Environment, Development and Sustainability
https://doi.org/10.1007/s10668-023-03691-2

REVIEW

Internet of Things integrated with solar energy applications: a state-of-the-art review

Dhruv Chakravarty Nath[1] · Indranil Kundu[1] · Ayushi Sharma[1] · Pranav Shivhare[1] · Asif Afzal[2,4] · Manzoore Elahi M. Soudagar[3,5] · Sung Goon Park[2]

Received: 7 October 2022 / Accepted: 23 July 2023

Abstract

Numerous investigations and research projects carried out over the past several years in a wide range of application domains have revealed the potential of IoT (Internet of Things). Solar energy is a renewable source of energy and a sustainable foundation for human civilization; thus, the use of IoT with solar energy-powered devices has definitely been a revolutionary reformation in technology. Researchers have looked into ways to use IoT to change the network structure by recognizing different ecosystem components for intelligent solar-powered city control. Furthermore, countless studies have been made on solar monitoring and solar tracking systems using different IoT technologies in order to target better efficiency, automated control, and monitoring, maximum energy generation etc. The contribution of this study is to make aware everyone about the integration of the renewable energy with the revolution 4.0 which is the major primary topic of the current technology nowadays. Also, the major projects like smart city are being pursued in many developing countries like India and so concepts like IoT are mandatory for these major projects. Also, the solar panel efficiency may be increased and maintenance expenses decreased with the help of the Internet of Things in monitoring and optimizing the panels. As this technology may aid in managing energy usage in real time, solar power can be more consistent and adaptable to fluctuating demand. This article provides a state-of-the-art review of the application of IoT in effective solar energy utilization. The use of IoT in solar energy tracking, power point tracking, energy harvesting, smart lighting system, PV panels, smart irrigation system, solar inverters, etc., is reviewed. Hence, by merging solar power with the Internet of Things, we can provide companies and households with long-term, affordable energy solutions that help encourage responsible expansion and a better future. The outcome of this study reveals that IoT is very much successful in providing smart and efficient solar energy output from countless devices. A vast scope of work and research on IoT applications for smart solar energy utilization still exists in the future.

Keywords IoT · Solar energy · Smart system · PV panel · Irrigation system · Sustainability

Extended author information available on the last page of the article

Published online: 12 October 2023

1 Introduction

Renewable energy sources have become essential to sustain the planet's energy needs. With the growing population of nearly 8 billion people, energy demands have risen exponentially over the years. Conventionally non-renewable sources of energy like coal, petroleum, diesel, etc., are being used to meet the planet's energy demands, but it has various drawbacks (Hestnes, 1999; Jing et al., 2015; Shah et al., 2021). Coal and petrol burning is found to be the most efficient form of producing energy but also generates a large amount of smoke and dust on burning and leaves great amounts of residue. Hence, renewable sources of energy are the solution to a more sustainable and clean future (Devabhaktuni et al., 2013; Khatib et al., 2012; Tsoutsos et al., 2005). Solar, wind, and hydro are some of the renewable sources of energy that, if implemented in the right way and controlled by governing organizations, can cater to the rising needs of the planet.

Solar energy is a form of energy that is harvested from the light and heat radiation of the sun. It is a very reliable source of energy as the availability of solar radiation is prevalent in countries around the equatorial region. As observed in Fig. 1, India, Thailand, Indonesia, and several African countries receive large amounts of solar radiation and, if harvested efficiently, can solve several energy-related issues and crises in many 1st world countries (Camacho & Berenguel, 2012; Hammer et al., 2003). This could reduce the carbon footprint by majorly not burning fossil fuels for energy production.

Global carbon emissions have increased daily, and our planet is on the verge of a major climate crisis. Carbon emissions have increased, and several countries have pledged to reduce their carbon footprint. The only way to do so is by inducting renewable energy sources to meet the energy requirement. The burning of coal and petroleum produces an immense amount of CO_2, which has a negative impact on the environment. Alternate methods have to be made efficient to such an extent that non-renewable sources of energy can be entirely put aside for other purposes (Ginley et al., 2008). As global temperatures are soaring, sea levels are rising, and glaciers are melting at an alarming rate, harvesting renewable sources of energy have to be made efficient, and usage of non-renewable sources of energy has to be minimized as much as possible (Fig. 2).

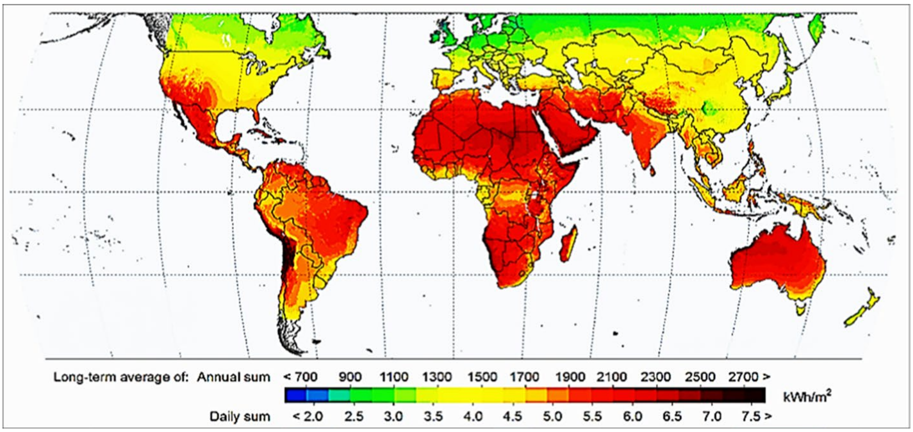

Fig. 1 Global solar radiation received world map (Kannan & Vakeesan, 2016)

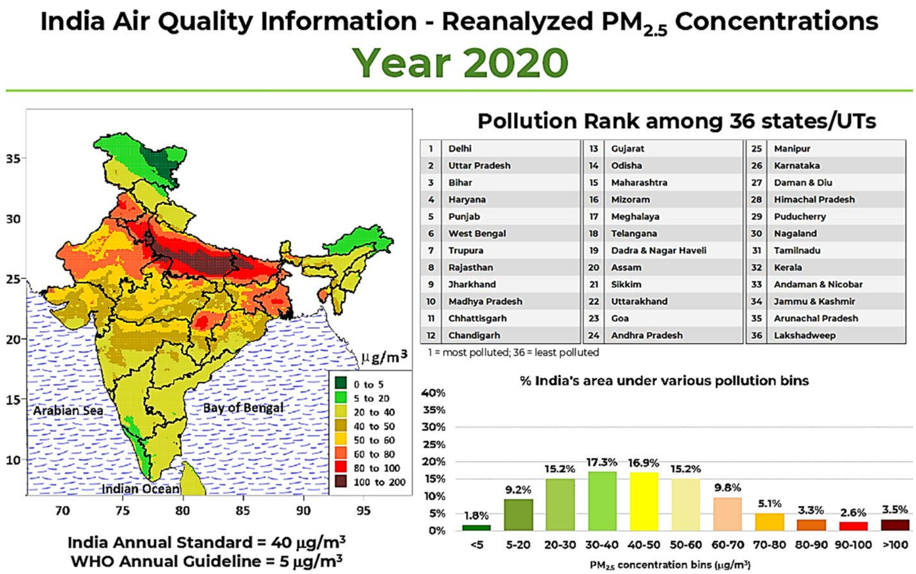

Fig. 2 Emission levels of states in India (Year 2020) (https:urbanemissions.info)

As shown in Fig. 3, the cells convert light energy into electrical energy, which can be stored in batteries or used as per the requirement. The photovoltaic cells use the principle of semiconductor diode, which converts the irradiation into electrical energy. The photovoltaic cells are made of highly doped silicon, which affects the holes and charge carriers. Using this phenomenon of the semi-conductor diode, electricity is produced in the photovoltaic cells (Kabir et al., 2018; Timilsina et al., 2012). This energy produced cannot be stored in the cells; hence, an external appliance such as a battery has to be attached to store the energy, or it could be used as soon as it is generated.

