dunne T. , “Relation of field studies and modelling in the prediction of storm runoff”, Journal of Hydrology, Volume 65, Issues 1–3, Pages 25-48, August 1983.

Tokar S. A. and Peggy J. A. “Rainfall-runoff modelling using artificial neural networks” Journal of Hydrologic Engineering, ASCE, Vol. 4(3), PP 232-239, 1999.

Govindaraju R. S. , “Artificial neural networks in hydrology, II: hydrologic applications. Journal of Hydrologic Engineering, 5, 124-137, 2000.

Ozesmi, S. L. & Ozesmi, U. “An artificial neural network approach to spatial habitat modelling with interspecific interaction”. Ecol. Modelling. 116, 15-31, 1999.

Beven K. J. , “Rainfall-runoff modelling: The primer (2nd ed.): Wiley Blackwell, 2012.

French M. N. , Krajewski W. F. , and Cuykendal R. R. , “Rainfall forecasting in space and time using a neural network.” J. Hydrol., Amsterdam, 137, 1–37, 1992.

Sharma, A. , Sharma, A. , Jately, V. , Averbukh, M. , Rajput, S. , & Azzopardi, B. (2022). A Novel TSA-PSO Based Hybrid Algorithm for GMPP Tracking under Partial Shading Conditions. Energies, 15(9), 3164.

Raman H. , and Sunilkumar N. , “multi-variate modelling of water resources time series using artificial neural networks” Hydrological Sci., 40, 1995.

Smakhtin V. U. , “Low flow hydrology: a review”, Journal of Hydrology, 147–186, www.elsevier.com/locate/jhydrol, 2001.

Nayak P. C. and Sudheer K. P. , “Fuzzy model identification based on cluster estimation for reservoir inflow forecasting”, Hydrological Processes, 827–841 Published online 11 June 2007, Wiley InterScience (www.interscience.wiley.com) DOI: 10.1002/hyp.6644

Kalteh, A. M. , “Rainfall-Runoff Modelling Using Artificial Neural Networks (ANNs). Department of Water Resources Engineering, Lund Institute of Technology, Lund University, 2007.

Dawson C. W. and Wilby R. L. , “Hydrological modelling using artificial neural networks” Progress in Physical Geograph, Vol. 25(1), PP 80–108, 2001.

Rajurkar M. P. , Kothyari U. C. and Chaube U. C. , “artificial neural networks for daily rainfall-runoff modelling” Hydrological sciences journal, vol. 47(6), pp 865, 2002.

Kalteh A. M. , “Rainfall-runoff modelling using artificial neural networks (ANNs): modelling and understanding” Caspian Journal of Environmental Sci., Vol. 6 No.1 pp. 53-58, 2008.

Garson, G. D. , “Interpreting Neural Network Connection Weights. AI Expert, 6, 47-51, 1991.

Antar M. A. , Elassiouti I. and Allam M. N. , “Rainfall-runoff modelling using artificial neural networks technique: a Blue Nile catchment case study” Hydrological Processes, Wiley International Science Publication, Vol. 20, PP 1201–1216, 2006.

Rodrigues, J. A. S. ; Andrade A. C. D. O. ; Viola M. R. ; Ferreira D. D. ; Mello C. R. D. M. ; Thebaldi M. S. , “Hydrological modeling in a basin of the Brazilian Cerrado biome”, January 2021, Ambiente & Água - An Interdisciplinary Journal of Applied Science 16(1):18, 2021.

Artificial Intelligence (AI) in Electrical Vehicles

European Commission (2011), Transport in Figures—Statistical Pocketbook. Available online: https://ec.europa.eu/transport/facts-funding’s/statistics/pocketbook-2011_en.

Chan, C. C. (2007), the state of the art of electric, hybrid, and fuel cell vehicles. Proc. IEEE, 95, 704–718.

Albatayneh, A. ; Assaf, M. N. ; Alterman, D. ; Jaradat, M. (2020), Comparison of the Overall Energy Efficiency for Internal Combustion Engine Vehicles and Electric Vehicles. Environ. Clim. Technol. 24, 669–680.

OECD iLibrary (2020), Non-Exhaust Particulate Emissions from Road Transport: An Ignored Environmental Policy Challenge; Technical Report; OECD Publishing: Paris, France. Available online: https://doi.org/10.1787/4a4dc6ca-en.

Blázquez Lidoy, J. ; Martín Moreno, J. M. (2010), Eficiencia energética en la automoción, el vehículo eléctrico, un reto del presente. Econ. Ind. 377, 76–85.

Nissan. Nissan Leaf. Available online: https://www.nissan.co.uk/vehicles/new-vehicles/leaf/range-charging.html.

Tesla (2019). Tesla Official Website. https://www.tesla.com/en_EU/supercharger

K. Morrow , D. Karner , and J. Francfort , (2008), “Plug-in hybrid electric vehicle charging infrastructure review,” U.S. Dept. Energy, US Dept. E nergyVehicle Technol. Program, Contract No. 58517, vol. 34.

Du Pasquier, A. ; Plitz, I. ; Menocal, S. ; Amatucci, G. (2003). A omparative study of Li-ion battery, supercapacitor and non-aqueous asymmetric hybrid devices for automotive applications. J. Power Sources, 115, 171–178.

Masikos, M. ; Demestichas, K. ; Adamopoulou, E. ; Theologou, M. (2013) Machine-learning methodology for energy efficient routing. IET Intell. Transp. Syst. 8, 255–265.

Alesiani, F. ; Maslekar, N. (2014), Optimization of Charging Stops for Fleet of Electric Vehicles: A Genetic Approach. IEEE Intell. Transp. Syst. Mag. 6, 10–21.

Sugii, Y. ; Tsujino, K. ; Nagano, T. (1999), A genetic-algorithm based scheduling method of charging electric vehicles. In Proceedings of the IEEE International Conference on Systems, Man, and Cybernetics (Cat No. 99CH37028), Tokyo, Japan, 12–15; Volume 4, pp. 435–440.

Panahi, D. ; Deilami, S. ; Masoum, M. A. S. ; Islam, S. M. (2015), Forecasting plug-in electric vehicles load profile using artificial neural networks. In Proceedings of the 2015 Australasian Universities Power Engineering Conference (AUPEC), Wollongong, Australia, pp. 1–6.

Park, J. ; Kim, Y. (2020), Supervised-Learning-Based Optimal Thermal Management in an Electric Vehicle. IEEE Access, 8, 1290–1302.

Karimi, G. ; Li, X. (2013), Thermal management of lithium-ion batteries for electric vehicles. Int. J. Energy Res., 37, 13–24.

Advances in Maximum Power Point Tracking of Solar Photovoltaic Systems Under Partially Shaded Conditions with Swarm Intelligence Techniques

S. K. Gupta and R. S. Anand , “Development of Solar Electricity Supply System in India: An Overview,” Journal of Solar Energy, pp. 1-10, 2013.

A. Urja , “Newsletter of the Ministry of New and Renewable Energy, Government of India,” vol. 12, no. 5, apr 2019.

T. V. Dixit , A. Yadav , and S. Gupta , “Experimental assessment of maximum power extraction from solar panel with different converter topologies,” International Transactions on Electrical Energy Systems, vol. 29, no. 2, p. e2712, 2019.

H. Patel and V. Agarwal , “Maximum power point tracking scheme for pv systems operating under partially shaded conditions,” IEEE Transactions on Industrial Electronics, vol. 55, no. 4, pp. 1689-1698, April 2008.

M. Balat , “Solar technological progress and use of solar energy in the world,” Energy Sources, Part A: Recovery, Utilization, and Environmental Effects, vol. 28, no. 10, pp. 979-994, 2006.

A. Mäki and S. Valkealahti , “Power losses in long string and parallelconnected short strings of series-connected silicon- based photovoltaic modules due to partial shading conditions,” IEEE Transactions on Energy Conversion, vol. 27, no. 1, pp. 173-183, 2012.

J. Cubas , S. Pindado , and C. D. Manuel , “Explicit Expressions for Solar Panel Equivalent Circuit Parameters Based on Analytical Formulation and the Lambert W-Function,” Energies, vol. 7, no. 7, pp. 1-18, June 2014.

E. A. Sweelem , F. H. Fahmy , M. M. A.-E. Aziz , P. Zacharias , and A. Mahmoudi , “Increased efficiency in the conversion of solar energy to electric power,” Energy Sources, vol. 21, no. 5, pp. 367-377, 1999.

A. Dadjé , N. Djongyang , J. D. Kana , and R. Tchinda , “Maximum power point tracking methods for photovoltaic sys- tems operating under partially shaded or rapidly variable insolation conditions: a review paper,” International Journal of Sustainable Engineering, vol. 9, no. 4, pp. 224-239, 2016.

H. D. Tafti , A. I. Maswood , G. Konstantinou , J. Pou , and F. Blaabjerg , “A general constant power generation algorithm for photovoltaic systems,” IEEE Transactions on Power Electronics, vol. 33, no. 5, pp. 4088-4101, 2018.

B. Subudhi and R. Pradhan , “A comparative study on maximum power point tracking techniques for photovoltaic power systems,” IEEE Transactions on Sustainable Energy, vol. 4, no. 1, pp. 89-98, Jan 2013.

M. Abdel-Salam , M. T. El-Mohandes , and M. Goda , “History of maximum power point tracking,” Green Energy and Technology, pp. 1-29, 2020.

N. Femia , G. Petrone , G. Spagnuolo , and M. Vitelli , “Optimization of perturb and observe maximum power point tracking method,” IEEE Transactions on Power Electronics, vol. 20, no. 4, pp. 963-973, July 2005.

Y. Liu , S. Huang , J. Huang , and W. Liang , “A particle swarm optimization-based maximum power point tracking algorithm for pv systems operating under partially shaded conditions,” IEEE Transactions on Energy Conversion, vol. 27, no. 4, pp. 1027-1035, Dec 2012.

