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An Overview of IoT Assisted Energy Harvesting Systems

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ABSTRACT

In last few decades, mankind has started harvesting energy from various non-traditional sources of energy such as solar, wind, hydro, chemical, biological and so on. Research and technology in these sectors has evolved to an extent that, significant role can be played by these sources in completing our total energy requirements on daily basis. However, integration of such a variety of non-traditional sources in combination with traditional sources for the continuous and smooth fulfillment of energy requirements remains a challenge. This is due to the limitations like fluctuating energy generation capacity, time and place dependent power output, and initial investments followed by limited but continuous maintenance. In view of above, to overcome the shortcomings, one can use internet of things (IoT) for seamless integration of two or more energy sources for the sustainable and continuous energy harvesting systems. Current review focuses on energy generation profile and integrated utilization of a major non-traditional source viz. solar. We also cite recent research approaches to provide constructive information to help in making decisions to develop innovative and sustainable IoT solutions.

Keyword: - Internet of Things (IoT), energy harvesting, integrated network, sustainable energy, solar and wind power.

1. Introduction

In the recent decade, the IoT is rapidly enabling seamless communication and data exchange between the physical and digital realms [1a,1b]. The implementation of IoT technologies has drastically changed various sectors, including healthcare, environmental monitoring, transportation, logistics, supply chain, agriculture, industrial automation, and smart cities [2]. This is due to the possible integrated networking and connectivity of various physical things viz. machines, vehicles, plants, animals, and human beings, for creating a more efficient, sustainable, and data-driven society [3, 4].

However, use of IoT technologies in the energy management in various industries with the help of integration of requirements and real-time data followed by automation has drastically attracted the researchers. In particular, this includes the management of battery, a common power source used in various systems, having limitations in the context of performance, energy storage systems, operational life, maintenance, disposal and replacement costs [5-8]. Thus, to optimize usage and maintenance of batteries efficient and synchronous management of energy from non-traditional sources becomes essential [9-14]. But, the time and location dependence of these non-traditional sources puts constraints on the continuous and sustainable power production, storage and transportation. In view of this, integration of such energy sources with the help of IoT can help in the efficient and automated management of energy [5-10]. Thus, in the present review, we focus on energy generation profile and integrated utilization of two major non-traditional sources viz. solar.

2. Energy Harvesting Profiles

Fig. 1 present widespread non-traditional energy harvesters used in various fields. The classification comprises categories like photovoltaic (PV), radio frequency (RF), Thermoelectric, Vibration and Kinetic and chemical and biological energy harvesters [15-21]. Understanding the energy generation profile and parameters which control the energy generation is a crucial input for IoT based management strategy to ensure desired output. Each taxonomy branch represents a distinct energy source, with subcategories further representing specific energy harvesting mechanisms.

2.1 Different Energy Harvesting Technologies

Different research articles have been undertaken to study the aspects of various non-traditional energy harvesting technologies. The important parameters like harvesting type, power density output, life span and area of applications have been tabulated in table 1.

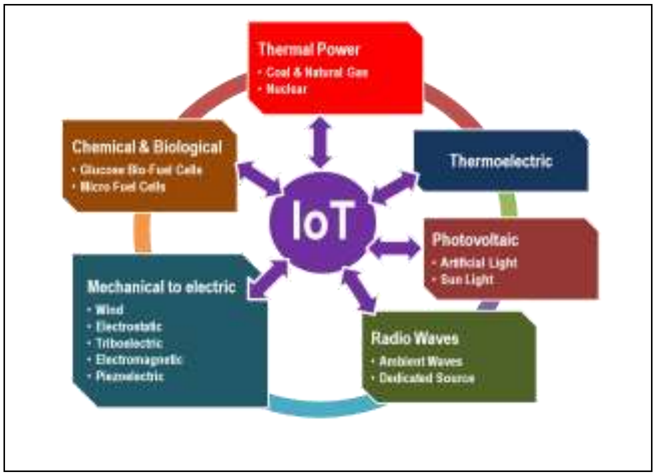

Fig -1 Various Energy Harvesting Systems to Integrate Using IoT

Table 1 Energy densities, life spans, and key applications of various non-conventional energy harvesting technologies. [22-28].