Silicon diodes are used in the making of photovoltaic cells due to the nature of the element having both holes and charge carriers depending on the doping of the element. Figure 4 indicates that *P–N* junction diodes are made by doping the element, and between the

Fig. 3 Solar panels are still able to produce energy even at the night-time as photovoltaic cells are installed in it (www.gizmodo.com.au, 2022, 05, night-time-solar-unsw, amp)

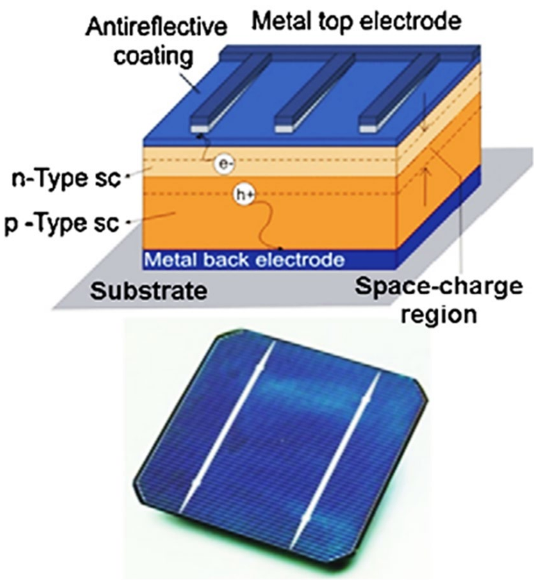

Fig. 4 Conventional silicon solar cell (Serrano et al., 2009)

junction, a depletion layer is created through which the energizing of the diode is made possible. A voltage difference between *P–N* junction diodes is created due to the irradiation falling on the panels from the sun (Oswald & Goluke, 1960). This voltage difference then charges the junctions, which in turn produce charge from the charge carriers in the diode, and the process is how electrical energy is generated from the panels converting solar energy into electrical energy.

The method of generating electricity has several drawback factors, which mainly include maintenance features. This process is highly inefficient if the panels are not cleaned, as a 1 mm layer of dust can reduce electricity generation by almost 40–45% (Crabtree & Lewis, 2008; Mekhilef et al., 2011). The panels have to be properly maintained and cleaned on a regular basis. In countries like India, where dust and dirt are very common, these panels must be cleaned daily to maintain efficiency and produce a constant amount of electricity regularly. Maintaining solar panels may not be easy, and hence other methods can be deployed which have the capability to monitor and maintain the panels automatically or alert the required authorities to act upon the same. Technological advancements and the Internet have made monitoring more accessible and more efficient. With the help of IoT, these systems can easily be managed, hence improving overall efficiency with the minimum human intervention (Kannan & Vakeesn, 2016).

1.1 Introduction of IoT with renewable energy

In this era of technology, the world can be seen speeding its pace toward technological advancements and achieving what was once considered impossible. We live in the Information Age where the presence of the Internet is a boon to mankind. It has not only opened doors for enormous applications but has also paved the way for the communication of things in our ecosystem with other things or humans (Budida & Mangrulkar, 2017; Islam et al., 2020). This development is termed as "Internet of Things," which has created wonders in numerous industries like healthcare, agriculture, energy management, etc. The evolution of the IoT took place with a series of developments or different phases, as shown in Fig. 5.

The first phase was the basic interconnection of one computer with another. The second phase involved a web connection of numerous computers over the World Wide Web (Abir et al., 2021). The third phase saw the emergence of mobile phones and eventually people's information which also developed social networks and led us to the fourth phase.

The present phase of IoT is about the connection of everyday physical objects to the Internet. IoT gives physical things and people the liberty to connect with anyone or anything at any time and anywhere with the support of any existing network. Following the development, there have been two new propositions, namely SIoT and IIoT. Social networks are an integral part of society today, and under SIoT or Social Internet of Things, objects have the potential to generate a social network with respect to their owners. The interconnection of IoT with human social networks is explained in the light of SIoT (Baker et al., 2017; Catarinucci et al., 2015). IIoT, or Industrial Internet of Things, aims at the interconnection of IoT with industries. It majorly directs industrial manufacturing and maintenance to work in a smarter way with the use of cognitive computing to level up automation.

This would not only transform the industry into an automation industry but also increase the efficiency and productivity of the machines involved with respect to the production of the items. The automation industry would automatically level up the technological advancement for the country, but many applications could also be carried out with the same approach. Figure 6 represents the layout of a smart home application of IoT. It uses local storage and processing units with cloud technology. Smart homes primarily aim to optimize energy consumption by considering different parameters like usage patterns, presence of residents, condition, time of the day, etc. (Gaur et al., 2015; Kim et al., 2017; Varvarigou et al., 2013).

The past few years have seen and will continue to see a major increase in the applications of IoT. The numerous applications of IoT have led to the four broad classifications of IoT applications based on the scope of functionality (Pawar, 2019; Pan et al., 2015; Pawar et al., 2020). The classification involves identity-related services, information aggregation services, collaborative-aware services, and ubiquitous services.

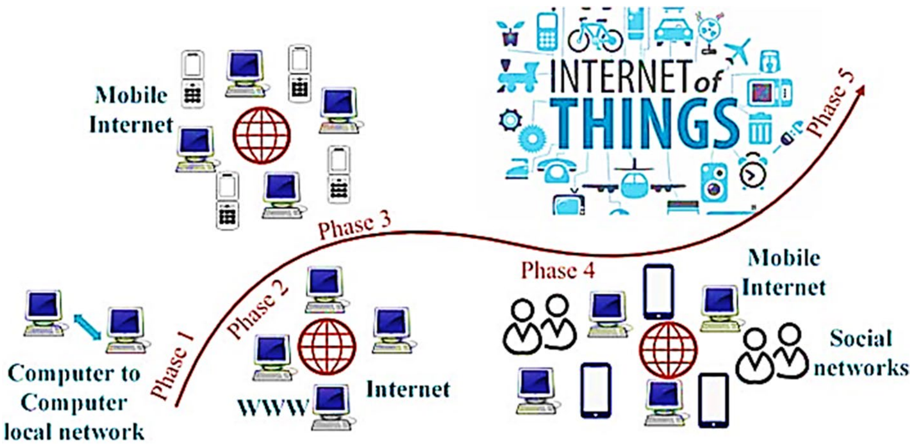

Fig. 5 Evolution of IoT (Kalla et al., 2020)