M. F. N. Tajuddin , M. S. Arif , S. M. Ayob , and Z. Salam , “Erratum to the ‘perturbative methods for maximum power point tracking (mppt) of photovoltaic (pv) systems: a review’ international journal of energy research 2015; 39:1153-1178,” International Journal of Energy Research, vol. 39, no. 12, pp. 1720-1720, 2015.

R. Rawat and S. S. Chandel , “Review of maximum-power-point tracking techniques for solar-photovoltaic systems,”Energy Technology, vol. 1, no. 8, pp. 438-448, 2013.

M. Seyedmahmoudian , B. Horan , T. K. Soon , R. Rahmani , A. M. Than Oo , S. Mekhilef , and A. Stojcevski , “State of the art artificial intelligence-based mppt techniques for mitigating partial shading effects on pv systems - a review,” Renewable and Sustainable Energy Reviews, vol. 64, no. C, pp. 435-455, 2016.

Sharma, A. , Sharma, A. , Jately, V. , Averbukh, M. , Rajput, S. , & Azzopardi, B. (2022). A Novel TSA-PSO Based Hybrid Algorithm for GMPP Tracking under Partial Shading Conditions. Energies, 15(9), 3164. M. Seyedmahmoudian , T. K. Soon , B. Horan , A. Ghandhari , S. Mekhilef , and A. Stojcevski , “New armo-based mppt technique to minimize tracking time and fluctuation at output of pv systems under rapidly changing shading conditions,” IEEE Transactions on Industrial Informatics, pp. 1-1, 2019.

A. Tavakoli and M. Forouzanfar , “A self-constructing lyapunov neural network controller to track global maximum power point in pv systems,” International Transactions on Electrical Energy Systems, vol. n/a, no. n/a, p. e12391.

E. Koutroulis and F. Blaabjerg , “Overview of maximum power point tracking techniques for photovoltaic energy production systems,” Electric Power Components and Systems, vol. 43, no. 12, pp. 1329-1351, 2015.

S. Bhattacharyya , D. S. K. Patnam , S. Samanta , and S. Mishra , “Steady output and fast tracking mppt (soft mppt) for p o and inc algorithms,” IEEE Transactions on Sustainable Energy, pp. 1-1, 2020.

Singh A , Sharma A , Rajput S , Bose A , Hu X. An Investigation on Hybrid Particle Swarm Optimization Algorithms for Parameter Optimization of PV Cells. Electronics. 2022; 11(6):909.

K. Aygül , M. Cikan , T. Demirdelen , and M. Tumay , “Butterfly optimization algorithm based maximum power point tracking of photovoltaic systems under partial shading condition,” Energy Sources, Part A: Recovery, Utilization, and Environmental Effects, vol. 0, no. 0, pp. 1-19, 2019.

S. Rajput , E. Bender , M. Averbukh , Simplified algorithm for assessment equivalent circuit parameters of induction motors, IET Electric Power Applications, 14 (2020) 426-432. M. Chamanpira , M. Ghahremani , S. Dadfar , M. Khaksar , A. Rezvani , and K. Wakil , “A novel mppt technique to increase accuracy in photovoltaic systems under variable atmospheric conditions using fuzzy gain scheduling,” Energy Sources, Part A: Recovery, Utilization, and Environmental Effects, vol. 0, no. 0, pp. 1-23, 2019.

Sharma, A. , Sharma, A. , Averbukh, M. , Rajput, S. , Jately, V. , Choudhury, S. , & Azzopardi, B. (2022). Improved moth flame optimization algorithm based on opposition-based learning and Lévy flight distribution for parameter estimation of solar module. Energy Reports, 8, 6576-6592.

D. K. Mathi and R. Chinthamalla , “A hybrid global maximum power point tracking method based on butterfly particle swarm optimization and perturb and observe algorithms for a photovoltaic system under partially shaded conditions.,” in Wiley International Transactions on Electrical Energy Systems, vol. 30, no. 10, e12543, 2020, .

D. K. Mathi and R. Chinthamalla , “Global maximum power point tracking technique based on adaptive salp swarm algorithm and P&O techniques for a PV string under partially shaded conditions.,” in Taylor & Francis; Energy Sources, Part A: Recovery, Utilization, and Environmental Effects, 2020, doi: 10.1080/15567036.2020.1755391.

D. K. Mathi and R. Chinthamalla , “A Hybrid Global Maximum Power Point Tracking of Partially Shaded PV System under Load Variation by Using Adaptive Salp Swarm and Differential Evolution - Perturb & Observe Technique.,” in Taylor & Francis; Energy Sources, Part A: Recovery, Utilization, and Environmental Effects, 2020, doi: 10.1080/15567036.2020.1850927.

Application of a Polymer Nanocomposite for Energy Harvesting

J. Zhao , A. K. Patwary , A. Qayyum , M. Alharthi , F. Bashir , M. Mohsin , I. Hanif , and Q. Abbas , The determinants of renewable energy sources for the fueling of green and sustainable economy, Energy, 238 (2022) 122029. https://doi.org/10.1016/j.energy.2021.122029

H. Husin , M. Zaki , A critical review of the integration of renewable energy sources with various technologies, Protection and Control of Modern Power Systems, 6(2021)1–18. https://doi.org/10.1186/s41601-021-00181-3

G. S. Aleman-Nava , V. H. Casiano-Flores , D. L. Cardenas-Chavez , R. Diaz-Chavez , N. Scarlat , J. Mahlknecht , J. F. Dallemand , R. Parra , Renewable energy research progress in Mexico: A review, Renew. Sustain. Energy Rev. 32 (2014) 140–153. https://doi.org/10.1016/j.rser.2014.01.004

S. Mishra , L. Unnikrishnan , S. K. Nayak , S. Mohanty , Advances in Piezoelectric Polymer Composites for Energy Harvesting Applications ă: A Systematic Review, Macromol. Mater. Eng. 1800463 (2019) 1–25. https://doi.org/10.1002/mame.201800463

G. J. Snyder , E. S. Toberer , Complex thermoelectric materials, Mater. Sustain. Energy a Collect. Peer-Reviewed Res. Rev. Artic. from Nat. Publ. Gr. (2011) 101–110. https://doi.org/10.1142/9789814317665_0016

H. Peng , X. Sun , W. Weng , X. Fang , Polymer materials for energy and electronic applications. Academic Press; 2016 Sep 1. https://doi.org/10.1016/C2015-0-01541-6

S. Patidar , Applications of Thermoelectric Energy: A Review, Int. J. Res. Appl. Sci. Eng. Technol. 6 (2018) 1992–1996. https://doi.org/10.22214/ijraset.2018.5325.

D. Enescu , Thermoelectric energy harvesting: basic principles and applications. Green energy advances. 2019 Jan 21:1. https://doi.org/10.5772/intechopen.83495

G. Sebald , D. Guyomar , A. Agbossou , On thermoelectric and pyroelectric energy harvesting, Smart Mater. Struct. 18 (2009). https://doi.org/10.1088/0964-1726/18/12/125006.

X. F. Zheng , C. X. Liu , Y. Y. Yan , Q. Wang , A review of thermoelectrics research-Recent developments and potentials for sustainable and renewable energy applications, Renew. Sustain. Energy Rev. 32 (2014) 486–503. https://doi.org/10.1016/j.rser.2013.12.053

H. C. Nayak , S. S. Parmar , R. P. Kumhar , S. Rajput , Modulation in Electric Conduction of PVK and Ferrocene-Doped PVK Thin Films, Electron. Mater., 3 (2022) 53–62. https://doi.org/10.3390/electronicmat3010005

D. Zhao , G. Tan , A review of thermoelectric cooling: materials, modeling and applications, Appl. Therm. Eng. 66 (2014) 15–24. https://doi.org/10.1016/j.applthermaleng.2014.01.074

N. Espinosa , M. Lazard , L. Aixala , H. Scherrer , Modeling a thermoelectric generator applied to diesel automotive heat recovery, J. Electron. Mater. 39 (2010) 1446–1455. https://doi.org/10.1007/s11664-010-1305-2

S. P. Muduli , S. Parida , S. K. Behura , S. Rajput , S. K. Rout , S. Sareen , Synergistic effect of graphene on dielectric and piezoelectric characteristic of PVDF-(BZT-BCT) composite for energy harvesting applications, Polym. Adv. Technol., 33 (2022) 3628–3642. https://doi.org/10.1002/pat.5816

Q. E. Hussain , D. R. Brigham , C. W. Maranville , Thermoelectric exhaust heat recovery for hybrid vehicles, SAE Int. J. Engines. 2 (2009) 1132–1142. https://www.jstor.org/stable/26308459

B. A. Papkin , N. A. Khripach , V. S. Korotkov , D. A. Ivanov , Thermoelectric generator for a vehicle engine cooling system research and development, Int. J. Appl. Eng. Res. 11 (2016) 8557–8564. https://doi.org/10.1016/j.ijft.2021.100063

J. Lofy , L. E. Bell , Thermoelectrics for environmental control in automobiles, In Twenty-First Int. Conf. Thermoelectr. 2002. Proc. ICT’02., 2002: pp. 471–476. https://doi.org/10.1109/ICT.2002.1190362.

C. A. Howells , Piezoelectric energy harvesting, Energy Convers. Manag. 50 (2009) 1847–1850. https://doi.org/10.1016/j.enconman.2009.02.020.

T. Yucel , P. Cebe , D. L. Kaplan , Structural origins of silk piezoelectricity, Adv. Funct. Mater. 21 (2011) 779–785. https://doi.org/10.1002/adfm.201002077.