Technology	Type	Power Density	Life Span	Key Applications
Photovoltaic	Sun Light	10 to 100 mW/cm^2	20 to 30 Years	Outdoor Sensors Wearable devices Remote Monitoring
	Artificial Light	Greater than 100 $microwatt/cm^2$		
Thermo-Electric	--	40 $microwatt/cm^2$ 135 $microwatt/cm^2$	~ 5 Years	Industrial Heat Recovery Wearable devices Automotive Applications
Mechanical	Piezoelectric	4 to 250 $microwatt/cm^3$	20 to 60 Years	Structural devices Wearable devices Industrial equipment
	Triboelectric	Greater than 4 $microwatt/cm^2$	~ 15 Years	
	Electromagnetic	300 to 800 $microwatt/cm^3$	~ 15 Years	
	Electrostatic	50 to 100 $microwatt/cm^3$	~ 5 Years	
Radio Wave	Dedicated Source	1 to 10 mW/cm^2	Long Lasting (Depending on RF Source)	RFID system Small IoT Devices Low Power Sensors
	Ambient Source	0.01 to 0.1 mW/cm^2		
Chemical and Biological	Microbial Fuel Cell	811 to 1540 mW/cm^2	~ 7 Years	Medical Implants Biosensors Remote Bio-systems
	Glucose Fuel Cell	Up to 115 mW/cm^2	Shorter (Depending on Substrate and Fuel)	

2.2 Analysis of PV Energy Harvester

PV harvesters can generate DC voltages when exposed to direct sunlight (Fig.2) [1b]. The output voltage and current of a solar cell depends on surface area of the cell, angle and intensity of the sunlight. PV harvesters are especially advantageous when sunlight is available for longer durations and with consistent intensity for a period making them ideal for energy generation during daytime. Usually, an array of PVs known as solar panels is used for energy generation on large scale. Since, panels generate DC an inverter system is a necessity before the energy may be transported or used in household or industrial applications [22-23].

Nevertheless, these photovoltaic harvesters also have few drawbacks, like fluctuation of light intensity due to change in seasons, weather conditions, angle of incident sun light and finally, unavailability of sunlight during night time.

The fluctuation in input to the panels causes fluctuations in energy output. Thus, only for a limited period of time during a day the panels may provide the desired energy output. To tackle this problem, smart systems must be used, which measure energy output and decide if the energy is to be sent to the inverter for integration with mains supply or store the energy for later use [19, 22]. Sever fluctuation in energy output under varying weather conditions and unavailability of sunlight at night time makes energy storage systems an essential part of the solar panels. Energy storage systems are not only expensive financially but they also are expensive from environmental point of view. IoT can help to optimize the energy storage systems by letting some energy go to the grid and store the surplus for later use. This not only reduces storage equipment needed but also increases the life of installed storage equipment. Another major factor that affects the performance of the panels is accumulation of dust and debris on them. IoTs can monitor the system and trigger automated or manual cleaning routines. As discussed before for large scale energy generation panels must be installed over a large surface area. In urban areas, this proves impractical to install all the required panels at one location. Thus, large number of small panels must be installed. This makes the installation fanatically viable and mutually beneficial to the energy generation centres and the individual landholders. However, for drawing optimized small amounts of energies from large number of individual panels, inter-connecting the panels using IoT becomes essential [19-22]. IoT management can continuously maintain optimum scales of final power output while fulfilling the requirement of the individuals where the solar panels are installed.

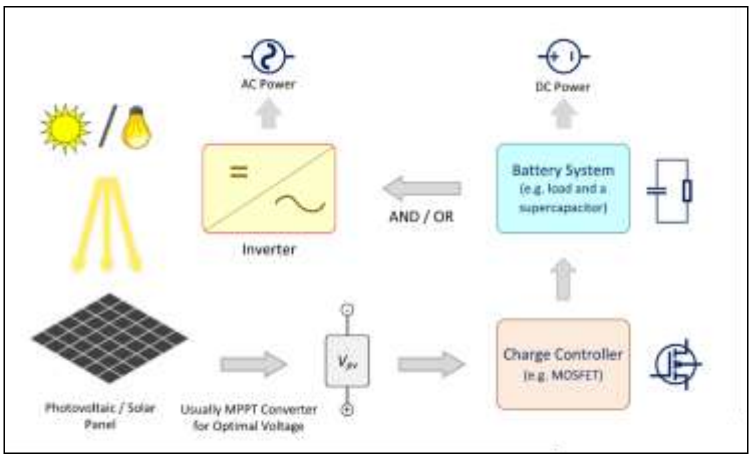

Fig -2 Power Generations of PV Harvesters

In view of above IoT assistance to the PV energy harvesting systems open widespread areas of applications. This makes PV technology, enhanced power output and longer life span, system suitable for outdoor conditions to provide sustainable and continuous power to the IoT devices. Whereas, one should look for energy storage management in order to have continuous application of IoT devices during night time or cloudy conditions. At the same time, integration of IoT for indoor PV systems make it useful in various applications including security purposes with reduced dependency over grid power followed by enhanced battery life.