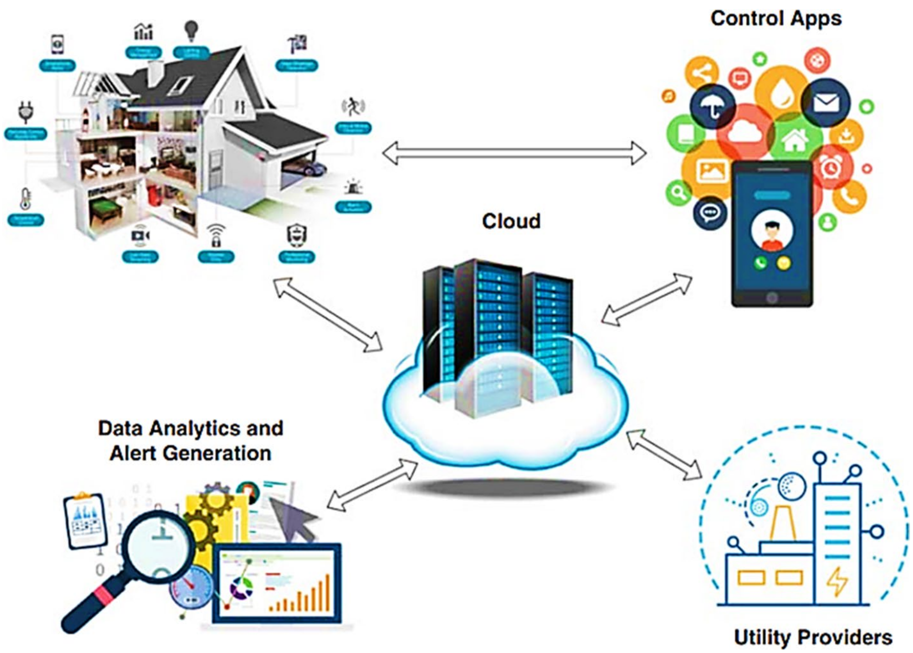

Fig. 6 Smart home application of IoT (Kalla et al., 2020)

Identity-related services involve addressing every single object in the network. Information aggregation services involve collecting aggregate data from objects and sending it for processing purposes. It involves smart energy, healthcare, wearables, etc. Collaborative-aware services involve decision-making, and the generated response is actuated. It involves smart agriculture, smart city, smart home, etc. Ubiquitous services aim at any time availability of collaborative-aware services (Cirillo et al., 2020). Based on the scope of usage and adaptation, IoT applications are further classified into four levels, infrastructural level, organizational level, individual level, and all-inclusive level. The infrastructural level involves applications like smart city, smart energy, etc., whereas the organizational level application involves smart agriculture, etc. Smart homes and wearables come under individual-level applications (Theodoridis et al., 2013).

Figure 7 shows the smart city application of IoT. An IoT-led smart city focuses on smart hygiene, smart governance smart mobility, smart surveillance, etc. The system has to be highly reliable with low latency and high security. Many countries, like the UK, the USA, India, Germany, etc., have undertaken smart city projects (Malche & Maheshwary, 2017; Pătru et al., 2016; Santoso & Vun, 2015). Figure 8 represents the components involved in a smart energy application of IoT. It involves the generation of power, the transmission of power to substations, and the distribution of the power to the end consumers (Alaa et al., 2017; Ma, 2014; Jie et al., 2013). It takes care of the billing at a defined time cycle. This is very useful in fault detection providing 24 h monitoring and maintenance facility to the user. It provides us with smart energy generation and smart maintenance services. Different technologies used in such systems are LoRa, Z-Wave, SigFox, etc. (Jaidka et al., 2020; Sharma et al., 2019a). These systems are highly sustainable, providing higher safety to the users and higher efficiency and level of optimization.

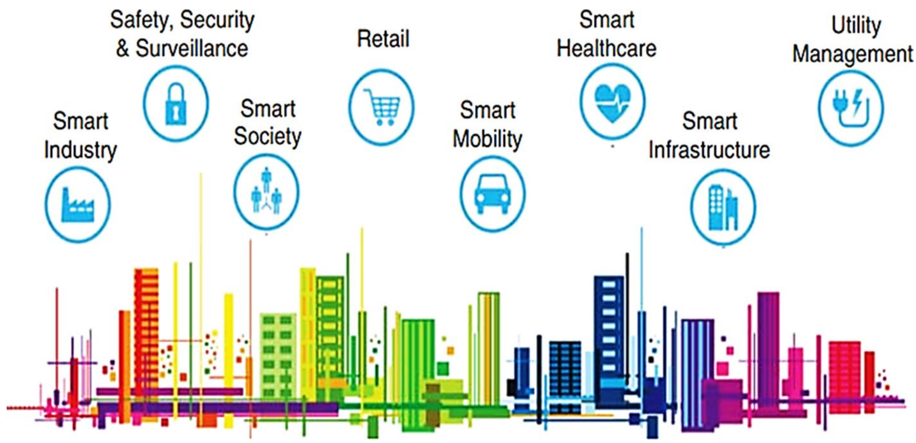

Fig. 7 Smart city application of IoT (Kalla et al., 2020)

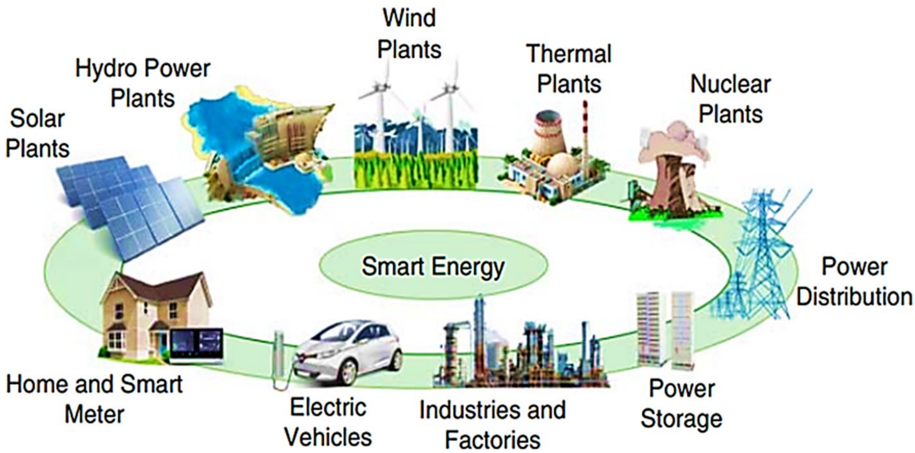

Fig. 8 Smart energy application of IoT (Kalla et al., 2020)

Figure 9 involves the various aspects of the Internet of Things in the healthcare industry. The IoT-based healthcare systems provide utmost precision, safety, and privacy with low energy consumption (Gubbi et al., 2013; Madakam et al., 2015; Sharma et al., 2019b). It benefits not only the doctors but also the patients, staff, hospitals, medical insurance companies, etc. This is the time when technology has surpassed the basic norms of existence and still has a massive scope ahead. IoT is an integral part of the development and has definitely created wonders and will continue to do so in the future of technology (Lee & Lee, 2015; Shafique et al., 2020).