E. Fukada , Piezoelectricity of wood, J. Phys. Soc. Japan. 10 (1955) 149–154. https://doi.org/10.1143/JPSJ.10.149

E. Fukada , I. Yasuda , On the piezoelectric effect of bone, J. Phys. Soc. Japan. 12 (1957) 1158–1162. https://doi.org/10.1143/JPSJ.12.1158

D. C. Mountain , A. E. Hubbard , A piezoelectric model of outer hair cell function, J. Acoust. Soc. Am. 95 (1994) 350–354. https://doi.org/10.1121/1.408273

V. Kumar , A. Kumar , S. S. Han , S.-S. Park , RTV silicone rubber composites reinforced with carbon nanotubes, titanium-di-oxide and their hybrid: Mechanical and piezoelectric actuation performance, Nano Mater. Sci. 3 (2021) 233–240. https://doi.org/10.1016/j.nanoms.2020.12.002

S. S. Rajput , S. Keshri , Structural and microwave properties of (Mg, Zn/Co)TiO3 dielectric ceramics. J. Mater. Eng. Perform., 23 (2014) 2103–2109. https://doi.org/10.1007/s11665-014-0950-7

B. D. Zaitsev , I. E. Kuznetsova , S. G. Joshi , I. A. Borodina , Shearhorizontal acoustic waves in piezoelectric plates bordered with conductive liquid, IEEE Trans. Ultrason. Ferroelectr. Freq. Control. 48 (2001) 627–631. https://doi.org/10.1109/58.911748

T. Satyanarayana , G. Srinivas , M. S. Prasad , Y. Srinivas , B. Sudheer , K. S. Rao , Design and analysis of MEMS based composite piezoelectric ultrasonic transducer, Electr. Electron. Eng. 2 (2012) 362–373. https://doi.org/10.5923/j.eee.20120206.04

S. Rajput , X. Ke , X. Hu , M. Fang , D. Hu , F. Ye , X. Ren , Critical triple point as the origin of giant piezoelectricity in PbMg1/3Nb2/3O3- PbTiO3 system. J. Appl. Phys., 128 (2020) 104105. https://doi.org/10.1063/5.0021765

Sonika, S. K. Verma , S. Samanta , A. K. Srivastava , S. Biswas , R. M. Alsharabi , S. Rajput , Conducting Polymer Nanocomposite for Energy Storage and Energy Harvesting Systems. Adv. Mater. Sci. Eng., 2022 (2022) 1–23. https://doi.org/10.1155/2022/2266899

Sonika, S. K. Verma , J. Saha , R. M. Alsharabi , S. Rajput , Microarticstructural, Spectroscopic, and Magnetic Analysis of Multiwalled Carbon Nanotubes Embedded in Poly (o-aminophenol) Matrices. Adv. Mater. Sci. Eng., 2022 (2022.) 1–9.

L. Mateu , F. Moll , Optimum piezoelectric bending beam structures for energy harvesting using shoe inserts, J. Intell. Mater. Syst. Struct. 16 (2005) 835–845. https://doi.org/10.1177/1045389X0505528

J. Granstrom , J. Feenstra , H. A. Sodano , K. Farinholt , Energy harvesting from a backpack instrumented with piezoelectric shoulder straps, Smart Mater. Struct. 16 (2007) 1810. https://doi.org/10.1088/0964-1726/16/5/036

B. J. Hansen , Y. Liu , R. Yang , Z. L. Wang , Hybrid nanogenerator for concurrently harvesting biomechanical and biochemical energy, ACS Nano. 4 (2010) 3647–3652. https://doi.org/10.1021/nn100845b

W. Liu , X. Cheng , X. Fu , C. Stefanini , P. Dario , Preliminary study on development of PVDF nanofiber based energy harvesting device for an artery microrobot, Microelectron. Eng. 88 (2011) 2251–2254. https://doi.org/10.1016/j.mee.2011.02.098

D. Koyama , K. Nakamura , Electric power generation using vibration of a polyurea piezoelectric thin film, Appl. Acoust., 71 (2010) 439–445. https://doi.org/10.1016/j.apacoust.2009.11.009

C. M. T. Tien , N. S. Goo , Use of a piezocomposite generating element in energy harvesting, J. Intell. Mater. Syst. Struct. 21 (2010) 1427–1436. https://doi.org/10.1177/1045389X10381658

C. R. Bowen , J. Taylor , E. Leboulbar , D. Zabek , A. Chauhan , R. Vaish , Pyroelectric materials and devices for energy harvesting applications, Energy Environ. Sci. 7 (2014) 3836–3856. https://doi.org/10.1039/c4ee01759e.

A. D. Lantada , P. L. Morgado , H. Hugo , H. Lorenzo-Yustos , J. E. Otero , J. M. Munoz-Guijosa , J. Munoz-Garcia , J. Luis , M. Sanz , Modelling and Trials of Pyroelectric Sensors for Improving Its Application for Biodevices, In Proceedings of the International Conference on Biomedical Electronics and Devices - Volume 1: Special Session AMMD (BIOSTEC 2009), 453–457, 2009, Porto, Portugal. https://doi.org/10.5220/0001828304530457.

S. S. Rajput , S. Keshri , Structural, vibrational and microwave dielectric properties of (1-x)Mg0.95Co0.05TiO3-(x)Ca0.8Sr0.2TiO3 ceramic composites, Journal of alloys and compounds, 581 (2013) 223–229. https://doi.org/10.1016/j.jallcom.2013.05.225

C. Mart , T. Kampfe , R. Hoffmann , S. Eslinger , S. Kirbach , K. Kuhnel , M. Czernohorsky , L. M. Eng , W. Weinreich , Piezoelectric Response of Polycrystalline Silicon-Doped Hafnium Oxide Thin Films Determined by Rapid Temperature Cycles, Adv. Electron. Mater. 6 (2020) 1–5. https://doi.org/10.1002/aelm.201901015.

H. Zhang , Y. Xie , X. Li , Z. Huang , S. Zhang , Y. Su , B. Wu , L. He , W. Yang , Y. Lin , Flexible pyroelectric generators for scavenging ambient thermal energy and as self-powered thermosensors, Energy, 101 (2016) 202–210. https://doi.org/10.1016/j.energy.2016.02.002.

Y. Yang , H. Zhang , G. Zhu , S. Lee , Z. H. Lin , Z. L. Wang , Flexible hybrid energy cell for simultaneously harvesting thermal, mechanical, and solar energies, ACS Nano, 7 (2013) 785–790. https://doi.org/10.1021/nn305247x.

Y. Li , Molecular Design of Photovoltaic Materials for Polymer Solar Cellsă: Toward Suitable Electronic Energy Levels and Broad Absorption, Accounts Chem. Res., 45 (2012) 723–733. https://doi.org/10.1021/ar2002446

C. Dun , C. A. Hewitt , H. Huang , J. Xu , D. S. Montgomery , W. Nie , Q. Jiang , D. L. Carroll , Layered Bi2Se3 Nanoplate/Polyvinylidene Fluoride Composite Based n-type Thermoelectric Fabrics, ACS Appl. Mater. Interfaces, 7(13), pp. 7054–7059. https://doi.org/10.1021/acsami.5b00514

S. Rajput , M. Averbukh , A. Yahalom , T. Minav , An Approval of MPPT Based on PV Cell's Simplified Equivalent Circuit During Fast-Shading Conditions, Electronics, 8 (2019) 1060. https://doi.org/10.3390/electronics8091060

G. P. Smestad , F. C. Krebs , C. M. Lampert , C. G. Granqvist , K. L. Chopra , X. Mathew , and H. Takakura , Reporting solar cell efficiencies in solar energy materials and solar cells. Sol. Energy Mater. Sol. Cells, 92 (2008) 371–373. https://doi.org/10.1016/j.solmat.2008.01.003

B. C. Brabec , A. Cravino , D. Meissner , N. S. Sariciftci , T. Fromherz , M. T. Rispens , L. Sanchez , J. C. Hummelen , Origin of the open circuit voltage of plastic solar cells. Adv. Funct. Mater., 11 (2001) 374–380. https://doi.org/10.1002/1616-3028(200110)11:5

X. Guo , N. Zhou , S. J. Lou , J. Smith , D. B. Tice , J. W. Hennek , S. Li , J. Strzalka , L. X. Chen , P. Ortiz , J. T. Lo , Polymer solar cells with enhanced fill factors, Nat. Photonics, 7 (2013) 825–833. https://doi.org/10.1038/nphoton.2013.207.

J. Lv , Y. Cheng , Fluoropolymers in biomedical applications: state-ofthe- art and future perspectives, Chemical Society Reviews, 50 (2021) 5435–5467. https://doi.org/10.1039/D0CS00258E

D. Vatansever , R. L. Hadimani , T. Shah , E. Siores , An investigation of energy harvesting from renewable sources with PVDF and PZT, Smart Mater. Struct. 20 (2011). https://doi.org/10.1088/0964-1726/20/5/055019.

D. Zabek , K. Seunarine , C. Spacie , C. Bowen , Graphene Ink Laminate Structures on Poly(vinylidene difluoride) (PVDF) for Pyroelectric Thermal Energy Harvesting and Waste Heat Recovery, ACS Appl. Mater. Interfaces. 9 (2017) 9161–9167. https://doi.org/10.1021/acsami.6b16477.

X. Liu , X. Zhao , Y. Yu , Y. Wang , Y. Shi , Q. Cheng , Z. Fang , Y. Yong , Facile fabrication of conductive polyaniline nanoflower modified electrode and its application for microbial energy harvesting, Electrochim. Acta., 255 (2017) 41–47.

T. Badapanda , R. Harichandan , T. B. Kumar , S. Parida , S. S. Rajput , P. Mohapatra , R. Ranjan , Improvement in dielectric and ferroelectric property of dysprosium doped barium bismuth titanate ceramic, J. Mater. Sci.: Mater. Electron., 27 (2016) 7211–7221. https://doi.org/10.1007/s10854-016-4686-z

J. Lu , K. S. Moon , B. K. Kim , C. P. Wong , High dielectric constant polyaniline/epoxy composites via in situ polymerization for embedded capacitor applications, Polymer, 48 (2007) 1510–1516. https://doi.org/10.1016/j.polymer.2007.01.057.

V. Gupta , N. Miura , Polyaniline/single-wall carbon nanotube (PANI/SWCNT) composites for high performance supercapacitors, Electrochim. Acta. 52 (2006) 1721–1726. https://doi.org/10.1016/j.electacta.2006.01.074.