2.2 Various Commercial ICs Designed for PV Harvesting Applications

As discussed above, in order to deploy PV systems with various applications, few of the ICs and modules have been designed to satisfy the continuous supply of power. Schematic in Fig.3 represent the readily used ICs and modules with PV harvesting systems.

3. F3. Future Scope and Conclusion

3.1 Future Scope

As discussed earlier, field of energy harvesting is rapidly evolving. It indeed need of time to look for self-powered and sustainable devices. Even though non-traditional sources are providing clean and abundant energy, limitations of harvesting technologies, makes us to look for developments or modifications of existing technologies to explore novel energy harvesting methodologies. In view of this, one of the upcoming approaches is to collaborate various fields like engineering, materials science, and advanced computer science like machine language (ML), Artificial Intelligence (A.I.) and IoT. This may help to explore the complete spectrum of energy with enhanced efficiency, power output. In addition, such collaboration will definitely help to develop integrated energy harvesting systems by combining minimum two or more energy harvesting technologies to provide continuous and sustainable power to the IoT devices having time, location and environmental dependent performance. Also, integration of these energy harvesting devices and energy management may provide enhanced energy utilization with increased lifetime of battery with decreased maintenance cost of the system, and hence providing good opportunity to the researchers from various sectors to collaborate for sustainable and green society.

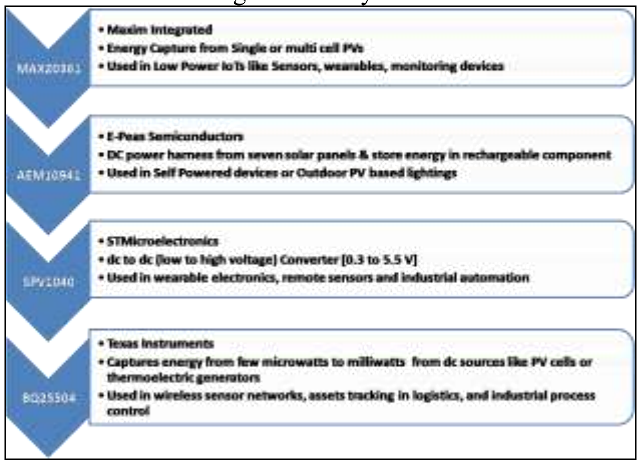

Fig -3 Various ICs and modules used in IoT assisted PV harvesting

3.2 Conclusions

Present article represents a brief overview over the energy harvesting systems for IoT applications. We have successfully discussed different energy harvesting technologies viz., photovoltaic, thermoelectric, RF, vibration and kinetic, and chemical and biological harvesters on the basis of power output, life span and area of applications. Main focus has been given over the abundantly available solar energy harvesting using PV technology with respect to its mechanism, advantages and limitations. In addition, article has revealed the role of IoT, to integrate PV with other technologies to get continuous and sustainable power for outdoor and indoor PV based applications.

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5. REFERENCES

1. D. Ma, G. Lan, M. Hassan, W. Hu, and S. K. Das, “Sensing, computing, and communications for energy harvesting IoTs: A survey,” IEEE Commun. Surveys Tuts., vol. 22, no. 2, pp. 1222–1250, Second quarter 2020.
2. B. Safaei, M. Peiravian and M. Siamaki, "Eco-Friendly IoT: Leveraging Energy Harvesting for a Sustainable Future," in IEEE Sensors Reviews, vol. 2, pp. 32-75, 2025.
3. J. Gubbi, R. Buyya, S. Marusic, and M. Palaniswami, “Internet of Things (IoT): A vision, architectural elements, and future directions,” Future Gener. Comput. Syst., vol. 29, no. 7, pp. 1645–1660, 2013.
4. Sayyah, M. N. Horenstein, and M. K. Mazumder, “Energy yield loss caused by dust deposition on photovoltaic panels,” Sol. Energy, vol. 107, pp. 576–604, 2014.
5. M. R. Sarker et al., “Micro energy harvesting for IoT platform: Review analysis toward future research opportunities,” Heliyon, vol. 10, no. 6, 2024, Art. no. e27778.
6. S. Zeadally, F. K. Shaikh, A. Talpur, and Q. Z. Sheng, “Design architectures for energy harvesting in the Internet of Things,” Renewable Sustain. Energy Rev., vol. 128, 2020, Art. no. 109901.
7. M. Catenacci, E. Verdolini, V. Bosetti, and G. Fiorese, “Going electric: Expert survey on the future of battery technologies for electric vehicles,” Energy Policy, vol. 61, pp. 403–413, 2013.
8. J.-M. Tarascon and M. Armand, “Issues and challenges facing rechargeable lithium batteries,” Nature, vol. 414, no. 6861, pp. 359–367, 2001.
9. M. Winter and R. J. Brodd, “What are batteries, fuel cells, and supercapacitors?” Chem. Rev., vol. 104, no. 10, pp. 4245–4270, 2004.
10. U. Olgun, C.-C. Chen, and J. L. Volakis, “Design of an efficient ambient WiFi energy harvesting system,” IET Microw., Antennas Propag.,vol. 6, no. 11, pp. 1200–1206, 2012.