1.2 IoT with smart city system

IoT is a technique that transforms the existing technology into the smarter one and can be more fruitful to the world when integrated with green technology. Green technology

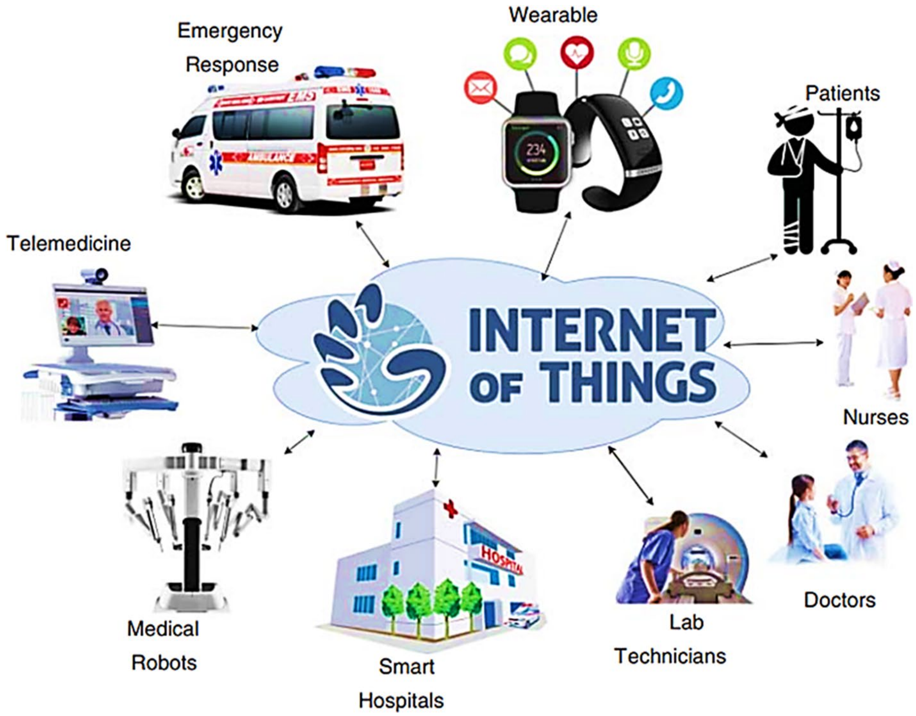

Fig. 9 Healthcare applications of IoT (Kalla et al., 2020)

is a revolutionary boon for the world as maximum energy generates from it. But there are innumerable energy losses, and on the contrast side, global warming is also increasing daily (Tung et al., 2022; Vieira et al., 2019). Moreover, to withdraw the maximum amount of energy from green technology, IoT has to be integrated with it. Revolution 4.0 also describes sustainable development in which there must be zero carbon emissions and also power consumption must be decreased. Presently, maximum energy is drawn by solar panels, and still, there are some reasons that cause energy loss. So, IoT integrated with solar panels can reduce power loss in the system and can increase the efficiency of the solar panels (Shaikh et al., 2018). Photovoltaic solar panels with battery storage systems are being utilized nowadays to be part of a smart city which includes applications like LED street lamps, etc.

IoT, which includes various actuators and sensors, is installed in different solar panel applications to increase efficiency and retrieve the maximum power output from the system. Also, as shown in Fig. 10, to make the street lighting system smart, the solar panels are integrated with IoT to consider it as a part of renewable source of energy, and sensors like LDR and motion sensors are being embedded into the system so that it could reduce the energy losses (Tat et al., 2018). Master Control Unit (MCU) is also implanted in the system to control the whole IoT process, and pulse width modulation (PWM) dimming system is used to control the current to dim the LED strips so that energy losses would be negligible. For example, if a car is passing near the smart pole, so the motion sensor can detect the moving car, and it will send signals to the controller to turn on the LED lights so that it would be convenient for the car to run on the road in

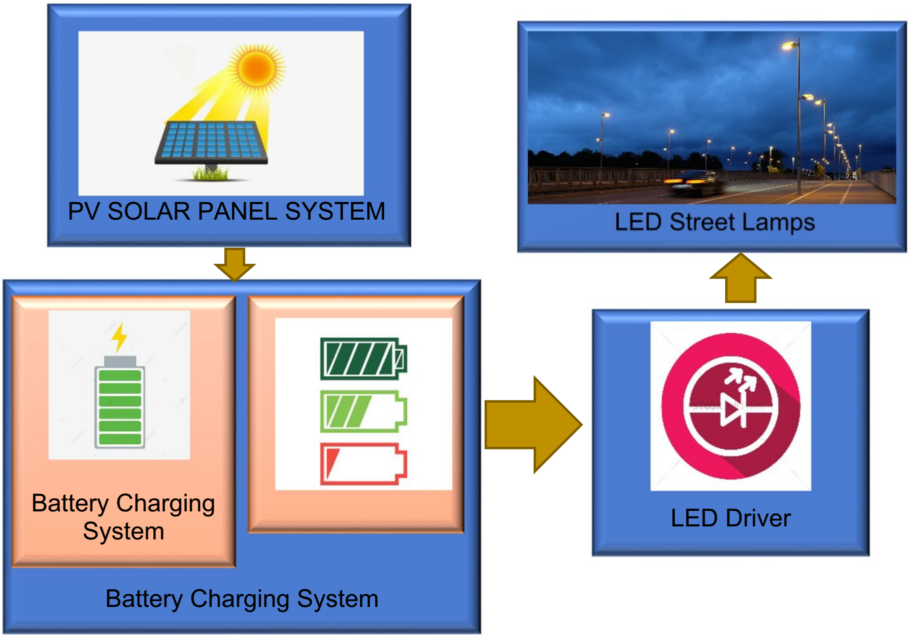

Fig. 10 Application of IoT in smart street light (Chen & Z., Sivaparthipan, C. B., Muthu, 2022)

the nights and when the car passes away from the smart pole, again the LED lights will automatically turn off, and this certain procedure will decrease the energy loss (Chen et al., 2022). The whole system is driven by an IoT technology that is embedded with solar panels. So, it is shown in Fig. 11 that how IoT consists of many smart sensors like voltage sensors, current sensors, temperature sensors, etc., to examine the condition of the solar panel so that the required data like voltage usage, current, power output, temperature, etc., can be retrieved and sent to the user's smartphone and the user can analyze the data and condition of the solar panel from any place (Firouzi & Farahani, 2020; Zafar et al., 2018).