P. Y. Stakhira , O. I. Aksimentyeva , B. R. Cizh , V. V. Cherpak , Hybrid solar cells based on dispersed InSe-polyaniline composites, Phys. Chem. Solid State. 6 (2005) 96–98.

Z. Liu , J. Zhou , H. Xue , L. Shen , H. Zang , W. Chen , Polyaniline/ TiO2 solar cells, Synth. Met. 156 (2006) 721–723. https://doi.org/10.1016/j.synthmet.2006.04.001.

C. Zhao , S. Xing , Y. Yu , W. Zhang , C. Wang , A novel all-plastic diode based upon pure polyaniline material, Microelectronics J. 38 (2007) 316–320. https://doi.org/10.1016/j.mejo.2007.01.004.

K. Ghanbari , M. F. Mousavi , M. Shamsipur , Preparation of polyaniline nanofibers and their use as a cathode of aqueous rechargeable batteries, Electrochim. Acta. 52 (2006) 1514–1522. https://doi.org/10.1016/j.electacta.2006.02.051.

W. Wang , E. A. Schiff , W. Wang , E. A. Schiff , Polyaniline on crystalline silicon heterojunction solar cells Polyaniline on crystalline silicon heterojunction solar cells, Appl. Phys. Lett., 91 (2007)133504. https://doi.org/10.1063/1.2789785.

M. Khalifa , S. Anandhan , PVDF Nanofibers with Embedded Polyaniline - Graphitic Carbon Nitride Nanosheet Composites for Piezoelectric Energy Conversion, ACS Appl. Nano Mater., 2 (2019) 7328–7339. https://doi.org/10.1021/acsanm.9b01812.

U. Johanson , A. Punning , A. Aabloo , Ionic polymer metal composites with electrochemically active electrodes, RSC Smart Mater. 2016 (2016) 215–227. https://doi.org/10.1039/9781782622581-00215.

V. F. Ferreira , M. C. B. V. de Souza , A. C. Cunha , L. O. R. Pereira , M. L. G. Ferreira , Recent advances in the synthesis of pyrroles, Org. Prep. Proced. Int. 33 (2001) 411–454.

M. Bharti , A. Singh , S. Samanta , A. K. Debnath , D. K. Aswal , K. P. Muthe , S. C. Gadkari , Flexo-green Polypyrrole-Silver nanocomposite films for thermoelectric power generation, Energy Convers. Manag. 144 (2017) 143–152.

M. Culebras , B. Uriol , C. M. Gomez , A. Cantarero , Controlling the thermoelectric properties of polymers: Application to PEDOT and polypyrrole, Phys. Chem. Chem. Phys. 17 (2015) 15140–15145. https://doi.org/10.1039/c5cp01940k.

J. Xu , Y. Tan , X. Du , Z. Du , X. Cheng , H. Wang , Cellulose nanofibril/ polypyrrole hybrid aerogel supported form-stable phase change composites with superior energy storage density and improved photothermal conversion efficiency, Cellulose. 27 (2020) 9547–9558. https://doi.org/10.1007/s10570-020-03437-7

M. Silakhori , H. Fauzi , M. R. Mahmoudian , H. S. C. Metselaar , T. M. I. Mahlia , H. M. Khanlou , Preparation and thermal properties of form-stable phase change materials composed of palmitic acid/polypyrrole/graphene nanoplatelets, Energy Build., 99 (2015) 189–195. https://doi.org/10.1016/j.enbuild.2015.04.042

A. Singh , A. Sharma , S. Rajput , A. K. Mondal , A. Bose , and M. Ram , Parameter Extraction of Solar Module Using the Sooty Tern Optimization Algorithm, Electronics, 11 (2022) 564. https://doi.org/10.3390/electronics11040564

B. Ponraj , R. Bhimireddi , K. B. R. Varma , Effect of nano-and micronsized K0.5Na0.5NbO3 fillers on the dielectric and piezoelectric properties of PVDF composites, J. Adv. Ceram., 5 (2016) 308–320. https://doi.org/10.1007/s40145-016-0204-2

A. Singh , A. Sharma , S. Rajput , A. Bose , and X. Hu , An Investigation on Hybrid Particle Swarm Optimization Algorithms for Parameter Optimization of PV Cells, Electronics, 11 (2022)909. https://doi.org/10.3390/electronics11060909

A. Mohammadi , M. Hossein , M. Bidi , M. Ghazvini , Exergy and economic analyses of replacing feedwater heaters in a Rankine cycle 140 *Application of a Polymer Nanocomposite for Energy Harvesting* with parabolic trough collectors, Energy Reports, 4 (2018) 243–251. https://doi.org/10.1016/j.egyr.2018.03.001.

D. Rojas , J. Beermann , S. A. Klein , D. T. Reindl , Thermal performance testing of flat-plate collectors, Solar Energy, 82 (2008) 746–757. https://doi.org/10.1016/j.solener.2008.02.001.

S. Rajput , A. Lugovskoy , M. Averbukh , A. Yahalom , Porous Metal- Oxide Based Electrostatic Energy Generator. In 2019 International IEEE Conference and Workshop in Obuda on Electrical and Power Engineering (CANDO-EPE) (pp. 133–136). https://doi.org/10.1109/CANDO-EPE47959.2019.9110961

R. Tang , Y. Yang , W. Gao , Comparative studies on thermal performance of water-in-glass evacuated tube solar water heaters with different collector tilt-angles, Sol. Energy. 85 (2011) 1381–1389. https://doi.org/10.1016/j.solener.2011.03.019.

K. Y. Leong , H. Chyuan , N. H. Amer , M. J. Norazrina , M. S. Risby , K. Z. K. Ahmad , An overview on current application of nano fl uids in solar thermal collector and its challenges, Renew. Sustain. Energy Rev. 53 (2016) 1092–1105. https://doi.org/10.1016/j.rser.2015.09.060.

F. S. Javadi , R. Saidur , M. Kamalisarvestani , Investigating performance improvement of solar collectors by using nano fl uids, Renew. Sustain. Energy Rev. 28 (2013) 232–245. https://doi.org/10.1016/j.rser.2013.06.053.

A. Sharma , A. Sharma , V. Jately , M. Averbukh , S. Rajput , and B. Azzopardi , A Novel TSA-PSO Based Hybrid Algorithm for GMPP Tracking under Partial Shading Conditions, Energies, 15 (2022) p. 3164. https://doi.org/10.3390/en15093164

L. Zhang , Y. Ding , M. Povey , D. York , ZnO nanofluids–A potential antibacterial agent, Prog. Nat. Sci., 18 (2008) 939–944. https://doi.org/10.1016/j.pnsc.2008.01.026.

K. Nakata , A. Fujishima , TiO2 photocatalysis: Design and applications, J. Photochem. Photobiol. C Photochem. Rev. 13 (2012) 169–189.

S. Rajput , M. Averbukh , N. Rodriguez , Energy Harvesting and Energy Storage Systems. Electronics, 11 (2022) 984.

D. V. Bavykin , J. M. Friedrich , F. C. Walsh , Protonated titanates and TiO2 nanostructured materials: synthesis, properties, and applications, Adv. Mater. 18 (2006) 2807–2824.

S.-J. Bao , C. M. Li , J.-F. Zang , X.-Q. Cui , Y. Qiao , J. Guo , New nanostructured TiO2 for direct electrochemistry and glucose sensor applications, Adv. Funct. Mater., 18 (2008) 591–599.

K. Nakata , A. Fujishima , Photochemistry Reviews TiO2 photocataly-sis: Design and applications, J. Photochem. Photobiol. C, 13 (2012) 169–189. https://doi.org/10.1016/j.jphotochemrev.2012.06.001.

W. U. Huynh , J. J. Dittmer , A. P. Alivisatos , Hybrid nanorod-polymer solar cells, Science, 295 (2002) 2425–2427.

X. Hu , S. Rajput , S. Parida , J. Li , W. Wang , L. Zhao , X. Ren , Electros-train Enhancement at Tricritical Point for $BaTi_{1-x}Hf_{x}O_3$ Ceramics. J. Mater. Eng. Perform., 29 (2020) 5388–5394.https://doi.org/10.1007/s11665-020-05003-5

L. Zhao , Z. Lin , Crafting semiconductor organic-inorganic nanocom-posites via placing conjugated polymers in intimate contact with nanocrystals for hybrid solar cells, Adv. Mater., 24 (2012) 4353–4368.

C. W. Tang , Two-layer organic photovoltaic cell, Appl.Phys.Lett., 48 (1986) 183–185. https://doi.org/10.1063/1.96937.

J. D. Major , R. E. Treharne , L. J. Phillips , K. Durose , A low-cost non-toxic post-growth activation step for CdTe solar cells, Nature, 511 (2014) 334–337. https://doi.org/10.1038/nature13435.

J. Yan , B. R. Saunders , RSC Advances Third-generation solar cellsă: a review and comparison of polymer: fullerene, hybrid polymer and perovskite solar cells, RSC Adv., 4 (2014) 43286–43314. https://doi.org/10.1039/C4RA07064J.

K. Saranya , A. Subramania , Developments in conducting polymer based counter electrodes for dye-sensitized solar cells - An overview, Eur. Polym. J., 66 (2015) 207–227. https://doi.org/10.1016/j.eurpolymj.2015.01.049.

A. Sharma , A. Sharma , M. Averbukh , S. Rajput , V. Jately , S. Choudhury , B. Azzopardi , Improved moth flame optimization algorithm based on opposition-based learning and Lévy flight distribution for parameter estimation of solar module, Energy Reports, 8 (2022) 6576–6592. https://doi.org/10.1016/j.egyr.2022.05.011

S. Collavini , S. F. Vçlker , J. L. Delgado , Understanding the Outstanding Power Conversion Efficiency of Perovskite-Based Solar Cells, Angew. Chem. Int. Ed., 54 (2015) 9757–9759. https://doi.org/10.1038/srep00591.

G. C. Bakos , Feasibility study of a hybrid wind/hydro power-system for low-cost electricity production, Applied Energy, 72 (2002) 599–608. https://doi.org/10.1016/S0306-2619(2)00045-4.