11. D. Rowe, "Thermoelectrics, an environmentally-friendly source of electrical power," Renewable Energy, vol. 16, no. 1–4, pp. 1251–1256, 1999.
12. F. Davis and S. P. Higson, "Biofuel cells—recent advances and applications," Biosensors Bioelectron., vol. 22, no. 7, pp. 1224–1235, 2007.
13. K. Calautit, D. S. Nasir, and B. R. Hughes, "Low power energy harvesting systems: State of the art and future challenges," Renewable Sustain. Energy Rev., vol. 147, 2021, Art. no. 111230.
14. R. J. Vullers, R. V. Schaijk, H. J. Visser, J. Penders, and C. V. Hoof, "Energy harvesting for autonomous wireless sensor networks," IEEE Solid-State Circuits Mag., vol. 2, no. 2, pp. 29–38, Spring 2010.
15. N. Garg and R. Garg, "Energy harvesting in IoT devices: A survey," in Proc. Int. Conf. Intell. Sustain. Syst., 2017, pp. 127–131.
16. P. Choudhary, L. Bhargava, V. Singh, M. Choudhary, and A. kumar Suhag, "A survey–Energy harvesting sources and techniques for Internet of Things devices," Mater. Today: Proc., vol. 30, pp. 52–56, 2020.
17. A.Zekry,A.Shaker,andM.Salem,"Solarcellsandarrays:Principles, analysis, and design," in Advances in Renewable Energies and Power Technologies. Amsterdam, The Netherlands: Elsevier, 2018, pp. 3–56.
18. P.Rappaport,"Thephotovoltaiceffectanditsutilization,"Sol.Energy, vol. 3, no. 4, pp. 8–18, 1959.
19. J. Zhao et al., "Self-powered implantable medical devices: Photovoltaic energy harvesting review," Adv. Healthcare Mater., vol. 9, no. 17, 2020, Art. no. 2000779.
20. V. Pushpabala and C. C. AsirRajan, "Case study in alternate source of load energy by photovoltaic cell in smart grid," in Proc. Int. Conf. Smart Technol. Syst. Next Gener. Comput., 2022, pp. 1–5.
21. T. V. Tran and W.-Y. Chung, "High-efficient energy harvester with flexible solar panel for a wearable sensor device," IEEE Sensors J., vol. 16, no. 24, pp. 9021–9028, Dec. 2016.
22. H. Sharma, A. Haque, and Z. A. Jaffery, "Modeling and optimisation of a solar energy harvesting system for wireless sensor network nodes," J. Sensor Actuator Netw., vol. 7, no. 3, 2018, Art. no. 40.
23. Sharafi, C. Chen, J.-Q. Sun, and M.-O. Fortier, "Carbon footprint of piezoelectrics from multi-layer PZT stacks to piezoelectric energy harvesting systems in roads," iScience, vol. 27, no. 10, 2024, Art. no. 110786.
24. S. N. Alam et al., "An introduction to triboelectric nanogenerators," Nano-Struct. Nano-Objects, vol. 34, 2023, Art. no. 100980.
25. Ahmed et al., "Environmental life cycle assessment and technoeconomic analysis of triboelectric nanogenerators," Energy Environ. Sci., vol. 10, no. 3, pp. 653–671, 2017.
26. L. Pearce Williams, "Faraday's discovery of electromagnetic induction," Contemporary Phys., vol. 5, no. 1, pp. 28–37, 1963.
27. M. Ga´canovi´c, "Electrostatic application principles," in Proc. Int. Ph.D. Seminar Comput. Electromagn. Optim. Elect. Eng., 2010, pp. 10–13.
28. Crovetto, F. Wang, and O. Hansen, "Modeling and optimization of an electrostatic energy harvesting device," J. Microelectromech. Syst., vol. 23, no. 5, pp. 1141–1155, 2014.
29. D. Enescu, "Thermoelectric energy harvesting: Basic principles and applications," Green Energy Adv., vol. 1, 2019, Art. no. 38.