Nowadays, innumerable solar panels with specific heights are getting installed with the grown crops on large farmlands. So as shown in Fig. 12, this captivating system is referred to as agrivoltaic technology. Also, to increase the efficiency of solar panels, the solar tracking system is being embedded with this technology known as the agrovoltaico system (Agostini et al., 2021; CA Food, 2021; Prathibha, 2017). In this system, maximum power point tracking (MPPT) technology has been used to track the sun's direction simultaneously. So after a certain period, whenever the sun changes its direction, solar panels will be redirected toward the sun, and this will cause solar panels to grasp the maximum amount of light from the sun, which will increase the efficiency of the solar panels (Usha et al., 2022; Wu et al., 2016). These kinds of systems are the greatest advantage for smart cities to provide electricity to them with zero carbon emissions, and so this will help to reduce the pollution also. MPPT system also consists of some actuators like servomotors to make the solar panels change their direction to a specific point. These servomotors are also getting energy from the PV panels, and the data which are regarding the solar panels can be easily retrieved by the controllers like NodeMCU and can be provided to the user's gadgets like smartphones or laptops (Abouaiana & Battisti,

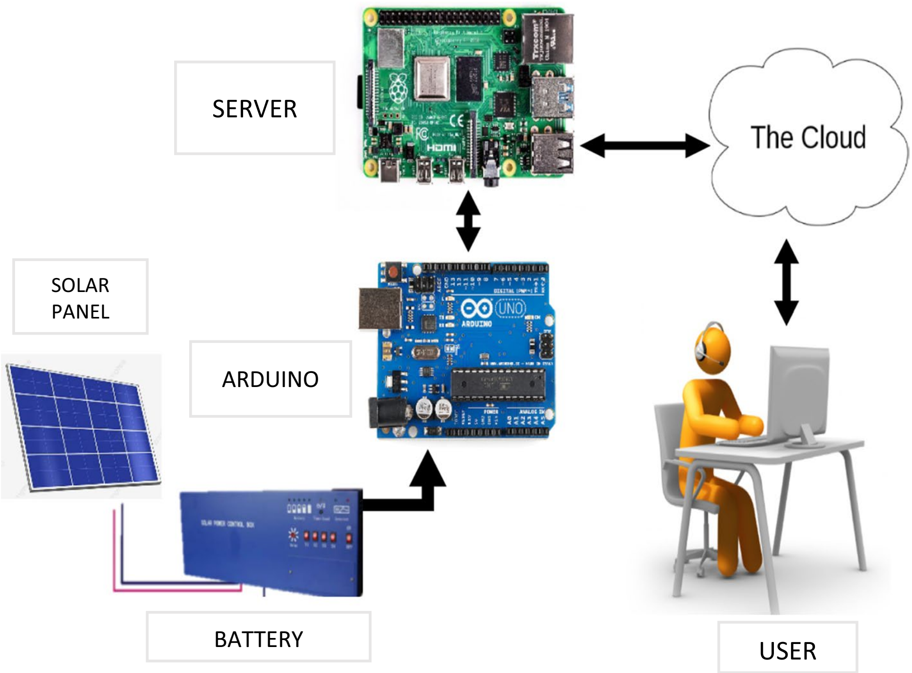

Fig. 11 IoT send data to the user through cloud (SKR Engineering College, Institute of Electrical and Electronics Engineers. Madras Section, and Institute of Electrical and Electronics Engineers, 2017)

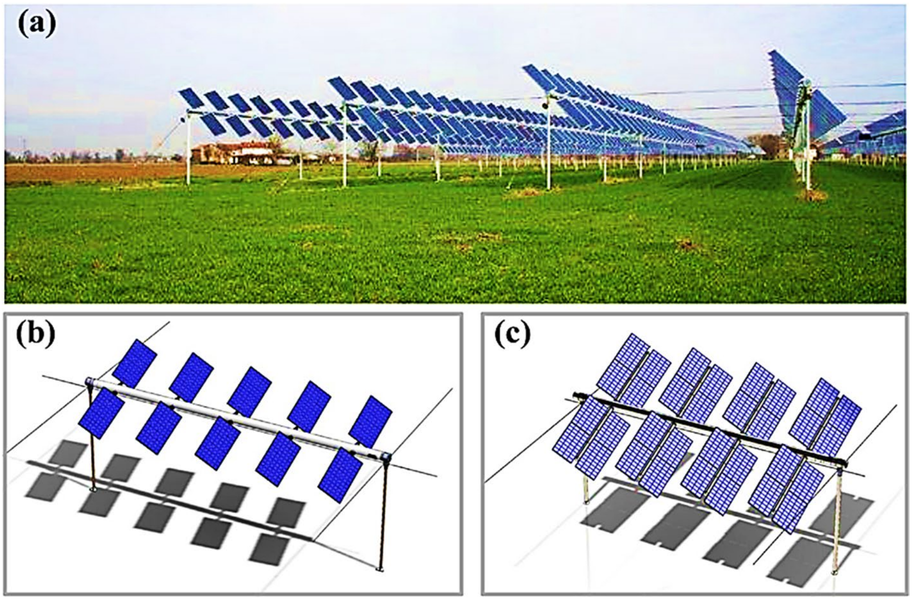

Fig. 12 IoT integrated with crops which is known as agrivoltaico system (Amaducci et al., 2018)

2022; Kamaruddin, et al., 2019). The whole data have been stored in the cloud and can be encrypted using a certain level of security.

Countries that are closer to equators, like Brazil and Argentina, can have the greatest advantage from this system as solar panels can get the appropriate amount of heat from these climatic conditions. However, nowadays PV panels do not require that much heat as they have enough capacity to generate a sufficient amount of energy due to photovoltaic cells (Shaw et al., 2020; Truong, 2015). So, in some rare cases where the temperature is extremely high, PV cells get deteriorate, and it leads to damage to the whole solar panel system, which can suddenly decrease the efficiency of the whole system. And if there is micro-damage in the panel, then it is exhausting to examine it as the solar panels are big enough. But when the whole solar panel system gets integrated with IoT technology, it turns out to be unchallenging as IoT can drive the required data to the user's smartphone or gadget (Jalali et al., 2016; Truong, 2015). Also, many applications like Blynk App can retrieve and store the data to the cloud and send it in any form like graphical, mathematical, or live simulation. And due to this, it is so uncomplicated to analyze the defect in the solar panel as a user can get the data simultaneously on their gadgets. Much research and groundwork have been done to analyze the defects in the solar panels due to excessive heat, dust layer, unwanted shades, etc., which cause the decrease in the efficiency of the solar panel (Rokonuzzaman et al., 2020).

This is the thermographic images of the photovoltaic modules (PM) in which the top most row (A) has no overheated defects, but row (B) has some single line defects, and the bottom row has multiple line defects which cause the total damage to the solar panel system. So, an IoT system is to be implemented to calculate and monitor the whole parameters; for example, a voltage sensor is used to calculate the voltage output, an LDR sensor is used to calculate the intensity of the light, and MCU unit calculates the power output (Deekshath, 2018; Williams, 2017; Xiaoyi et al., 2021). So, this procedure requires less manpower, increasing efficiency, and reducing complexity. The applications of IoT and solar have a more significant potential to serve in this era, for instance, the Automated Agricultural Field Analysis and Monitoring System. Agriculture is one of the most important sectors in the world. It definitely needs to reform its traditional techniques for manual field monitoring, water feeding, pest detection, soil testing, etc. (Ozkan et al., 2019; Wu et al., 2019a). To overcome these traditional methods, AAFAMS (Automated Agricultural Field Analysis and Monitoring System) using IoT is implemented. It provides an effective and smarter way of monitoring the fields for farmers. It reduces the efforts of the farmers by automating the analysis process and helps to detect pests in the fields and predicts pesticides that can be applied to these pests (Wu et al., 2019b).