S. Rajput , M. Averbukh , A. Yahalom , Electric power generation using a parallel-plate capacitor, Int. J. Energy Res, 43 (2019) 3905–3913. https://doi.org/10.1002/er.4492

K. K. Sahoo , S. S. Rajput , R. Gupta , A. Roy , A. Garg , Nd and Ru co-doped bismuth titanate polycrystalline thin films with improved ferroelectric properties, J. Phys. D: Appl. Phys., 51 (2018) 055301. https://doi.org/10.1088/1361-6463/aa9fa5

M. M. Wienk , M. G. R. Turbiez , M. P. Struijk , M. Fonrodona , R. A. J. Janssen , M. M. Wienk , M. G. R. Turbiez , M. P. Struijk , Low-band gap poly (di-2-thienylthienopyrazine): fullerene solar cells, Appl. Phys. Lett., 88 (2006) 153511. https://doi.org/10.1063/1.2195897.

S. Dayal , N. Kopidakis , D. C. Olson , D. S. Ginley , G. Rumbles , Photovoltaic Devices with a Low Band Gap Polymer and CdSe Nanos-tructures Exceeding 3 % Efficiency, Nano letters, 10 (2010) 239–242. https://doi.org/10.1021/nl903406s.

Z. A. Peng , X. Peng , Formation of High-Quality CdTe, CdSe, and CdS Nanocrystals Using CdO as Precursor, J. Am. Chem. Soc., 123 (2001), 183-184. https://doi.org/10.1021/ja003633m

S. Keshri , S. Rajput , S. Biswas , L. Joshi , W. Suski , P. Wiśniewski , Structural, magnetic and transport properties of Ca and Sr doped Lanthanum manganites, J. Met. Mater. Miner., 31 (2021) 62–68.https://doi.org/10.14456/jmmm.2021.58

A. Ghani , S. Yang , S. Rajput , S. Ahmed , A. Murtaza , C. Zhou , X. Song , Tuning the conductivity and magnetism of silicon coated multiferroic GaFeO3 nanoparticles. J. Sol-Gel Sci.

Technol., 92 (2019) 224–230.ht tps://doi.org/10.1007/s10971-019-05096-y

P. D. Cozzoli , A. Kornowski , H. Weller , Low-Temperature Synthesis of Soluble and Processable Organic-Capped Anatase TiO2 Nanorods, Journal of the American chemical society, 125 (2003) 14539–14548. https://doi.org/10.1021/ja036505h

X. Wang , J. Zhuang , Q. Peng , Y. Li , A general strategy for nanocrystal synthesis, Nature, 437 (2005) 121–124. https://doi.org/10.1038/nature03968.

S. M. Liu , L. M. Gan , L. H. Liu , W. D. Zhang , H. C. Zeng , Synthesis of Single-Crystalline TiO2 Nanotubes, Chemistry of materials, 14 (2005) 1391–1397.https://doi.org/10.1021/cm0115057

J. H. Park , S. Kim , A. J. Bard , Novel Carbon-Doped TiO 2 Nanotube Arrays with High Aspect Ratios for Efficient Solar Water Splitting, Nano letters, 6 (2006) 24–28. https://doi.org/10.1021/nl051807y

Y. Xie , P. Joshi , S. B. Darling , Q. Chen , T. Zhang , D. Galipeau , Q. Qiao , Electrolyte Effects on Electron Transport and Recombination at ZnO Nanorods for Dye-Sensitized Solar Cells, The Journal of Physical Chemistry C, 114 (2010) 17880–17888.https://doi.org/10.1021/jp106302m

C. Hung , W. Whang , A novel low-temperature growth and characterization of single crystal ZnO nanorods, Materials Chemistry and Physics 82 (2003) 705–710. https://doi.org/10.1016/S0254-0584(3)00331-6.

A. M. Peiro , P. Ravirajan , K. Govender , D. S. Boyle , P. O. Brien , D. D. C. Bradley , J. R. Durrant , Hybrid polymer / metal oxide solar cells based on ZnO columnar structures, Journal of Materials Chemistry, 16 (2006) 2088–2096. https://doi.org/10.1039/b602084d.

S. Zhang , Y. Shen , H. Fang , S. Xu , Z. Lin , Growth and replication of ordered ZnO nanowire arrays on general flexible substrates, Journal of Materials Chemistry 20 (2010) 10606–10610. https://doi.org/10.1039/c0jm02915g.

L. E. Greene , B. D. Yuhas , M. Law , D. Zitoun , P. Yang , Solution Grown Zinc Oxide Nanowires, Inorganic chemistry, 45 (2006) 4977–4984. https://doi.org/10.1021/ic0601900

D. S. Ginger , N. C. Greenham , Charge separation in conjugated-polymer/nanocrystal blends, Synthetic Metals, 101 (1999) 425–428. https://doi.org/10.1016/S0379-6779\(98)00330-0

J. Boucle , J. Nelson , Hybrid polymer – metal oxide thin films for photovoltaic applications, Journal of Materials Chemistry 17 (2007) 3141–3153. https://doi.org/10.1039/b706547g.

S. Tepavcevic , S. B. Darling , N. M. Dimitrijevic , T. Rajh , J. Sibener , Improved Hybrid Solar Cells via in situ UV Polymerization, Small, 5 (2009) 1776–1783. https://doi.org/10.1002/smll.200900093.

S. Dwivedi , H. C. Nayak , S. S. Parmar , R. P. Kumhar , S. Rajput , Calci-nation temperature reflected structural, optical and magnetic properties of nickel oxide. Magnetism, 2 (2022) 45–55. https://doi.org/10.3390/magnetism2010004

Y. Hao , J. Pei , Y. Wei , Y. Cao , S. Jiao , F. Zhu , J. Li , D. Xu , Efficient Semiconductor-Sensitized Solar Cells Based on Poly (3 hexylthiophene)@CdSe@ZnO Core-Shell Nanorod Arrays, J. Phys. Chem. C, 114 (2010) 8622–8625. https://doi.org/10.1021/jp911263d

S. D. Oosterhout , M. M. Wienk , S. S. Van Bavel , R. Thiedmann , L. J. A. Koster , J. Gilot , J. Loos , V. Schmidt , R. A.J. Janssen , the efficiency of hybrid polymer solar cells, Nat. Mater. 8 (2009) 818–824. https://doi.org/10.1038/nmat2533.

H. Savin , P. Repo , G. Gastrow , P. Ortega , E. Calle , M. Garin , R. Alcubilla , Black silicon solar cells with inter-digitated back contacts achieve 22.1% efficiency, Nat. Nanotech. 10 (2015) 624–628.

Fabrication of Piezoelectric Material and Energy Harvesting While Walking

Frank, R. (2005). Handbook of modern sensors: physics, designs, and applications. Anal Bioanal Chem 382, 8–9. doi: 10.1007/s00216-0043037-8.

Howells, C. A. (2009) Piezoelectric energy harvesting, Energy Conservation and Management, 50(7), 1847–1847. doi: 10.1016/j.enconman.2009.02.020.

Swallow, L. M. , Luo, J. K. , Siores, E. , Patel, I. , & Dodds, D. (2008). A piezoelectric fibre composite based energy harvesting device for potential wearable applications. Smart Materials and Structures, 17(2), 025017. doi: 10.1088/0964-1726/17/2/025017/meta.

Covaci, C. , & Gontean, A. (2020). Piezoelectric Energy Harvesting Solutions: A Review. Sensors (Basel, Switzerland), 20(12), 3512. doi: 10.3390/s201235122.

Minazara, E. , Vasic, D. , Costa, F. , & Poulin, G. (2006). Piezoelectric diaphragm for vibration energy harvesting. Ultrasonics, 44 Suppl 1, e699–e703. doi: 10.1016/j.ultras.2006.05.141.

Zhao, J. , & You, Z. (2014). A shoe-embedded piezoelectric energy harvester for wearable sensors. Sensors, 14(7), 12497–12510. doi: 10.3390/s140712497.

Xue, H. , Hu, Y. , & Wang, Q. M. (2008). Broadband piezoelectric energy harvesting devices using multiple bimorphs with different operating frequencies. IEEE transactions on ultrasonics, ferroelectrics, and frequency control, 55(9), 2104–2108. doi: 10.1109/tuffc.903.

Umeda, M. , Nakamura, K. and Ucha, S. (1996). Analysis of Transformation of Mechanical Impact Energy to Electrical Energy Using a Piezoelectric Vibrator. Japanese Journal of Applied Physics, 35(1), 3267–3267. doi: 10.1143/JJAP.35.3267.

Granstrom J. , Feenstra J. , Sodano H. A. , Farinholt K. (2007). Energy harvesting from a backpack instrumented with piezoelectric shoulder straps. Smart Mater. Struct., 16(5), 1810–1810. doi: 10.1088/09641726/16/5/036.

Yang B. , Kwang-Seok Y. (2012). Piezoelectric shell structures as wearable energy harvesters for effective power generation at lowfrequency movement. Sens. Actuators A Phys., 188, 427–433. doi: 10.1016/j.sna.2012.03.026

Choi, W. B. (2001) Potassium Sodium Tartrate, John Wiley & Sons.

Egbe, K-J. I. , Nazar, A. M. , Jiao, P. , Yang, Y. , Ye, X. , Wang, H. , (2021). Vibrational turbine piezoelectric nanogenerators for energy harvesting in multiphase flow fields. Energy Reports, 6384–6393. doi: 10.1016/j.egyr.2021.09.085.

Kenji Uchino . (2010). Advanced Piezoelectric Materials. Woodhead Publishing Series in Electronic and Optical Materials.

Kymissis, J. , Kendall, C. , Paradiso, J. , & Gershenfeld, N. (1998, October). Parasitic power harvesting in shoes. In Digest of papers. Second international symposium on wearable computers (Cat. No. 98EX215) (pp. 132–139). IEEE. doi: 10.1109/ISWC.1998.7295399.