This helps to increase the production of agricultural fields that maintains the fertility of the soil from water logging and monitors the number of pesticides going into the crops. A solar panel is a major component of the proposed model as they accumulate the natural energy for the power supply. It monitors the soil moisture level at every 100 m distance using a soil moisture sensor, and the information obtained from the sensor is sent to cloud storage. A camera will be connected to the AAFAMS, which will detect the pests. After a complete survey of the field, AAFAMS retrieves all stored data from the cloud and SQLite database (). Furthermore, it provides a detailed report of moisture content and pest information which is displayed through the android application. IoT systems powered with solar energy are an exceptional combination with many applications sustaining in their vicinity. The major contribution of solar powered IoT systems has been the Healthcare Industry as shown in Fig. 13. Smart healthcare will definitely serve any country and its people.

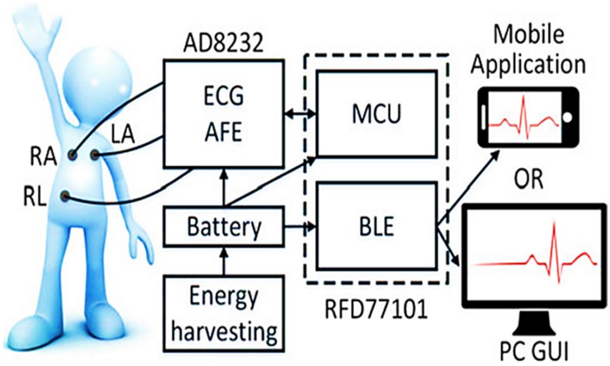

Fig. 13 Proposed ECG monitoring system (Wu et al., 2019c)

One such development would be wearable health monitoring systems or smart wearables (Adhya et al., 2016a, 2016b).

1.3 IoT with home application system

A study proposed the development of an Electrocardiograph Monitoring System integrated into a T-shirt. The system is compact, easy to wear, and flexible and has the potential to deliver real-time monitoring. The study used AFE (analog front end) chip. The ECG data gathered are transmitted over BLE to the end device or a graphical user interface (GUI) (Chieochan et al., 2017; López-Vargas et al., 2021). The layout of the proposed ECG monitoring system can be seen in Fig. 13. A study successfully completed and developed a prototype, as shown in Fig. 14. The prototype has a solar panel sheet, which makes the design even more efficient as the solar energy is absorbed and used to power the smart wearable. A smartphone application was also designed for easy monitoring purposes (Kamble & Birajdar, 2019).

In the present world, the comfort of living at home has almost at a luxurious level and has a huge significance. To maintain the order of living, various studies have led to the concept of smart homes, which uses an IoT-based home monitoring system to meet the needs of a smart autonomous household. This smart home takes care of thermal comfort, visual comfort, hygiene, and comfort (Patil et al., 2017). The system uses a variety of sensors to sense different parameters to maintain the ideal comfort conditions. It has a remote control for different parameters. This system is based on solar power and so is highly efficient and highly sustainable. Figure 15 represents a

Fig. 14 Smart wearable prototype (Wu et al., 2019c)

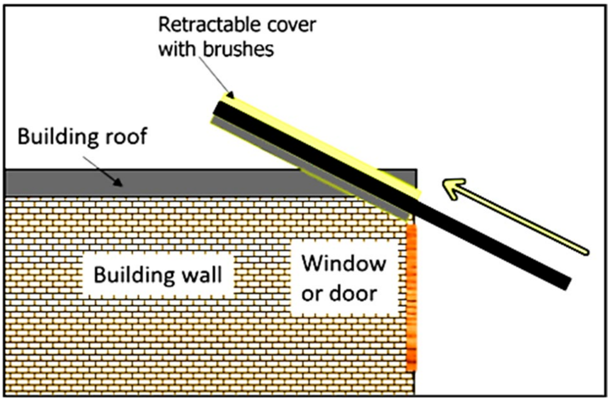

Fig. 15 Solar panel cleaning system principle of operation (Al-Kuwari, et al., 2022)

solar panel cleaning system principle of operation used as shade for the house's garage (Gunawan, et al., 2017; Patil et al., 2017a). This is not just creative but the most efficient and reformed house. A basic representation of an IoT-based home monitoring system can be seen in Fig. 16. Smart home monitoring can be seen using numerous parameters, as shown in Fig. 16. This maintains the safety of the household and increases the quality of the comfort.

It can be clearly seen in Fig. 17 how the IoT server interconnects the components inside a home to the end-user or humans. The solar panels installed in a smart home, as shown in Fig. 17, are used to power the entire system and the WiFi. The use of various sensors like humidity sensors, temperature sensors, LDR sensors, etc., is used to monitor the temperature, humidity level, light intensity, etc., for the smart home. It has an inbuilt fire detection, electrical hazard detection, and other hazard monitoring systems to ensure high safety and security of the house (López-Vargas et al., 2021; Wu et al., 2019c). Solar energy-powered IoT systems have numerous applications to catch their service. The field is constantly seeing a rise in further development and applications (Maheswari et al., 2019; Sadowski & Spachos, 2018; Sharma et al., 2020a,b).

The principle of operation and the applications of IoT in the solar field clearly illustrate the wide applicability and necessity to use them in modern days to have sustainable and efficient energy utilization. However, in recent times, authors have been focusing on smart grids, energy harvesting, the energy sector and IoT, and a few other areas. The focus on IoT and solar energy utilization is, however, very new in the renewable energy sector. Hence, referring to many recent articles where the review integrated the use of IoT and smart grid system, energy harvesting using IoT, smart grid and solar energy, IoT and solar (Ahmed Abdulkadir & Al-Turjman, 2021; Elahi et al., 2020; Luo et al., 2018; Motlagh et al., 2020; Qjlqhhulqj & Qjlqhhulqj, 2020), it is noticed that a systematic review of in detail research works pertinent to the application of IoT and solar energy use is much required. With this motivation, this review article focuses on collecting all scientific works on developing prototypes and models for effective and sustainable solar energy harvesting using IoT. The review is demonstrated with schematic figures and analysis for better readability. The overall summary of each research

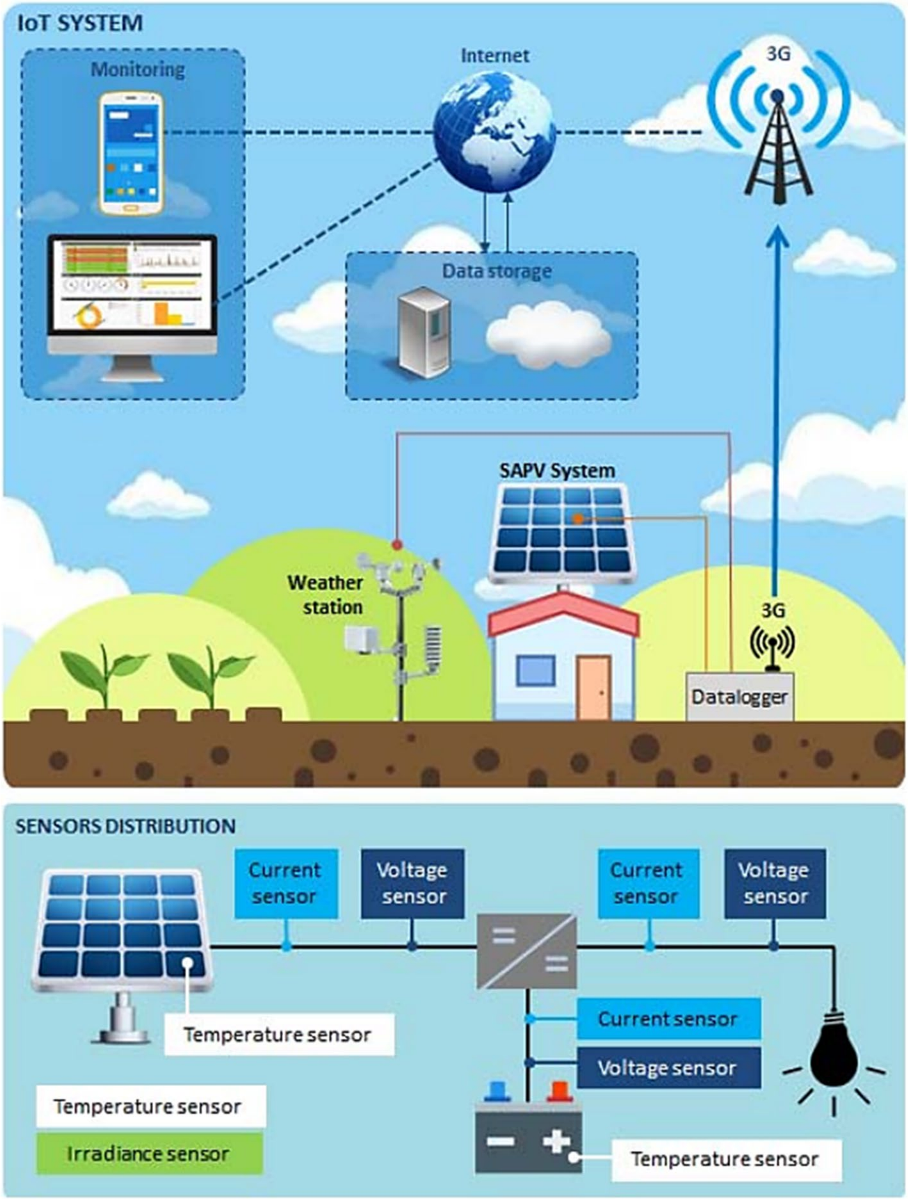

Fig. 16 IoT-based home monitoring system (Lopez-Vargas et al., 2018)

work is provided in the form of tables to give an idea in a quick glimpse. At the end of this review, the summary and conclusions are also detailed. The future scope of work related to IoT and solar energy is described at the end of this work.

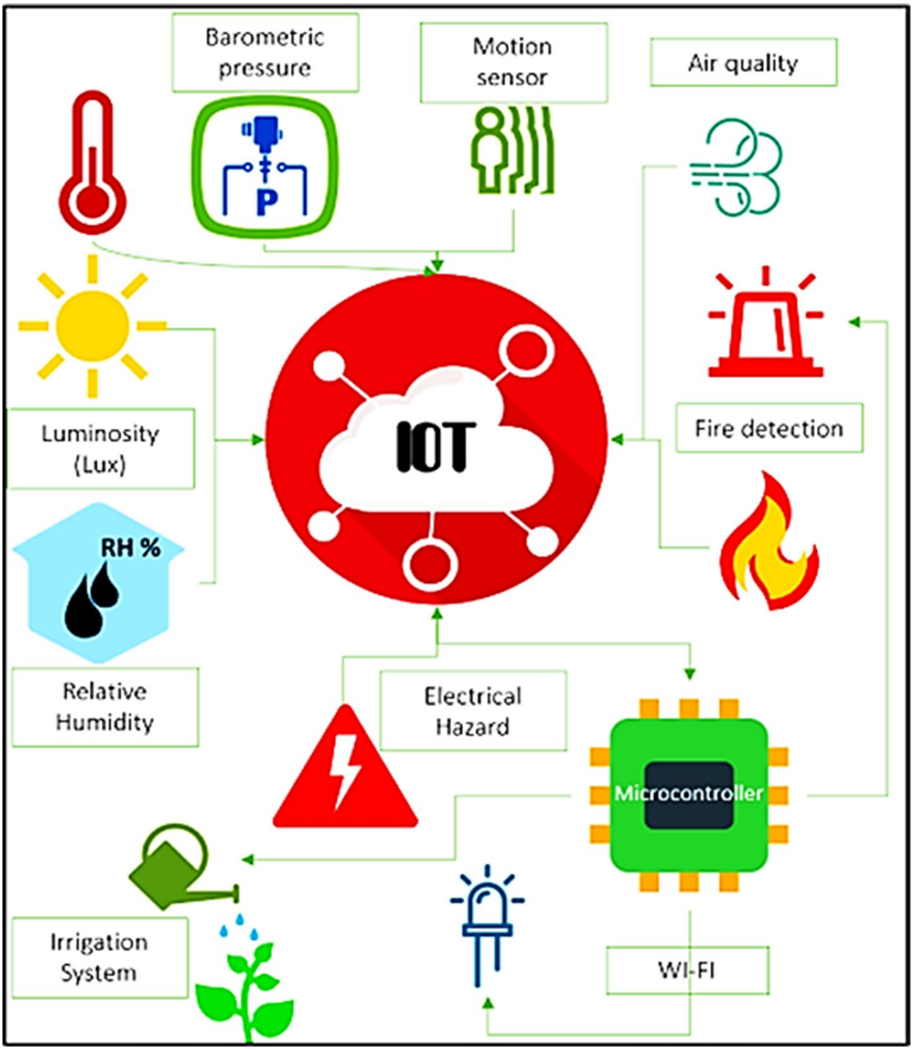

Fig. 17 Parameters of smart home monitoring system (Al-Kuwari, et al., 2022)

2 Integration of IoT and solar energy

The potential of IoT has been uncovered by a variety of research and studies conducted over the past many years in all fields of application. The application of IoT with solar energy-powered systems has indeed been a revolutionary reformation in technology as solar energy is a renewable form of energy and is a sustainable base for the future of human civilization. Researches have been done to reform the network structure using IoT by identifying various objects in the ecosystem for efficient control of smart solar-operated cities. Following, an in-detail review of state-of-the-art pertinent to the application of IoT in solar energy devices is thoroughly provided. The review is mainly divided into four sections where the majority of analyses are performed using IoT, which are: (1) maximum power point tracking (MPPT) and solar tracking, (2) combined other renewable sources of energy with solar energy, (3) smart lightning and PV systems, (4) solar energy monitoring System.

2.1 MPPT and solar tracking

The energy from solar panels is a substitute for renewable energy. However, the dominant problem in solar panels is heat. The normal temperature of solar panels is 25 °C. If the temperature is above 25 °C; then, the components of the panels may get heated up, and this would cause a downfall in the efficiency and could not get the maximum power output. So, Haris Isyanto and Wahyu Ibrahim (Isyanto & Ibrahim, 2021) have developed an IoT system that can recognize overheating at an early stage and can be monitored through a smartphone using the Blynk application. In this procedure, after the comparison between measuring instruments and sensor applications in the form of average percentage is current 2.61%, voltage Vdc 1.32%, power 3.89%, and temperature 2.14%. This system lets the user know about early heating warnings and helps to monitor the solar panel parameters through smartphones from any location. Padma et al. (Padma & Ilavarasi, 2017) have developed a system to solve this challenge by controlling and monitoring the output of the solar panel through servers using IoT. Each user can access their own output page, as each page consists of a unique IP address. Additional control and monitoring of the solar panels can be processed using relay boards and circuits which can increase the efficiency.