Sodano, H. A. , Inman, D. J. and Park, G. (2004) A Review of Power Harvesting from Vibration Using Piezoelectric Materials. The Shock and Vibration Digest, 36, 197–205. doi: 10.1177/0583102404043275

Jo, S. H. , Yoon, H. , Shin, Y. C. , Youn, B. D. , (2021). An analytical model of a phononic crystal with a piezoelectric defect for energy harvesting using an electro elastically coupled transfer matrix. International Journal of Mechanical Sciences, 193, 106160. doi: 10.1016/j.ijmecsci.2020.106160.

Shao, H. , Chen, G. , He, H. , (2021). Elastic wave localization and energy harvesting defined by piezoelectric patches on phononic crystal waveguide. Physics Letters A, 403. doi: 10.1016/j.physleta.2021.127366.

Jo, S. H. , Yoon, H. , Shin, Y. C. , Youn, B. D. , (2021). An analytical model of a phononic crystal with a piezoelectric defect for energy harvesting using an electroelastically coupled transfer matrix. International Journal of Mechanical Sciences, 193, 106160. doi: 10.1016/j.ijmecsci.2020.106160.

Shao, H. , Chen, G. , He, H. , (2021). Elastic wave localization and energy harvesting defined by piezoelectric patches on phononic crystal waveguide. Physics Letters A, 403. doi: 10.1016/j.physleta.2021.127366

Zaarour, B. , Zhu, L. , Huang, C. , Jin, X. , Alghafari, H. , Fang, J. , & Lin, T. (2021). A review on piezoelectric fibers and nanowires for energy harvesting. Journal of Industrial Textiles, 51(2), 297–340. doi: 10.1177/1528083719870197

Lu, Z. Q. , Chen, J. , Ding, H. , Chen, L. Q. , (2022). Energy harvesting of a fluid-conveying piezoelectric pipe. Applied Mathematical Modelling, 107, 165–181. doi: 10.1016/j.apm.2022.02.027.

Starner, T. , & Paradiso, J. A. (2004). Human generated power for mobile electronics. Low-power electronics design, 45, 1–35.

Ishida, K. , Huang, T. C. , Honda, K. , Shinozuka, Y. , Fuketa, H. , Yokota, T & Sakurai, T. (2012). Insole pedometer with piezoelectric energy harvester and 2 V organic circuits. IEEE Journal of Solid-State Circuits, 48(1), 255–264. doi: 10.1109/JSSC.2012.2221253.

Overview of Swarm Intelligence Techniques for Harvesting Solar Energy

Ghannam, R. , P. V. Klaine , and M. Imran , Artificial intelligence for photovoltaic systems, in Solar Photovoltaic Power Plants. 2019, Springer. p. 121–142.

Sharma, A. , et al., Improved moth flame optimization algorithm based on opposition-based learning and Lévy flight distribution for parameter estimation of solar module. Energy Reports, 2022. 8: p. 6576–6592.

Marini, F. and B. Walczak , Particle swarm optimization (PSO). A tutorial. Chemometrics and Intelligent Laboratory Systems, 2015. 149: p. 153–165.

Singh, A. , et al., An Investigation on Hybrid Particle Swarm Optimization Algorithms for Parameter Optimization of PV Cells. Electronics, 2022. 11(6): p. 909.

Liu, F. , et al. Comparison of P&O and hill climbing MPPT methods for grid-connected PV converter. in 2008 3rd IEEE Conference on Industrial Electronics and Applications. 2008. IEEE.

Dorigo, M. , M. Birattari , and T. Stutzle , Ant colony optimization. IEEE computational intelligence magazine, 2006. 1(4): p. 28–39.

Sharma, A. , et al., A review on artificial bee colony and it’s engineering applications. Journal of Critical Reviews, 2020. 7(11): p. 4097–4107.

Faris, H. , et al., Grey wolf optimizer: a review of recent variants and applications. Neural computing and applications, 2018. 30(2): p. 413435.

Sharma, A. , et al., An effective method for parameter estimation of solar PV cell using Grey-wolf optimization technique. International Journal of Mathematical, Engineering and Management Sciences, 2021. 6(3): p. 911.

Beni, G. and J. Wang , Swarm intelligence in cellular robotic systems, in Robots and biological systems: towards a new bionics? 1993, Springer. p. 703–712.

Sharma, A. , et al., Swarm intelligence: foundation, principles, and engineering applications. 2022: CRC Press.

Dorigo, M. , In The Editorial of the First Issue of: Swarm Intelligence Journal. LLC, 2007. 1(1).

Valentinuzzi, M. E. , Handbook of bioinspired algorithms and applications. BioMedical Engineering OnLine, 2006. 5: p. 47.

Sharma, A. , et al., Path planning for multiple targets interception by the swarm of UAVs based on swarm intelligence algorithms: A review. IETE Technical Review, 2021: p. 1–23.

Guerrero, J. M. , et al., Hierarchical control of droop-controlled AC and DC microgrids—A general approach toward standardization. IEEE Transactions on industrial electronics, 2010. 58(1): p. 158–172.

Sharma, A. , et al., A Novel Opposition-Based Arithmetic Optimization Algorithm for Parameter Extraction of PEM Fuel Cell. Electronics, 2021. 10(22): p. 2834.

Pachauri, R. K. , et al., Applied Soft Computing and Embedded System Applications in Solar Energy. 2021: CRC Press.

Lasseter, R. H. Microgrids. in 2002 IEEE power engineering society winter meeting. Conference proceedings (Cat. No. 02CH37309). 2002. IEEE.

Nejabatkhah, F. and Y. W. Li , Overview of power management strategies of hybrid AC/DC microgrid. IEEE Transactions on power electronics, 2014. 30(12): p. 7072–7089.

Zeng, Z. , et al., Topologies and control strategies of multi-functional grid-connected inverters for power quality enhancement: A comprehensive review. Renewable and Sustainable Energy Reviews, 2013. 24: p. 223–270.

Pedrasa, M. A. and T. Spooner , A survey of techniques used to control microgrid generation and storage during island operation. Aupec2006, 2006. 1: p. 15.

Mohamed, Y. , New control algorithms for the distributed generation interface in grid-connected and micro-grid systems. 2008.

Majumder, R. , et al., Improvement of stability and load sharing in an autonomous microgrid using supplementary droop control loop. IEEE transactions on power systems, 2009. 25(2): p. 796–808.

Kow, K. W. , et al., A review on performance of artificial intelligence and conventional method in mitigating PV grid-tied related power quality events. Renewable and Sustainable Energy Reviews, 2016. 56: p. 334346.

Sedighizadeh, M. , M. Esmaili , and A. Eisapour-Moarref , Voltage and frequency regulation in autonomous microgrids using Hybrid Big BangBig Crunch algorithm. Applied Soft Computing, 2017. 52: p. 176–189.

Dasgupta, S. , S. Sahoo , and S. Panda . Design of a spatial iterative learning controller for single phase series connected PV module inverter for grid voltage compensation. in The 2010 International Power Electronics Conference-ECCE ASIA-. 2010. IEEE.

Bai, W. , M. R. Abedi , and K. Y. Lee , Distributed generation system control strategies with PV and fuel cell in microgrid operation. Control Engineering Practice, 2016. 53: p. 184–193.

Chaurasia, G. S. , et al., A meta-heuristic firefly algorithm based smart control strategy and analysis of a grid connected hybrid photovoltaic/wind distributed generation system. Solar Energy, 2017. 150: p. 265–274.

Banerjee, A. , V. Mukherjee , and S. Ghoshal , Modeling and seeker optimization based simulation for intelligent reactive power control of an isolated hybrid power system. Swarm and Evolutionary Computation, 2013. 13: p. 85–100.

Banerjee, A. , V. Mukherjee , and S. Ghoshal , Intelligent fuzzy-based reactive power compensation of an isolated hybrid power system. International Journal of Electrical Power & Energy Systems, 2014. 57: p. 164–177.

Jumani, T. A. , et al., Optimal voltage and frequency control of an islanded microgrid using grasshopper optimization algorithm. Energies, 2018. 11(11): p. 3191.

Akbari, M. , M. Golkar , and S. M. Tafreshi . Firefly algorithm-based voltage and frequency control of a hybrid ac-dc microgrid. in 2012 Proceedings of 17th Conference on Electrical Power Distribution. 2012. IEEE.

Houshyari, M. , H. Shayeghi , and A. Younesi . Comparison of PID type controller performance in microgrid frequency deviation enhancement using MFO algorithm. in Univ. of Mohaghegh Ardabili. 2016.

Shayanfar, H. , H. Shayeghi , and A. Younesi . Optimal PID controller design using Krill Herd algorithm for frequency stabilizing in an isolated wind-diesel system. in proceedings on the international conference on artificial intelligence (ICAI). 2015. The Steering Committee of The World Congress in Computer Science, Computer ....

Jumani, T. A. , et al. , Salp swarm optimization algorithm-based controller for dynamic response and power quality enhancement of an islanded microgrid. Processes, 2019. 7(11): p. 840.

Saad, N. H. , A. A. El-Sattar , and M. E. Marei , Improved bacterial foraging optimization for grid connected wind energy conversion system based PMSG with matrix converter. Ain Shams Engineering Journal, 2018. 9(4): p. 2183–2193.

Yang, Y. and H. Wen , Adaptive perturb and observe maximum power point tracking with current predictive and decoupled power control for grid-connected photovoltaic inverters. Journal of Modern Power Systems and Clean Energy, 2019. 7(2): p. 422–432.

Yung, Y. K. , et al. , Central composite design (CCD) for parameters optimization of maximum power point tracking (MPPT) by response surface methodology (RSM). Journal of Mechanics of Continua and Mathematical Sciences, 2019. 1: p. 259.

Sharma, A. , et al. , A Novel TSA-PSO Based Hybrid Algorithm for GMPP Tracking under Partial Shading Conditions. Energies, 2022. 15(9): p. 3164.

Mishra, D. P. and S. Chakraborty . Application of soft computing in simulation of solar power tracking. in 2018 Technologies for Smart-City Energy Security and Power (ICSESP). 2018. IEEE.

Jately, V. , et al., Experimental analysis of hill-climbing MPPT algorithms under low irradiance levels. Renewable and Sustainable Energy Reviews, 2021. 150: p. 111467.

Sharma, A. , et al. , An effective method for parameter estimation of a solar cell. Electronics, 2021. 10(3): p. 312.

Rajput, S. , et al., An approval of MPPT based on PV Cell’s simplified equivalent circuit during fast-shading conditions. Electronics, 2019. 8(9): p. 1060.

Rajput, S. , M. Averbukh , and N. Rodriguez , Energy Harvesting and Energy Storage Systems. 2022, MDPI. p. 984.

Li, H. , et al. , An overall distribution particle swarm optimization MPPT algorithm for photovoltaic system under partial shading. IEEE Transactions on Industrial Electronics, 2018.

66(1): p. 265–275.

Jiang, L. L. , D. L. Maskell , and J. C. Patra , A novel ant colony optimization-based maximum power point tracking for photovoltaic systems under partially shaded conditions. Energy and Buildings, 2013. 58: p. 227–236.

Aouchiche, N. , et al., AI-based global MPPT for partial shaded grid connected PV plant via MFO approach. Solar Energy, 2018. 171: p. 593-603.

Farayola, A. M. , A. N. Hasan , and A. Ali , Efficient photovoltaic MPPT system using coarse gaussian support vector machine and artificial neural network techniques. International Journal of Innovative Computing Information and Control (IJICIC), 2018. 14(1): p. 323–329.

Li, L.-L. , et al. , A maximum power point tracking method for PV system with improved gravitational search algorithm. Applied Soft Computing, 2018. 65: p. 333–348.

Mohanty, S. , B. Subudhi , and P. K. Ray , A new MPPT design using grey wolf optimization technique for photovoltaic system under partial shading conditions. IEEE Transactions on Sustainable Energy, 2015. 7(1): p. 181–188.

Mohanty, S. , B. Subudhi , and P. K. Ray , A grey wolf-assisted perturb & observe MPPT algorithm for a PV system. IEEE Transactions on Energy Conversion, 2016. 32(1): p. 340–347.

Sundareswaran, K. , et al. , Enhanced energy output from a PV system under partial shaded conditions through artificial bee colony. IEEE transactions on sustainable energy, 2014. 6(1): p. 198–209.

Padmanaban, S. , et al., A hybrid ANFIS-ABC based MPPT controller for PV system with anti-islanding grid protection: Experimental realization. Ieee Access, 2019. 7: p. 103377–103389.

Li, N. , et al. Maximum power point tracking control based on modified ABC algorithm for shaded PV system. in 2019 AEIT International Conference of Electrical and Electronic Technologies for Automotive (AEIT AUTOMOTIVE). 2019. IEEE.

Sharma, A. , et al., Cuckoo search algorithm: A review of recent variants and engineering applications. Metaheuristic and Evolutionary Computation: Algorithms and Applications, 2021: p. 177–194.

Yang, X.-S. and S. Deb , Multiobjective cuckoo search for design optimization. Computers & Operations Research, 2013. 40(6): p. 1616-1624.

Energy Harvesting from Conducting Nanocomposites

Agency Energy and environment (EE) report , 2008

Commission IE Efficient electrical energy transmission and distribution , 2007

T. M. Tritt , H. Böttner , L. Chen , Thermoelectrics: direct solar thermal energy conversion, MRS Bull. 33(4), 366-368, 2008.

A. Abhat , Low temperature latent heat thermal energy storage: heat storage materials, Solar Energy, 30(4) 313-332, 1981.

D. Buddhi , R. L. Sawhney , In: Proceedings on thermal energy storage and energy conversion, 1994.

M. Telkes , Thermal storage for solar heating and cooling. In: Proceedings of the workshop on solar energy storage sub-systems for heating and cooling of buildings, University of Virginia, Charlottesville, 1975.

A. George , Hand book of thermal design, In: C. Guyer , editor. Phase change thermal storage materials. McGraw Hill Book Co., 1989.

J. P. Heremans , C. M. Thrush , D. T. Morelli , M. C. Wu , Thermoelectric power of bismuth nanocomposites. Phys. Rev. Lett. 88, 4361-4365, 2002.

W. He , G. Zhang , X. Zhang , J. Ji , G. Li , X. Zhao , Recent development and application of thermoelectric generator and cooler, Appl. Energy, 143, 1-25, 2015.

J. Yang , T. Caillat , Thermoelectric materials for space and automotive power generation, MRS Bull. 31(3) 224-229, 2006.

J. Changyoon , J. Chanwoo , L. Seonghwan , Q. F. Maria , B. P. Young , Carbon Nanocomposite Based Mechanical Sensing and Energy Harvesting, International Journal of Precision Engineering and ManufacturingGreen Technology, 1, 85, 2020

A. Dey , O. P. Bajpai , A. K. Sikder , S. Chattopadhyay , M. A. S. Khan , Recent advances in CNT/graphene based thermoelectric polymer nanocomposite: A proficient move towards waste energy harvesting, Renewable and Sustainable Energy Reviews 53 653-671, 2016

E. T. Thostenson , Ren Z , Chou T W , Advances in the science and technology of carbon nanotubes and their composites: a review. Compos. Sci. Technol. 61(13) 1899-1912, 2001.

R. H. Baughman , A. A. Zakhidov , de Heer W A , Carbon nanotubes - the route toward applications. Science 297(5582) 787-792, 2002.

J. Prasek , J. Drbohlavova , J. Chomoucka , J. Hubalek , O. Jasek , V. Adam , R. Kizek , Methods for carbon nanotubes synthesis - review, J Mater Chem 21(40) 15872-15884, 2011.

S. Iijima , Helical microtubules of graphitic carbon. Nature 354(6348) 56-58, 1991.

M. Farukh , R. Dhawan , B. P. Singh , S. Dhawan , Sandwich composites of polyurethane reinforced with poly (3,4-ethylene di oxythiophene)coated multiwalled carbon nanotubes with exceptional electromagnetic interference shielding properties, RSC Adv 5(92) 75229-75238, 2015.

R. Mathur , S. Pande , B. Singh , T. Dhami , Electrical and mechanical properties of multiwalled carbon nanotubes reinforced PMMA and PS composites. Polym Compos 29(7) 717-727, 2008.

A. P. Graham , G. S. Duesberg , W. Hoenlein , F. Kreupl , M. Liebau , R. Martin , B. Rajasekharan , W. Pamler , R. Seidel , W. Steinhoegl , E. Unger , How do carbon nanotubes fit into the semiconductor roadmap? Appl Phys A 80(6), 1141-1151, 2005.

P. Jindal , S. Pande , P. Sharma , V. Mangla , A. Chaudhury , D. Patel , B. P. Singh , R. B. Mathur , M. Goyal , High strain rate behavior of multiwalled carbon nanotubes-polycarbonate composites. Compos B Eng 45(1) 417-422, 2013.

S. Pande , B. P. Singh , R. B. Mathur , Processing and properties of carbon nanotube/polycarbonate composites, polymer nanotube nanocomposites: synthesis, properties, and applications, 2nd ed. Wiley, New Jersey, 333-364, 2014

B. P. Singh , P. Saini , T. K. Gupta , P. Garg , G. Kumar , I. Pande , S. Pande , R. K. Seth , S. K. Dhawan , R. B. Mathur , Designing of multiwalled carbon nanotubes reinforced low density polyethylene nanocomposites for suppression of electromagnetic radiation, J Nanopart Res 13(12) 7065-7074, 2011

F. C. Fim , N. R. Basso , A. P. Graebin , D. S. Azambuja , G. B. Galland , Thermal, electrical, and mechanical properties of polyethylene- graphene nanocomposites obtained by in situpolymerization, J ApplPolym Sci 128(5) 2630-2637, 2013.

B. Li , J. Zhang , Polysiloxane/multiwalled carbon nanotubes nanocomposites and their applications as ultrastable, healable and super hydrophobic coatings, Carbon 93, 648-658, 2015.

Z. Wang , Y. Yang , R. Burtovyy , I. Luzinov , M. W. Urban , UV-induced self-repairing polydimethylsiloxane-polyurethane (PDMS-PUR) and polyethylene glycol-polyurethane (PEG-PUR) Cu-catalyzed networks, J Mater Chem A 2(37) 15527-15534, 2014.

J. Ling , M. Z. Rong , M. Q. Zhang , Photo-stimulated self-healing polyurethane containing dihydroxyl coumarin derivatives, Polymer 53(13) 2691-2698, 2012.

M. Verma , P. Verma , S. Dhawan , V. Choudhary , Tailored graphene based polyurethane composites for efficient electrostatic dissipation and electromagnetic interference shielding applications, RSC Adv 5(118) 97349-97358, 2015.

P. Saini , V. Choudhary , B. Singh , R. Mathur , S. Dhawan , Enhanced microwave absorption behavior of polyaniline-CNT/polystyrene blend in 12.4-18.0 GHz range, Synth Met 161(15) 1522-1526, 2011.

F. Shahzad , S. Yu , P. Kumar , J-W. Lee , Y-H. Kim , S. M. Hong , C. M. Koo , Sulfur doped graphene/polystyrene nanocomposites for electromagnetic interference shielding, Compos Struct 133, 1267-1275, 2015.

A. Babal , R. Gupta , B. Singh , V. Singh , R. Mathur , S. Dhakate , Mechanical and electrical properties of high performance MWCNT/polycarbonate composites prepared by industrial viable twin screw extruder with back flow channel, RSC Adv 4, 64649-64658, 2014.

G. Gedler , M. Antunes , J. Velasco , R. Ozisik , Enhanced electromagnetic interference shielding effectiveness of polycarbonate/graphene nanocomposites foamed via 1-step supercritical carbon dioxide process, Mater Des 90, 906-914, 2016.

B. Shen , W. Zhai , M. Tao , D. Lu , W. Zheng , Enhanced interfacial interaction between polycarbonate and thermally reduced graphene induced by melt blending, Compos Sci Technol 86, 109-116, 2013.

X. Zeng , J. Yang , W. Yuan , Preparation of a poly (methyl methacrylate)reduced graphene oxide composite with enhanced properties by a solution blending method, Eur Polym J 48(10) 1674-1682, 2012.

Y. M. Malinskii , V. Prokopenko , N. Ivanova , V. Kargin , Investigation of self-healing of cracks in polymers, Polym Mech 6(2), 240-244, 1970.

R. P. Wool , Crack healing in semicrystalline polymers, block copolymers and filled elastomers. In: Adhesion and adsorption of polymers, Springer, Berlin, 341-362, 1980.

R. Wool , K. O'Connor , A theory crack healing in polymers, J Appl Phys 52(10), 5953-5963, 1981.

S. R. White , N. Sottos , P. Geubelle , J. Moore , M. R. Kessler , S. Sriram , E. Brown , S. Viswanathan , Autonomic healing of polymer composites, Nature 409(6822) 794-797, 2001.

M. Kessler , Self-healing: a new paradigm in materials design, proceedings of the institution of mechanical engineers, Part G. J AerospEng 221(4) 479-495, 2007

G. Lanzara , Y. Yoon , H. Liu , S. Peng , W. Lee , Carbon nanotube reservoirs for self-healing materials, Nanotechnology 20(33), 335704, 2009.

R. S. Sinha , D. Pelot , Z. Zhou , A. Rahman , X-F. Wu , A. L. Yarin , Encapsulation of self-healing materials by coelectrospinning, emulsion electrospinning, solution blowing and intercalation, J Mater Chem 22(18) 9138-9146, 2012.

L. Mario , N. Ahmed , Organic thermoelectrics: Green energy from a blue polymer, Nat. Mater. 10(6) 409-410, 2011.

B. Blaiszik , S. Kramer , S. Olugebefola , J. S. Moore , N. R. Sottos , White SR , Self-healing polymers and composites, Annu Rev Mater Res 40, 179-211, 2010

Y. Yuan , T. Yin , M. Rong , M. Zhang , Self-healing in polymers and polymer composites. Concepts, realization and outlook: a review, Polym Lett 2(4) 238-250, 2008.

F. Herbst , D. Döhler , P. Michael , W. H. Binder , Self-healing polymers via supramolecular forces, Macromol Rapid Commun 34(3), 203-220, 2013.

B. Aissa , E. Haddad , W. Jamroz , S. Hassani , R. Farahani , P. Merle , Therriault D. , Micromechanical characterization of single-walled carbon nanotube reinforced ethylidene norbornene nanocomposites for self-healing applications, Smart Mater Struct 21(10), 105028, 2012.

B. M. Bailey , Y. Leterrier , S. Garcia , S. Van Der Zwaag , V. Michaud , Electrically conductive self-healing polymer composite coatings, Prog Org Coat 85, 189-198, 2015.

W. Cui , J. Ji , Y-F. Cai , H. Li , R. Ran , Robust, Anti-fatigue, and selfhealing graphene oxide/ hydrophobically associated composite hydrogels and their use as recyclable adsorbents for dye wastewater treatment, J Mater Chem A 3(33) 17445-17458, 2015.

J. Jyoti , S. Basu , B. Singh , S. Dhakate , Superior mechanical and electrical properties of multiwall carbon nanotube reinforced acrylonitrile butadiene styrene high performance composites, Compos B Eng 83, 58-65, 2015

S. Sharma , V. Gupta , R. Tandon , V. Sachdev , Synergic effect of graphene and MWCNT fillers on electromagnetic shielding properties of graphene-MWCNT/ABS nanocomposites, RSC Adv 6(22) 18257-18265, 2016.

a) D. M. Rowe , in Handbook of electrics, CRC Press, Boca Raton, FL, 1995; b) D. Zhao , G. Tan , A review of thermoelectric cooling: materials, modeling and applications, Appl. Therm. Eng. 66(1-2) 15-24, 2014.

a) S. B. Riffat , X. Ma , Thermoelectrics: a review of present and potential applications, Appl. Therm. Eng. 23(8) 913-935, 2003.

F. J. Di Salvo , Thermoelectric cooling and power generation, Science 285(5428) 703-706, 1999.

G. Chen , M. S. Dresselhaus , G. Dresselhaus , J.-P. Fleurial , T. Caillat , Recent developments in thermoelectric materials, Int. Mater. Rev. 48 (1) 45-66, 2003.

G. J. Snyder , E. S. Toberer , Complex thermoelectric materials, Nat. Mater. 7(2) 105-114, 2008.

B. C. Tee , C. Wang , R. Allen , Z. Bao , An electrically and mechanically self-healing composite with pressure-and flexion-sensitive properties for electronic skin applications, Nat Nanotechnol 7(12) 825-832, 2012.

Y. Han , T. Wang , X. Gao , T. Li , Q. Zhang , Preparation of thermally reduced graphene oxide and the influence of its reduction temperature on the thermal, mechanical, flame retardant performances of PS nanocomposites, Compos A Appl Sci Manuf 84, 336-343, 2016.

P. Garg , B. P. Singh , G. Kumar , T. Gupta , I. Pandey , R. Seth , R. Tandon , R. B. Mathur , Effect of dispersion conditions on the mechanical properties of multi-walled carbon nanotubes-based epoxy resin composites. J Polym Res 18(6) 1397-1407, 2010.

B. P. Singh , K. Saini , V. Choudhary , S. Teotia , S. Pande , P. Saini , R. B. Mathur , Effect of length of carbon nanotubes on electromagnetic interference shielding and mechanical properties of their reinforced epoxy composites, J Nanopart Res 16(1) 1-11, 2014.

L-C. Tang , Y-J. Wan , D. Yan , Y.-B. Pei , L. Zhao , Y.-B. Li , L-B Wu , J.-X. Jiang , G.-Q. Lai , The effect of graphene dispersion on the mechanical properties of graphene/epoxy composites, Carbon 60, 16-27, 2013.

R. B. Mathur , B. P. Singh , T. Dhami , Y. Kalra , N. Lal , R. Rao , A. M. Rao , Influence of carbon nanotube dispersion on the mechanical properties of phenolic resin composites, Polym Compos 31(2) 321-327, 2010

Energy Information Administration, International Energy Outlook 2010.

A PV Energy Harvesting System using MPPT Algorithms

S. K. Nag , T. K. Gangopadhyay and J. Paserba , "Solar Photovoltaics: A Brief History of Technologies [History]," in IEEE Power and Energy Magazine, vol. 20, no. 3, pp. 77–85, May-June 2022, doi: 10.1109/MPE.2022.3150814.

N. Swaminathan , N. Lakshminarasamma and Y. Cao , "A Fixed Zone Perturb and Observe MPPT Technique for a Standalone Distributed PV System," in IEEE Journal of Emerging and Selected Topics in Power Electronics, vol. 10, no. 1, pp. 361–374, Feb. 2022, doi: 10.1109/JESTPE.2021.3065916.

V. Jately and S. Arora , "Development of a dual-tracking technique for extracting maximum power from PV systems under rapidly changing environmental conditions," Energy (Oxf.), vol. 133, pp. 557–571, 2017.

A. Sharma , A. Sharma , V. Jately , M. Averbukh , S. Rajput , and B. Azzopardi , "A Novel TSA-PSO Based Hybrid Algorithm for GMPP Tracking under Partial Shading Conditions," Energies, vol. 15, no. 9, p. 3164, Apr. 2022, doi: 10.3390/en15093164.

V. Jately , S. Bhattacharya , B. Azzopardi , A. Montgareuil , J. Joshi and S. Arora , "Voltage and Current Reference Based MPPT Under Rapidly Changing Irradiance and Load Resistance," in IEEE Transactions on Energy Conversion, vol. 36, no. 3, pp. 2297–2309, Sept. 2021, doi: 10.1109/TEC.2021.3058454.

A. K. Abdelsalam , A. M. Massoud , S. Ahmed and P. N. Enjeti , "High-Performance Adaptive Perturb and Observe MPPT Technique for Photovoltaic-Based Microgrids," in IEEE Transactions on Power Electronics, vol. 26, no. 4, pp. 1010–1021, April 2011, doi:10.1109/TPEL.2011.2106221.

V. Jately , B. Azzopardi , J. Joshi , B. Venkateswaran V , A. Sharma , and S. Arora , "Experimental Analysis of hill-climbing MPPT algorithms under low irradiance levels," Renewable and Sustainable Energy Reviews, vol. 150, p. 111467, Oct. 2021, doi: 10.1016/j.rser.2021.111467.

V. Jately and S. Arora , "Performance Investigation of Hill-Climbing MPPT Techniques for PV Systems Under Rapidly Changing Environment," Advances in Intelligent Systems and Computing, pp. 1145–1157, 2018, doi: 10.1007/978-981-10-5903-2_120.

J. Ahmed and Z. Salam , "A Modified P&O Maximum Power Point Tracking Method With Reduced Steady-State Oscillation and Improved Tracking Efficiency," in IEEE Transactions on Sustainable Energy, vol. 7, no. 4, pp. 1506–1515, Oct. 2016, doi: 10.1109/TSTE.2016.2568043.

S. B. Kjær , "Evaluation of the "Hill Climbing" and the "Incremental Conductance" Maximum Power Point Trackers for Photovoltaic Power Systems," in IEEE Transactions on Energy Conversion, vol. 27, no. 4, pp. 922–929, Dec. 2012, doi: 10.1109/TEC.2012.2218816.

J. A. Carrasco , F. G. de Quirós , H. Alavés and M. Navalón , "An Analog Maximum Power Point Tracker With Pulsewidth Modulator Multiplication for a Solar Array Regulator," in IEEE Transactions on Power Electronics, vol. 34, no. 9, pp. 8808–8815, Sept. 2019, doi: 10.1109/TPEL.2018.2886887.

V. Jately and S. Arora , "An efficient hill-climbing technique for peak power tracking of photovoltaic systems," 2016 IEEE 7th Power India International Conference (PIICON), 2016, pp. 1–5, doi: 10.1109/POWERI.2016.8077327.