Dinesh et al. (2021) have developed a dual-axis sun tracker framework to increase the efficiency of solar panels. This system consists dual-axis tracker that can face the photovoltaic cells in all different directions, and LDR also has been used in this system to feel the depth of the mild and convey the information to the microcontroller. This system can also monitor temperature, humidity, and raindrops and can be presented on the LCD screen. Bedi et al. (2018) have reviewed how IoT can impact electric and energy systems (EPES) and transform the technologies like real-time monitoring, cybersecurity, etc., so that these technologies can be more sustainable, reliable, secure, and efficient. He has reviewed cognitive computation and other computational intelligence to analyze the transformation in the IoT sector. Energy crises have been rising in recent times, and renewable energy resources are now given higher preference; hence, Rahman et al. (2019) have proposed an IoT-based system to optimize renewable energy sources to light up street lights on a highway. Only solar energy can sometimes be inconsistent, and hence, they have derived a hybrid system for lighting on highways. This system is an intra-network IoT-based solution that optimizes battery performance by selecting a suitable energy source to charge the battery and also uses wind that is produced by ongoing vehicles. Vertical-axis wind turbine (VWAT) along with solar panels has been used in the hybrid system for uninterrupted lighting throughout the day for maximum efficiency, which is connected to a microcontroller to assess internal parameters. This system utilized less energy and proved to be more efficient depending on the level of traffic on the highway. Figure 18 describes the power Line setup when integrating solar power energy.

Divakaran et al. (2021) have set up a solar tracking system that would be able to harvest the maximum possible solar energy by tracking the position of the sun. The setup would rotate the solar system as per the direction of the sun using a single axis with one degree of freedom. The movement would be done using a DC motor which is controlled

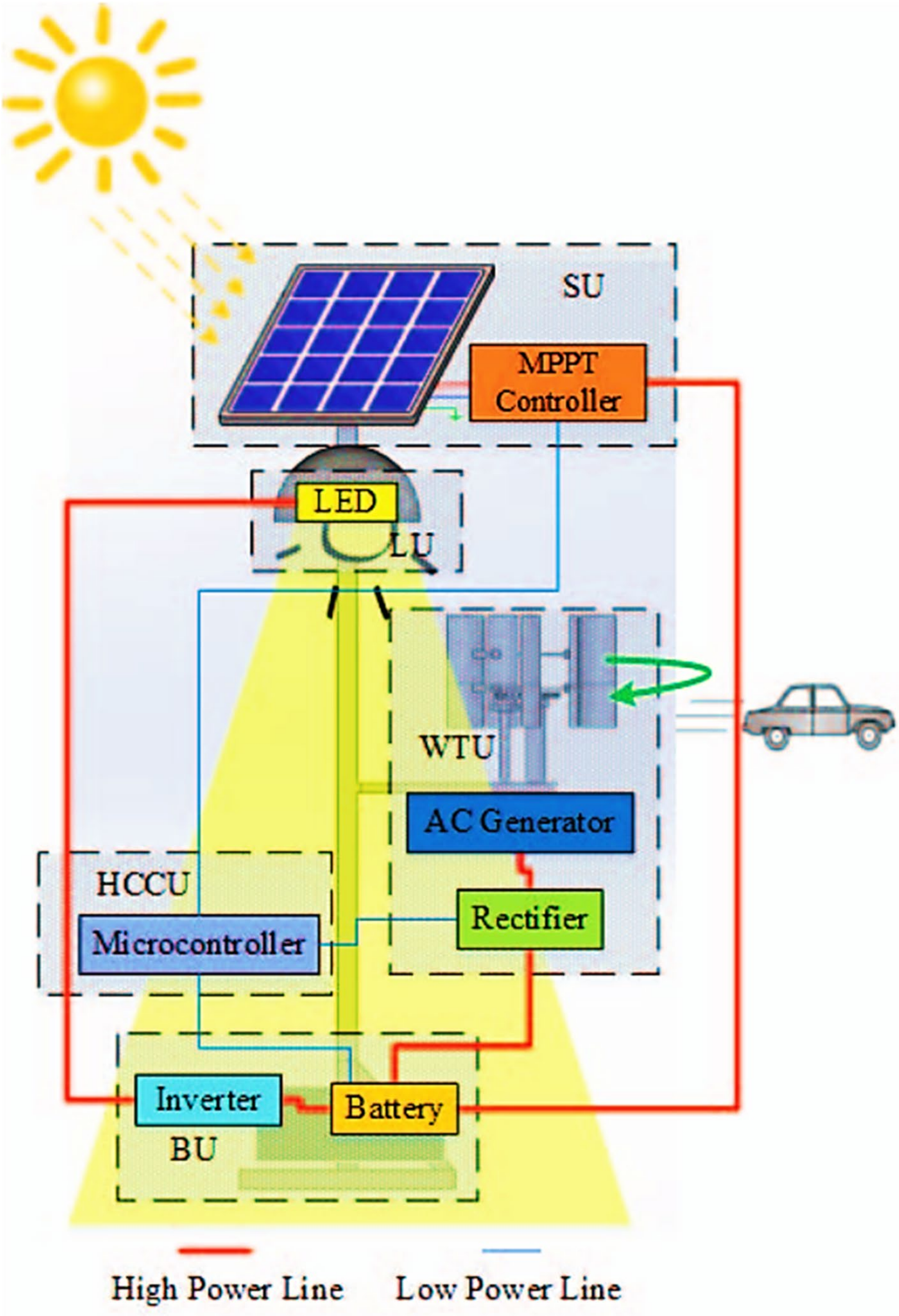

Fig. 18 Block diagram of integration of solar power (Rahman et al., 2019)

by a microcontroller ATmega 2560 and LDRs to detect the direction in a closed-loop system. This system proved 71% more efficient than the conventional solar system without a tracking system. The data would then be shared using IoT, which can be used for monitoring and control.

IoT-based systems can be used for maintenance and fault detection in solar panels, and for proper harvesting of solar energy, the solar panels have to be maintained regularly. Suresh et al. (2018) have researched an IoT-based system that would be used to monitor the power generation, efficiency, and other solar-related parameters in the solar panels to reduce breakdowns and faults hence increasing efficiency. Monitoring and maintaining photovoltaic solar panels are essential to preserve the system and keep its efficiency intact. Gusa et al. (2018) have proposed a paper for monitoring the solar system in real time using ATmega 2560 Arduino as the microcontroller along with other current, voltage, and temperature sensors. This is connected to a WiFi module which connects the solar system to the Internet and can be controlled using a smartphone. Real-time monitoring of the system was done successfully, which detected any abnormalities in the solar system, if any. Kodali and John (2020) describe systems that can be used for solar monitoring. The system consists of a microcontroller and sensors which helps to take data and sends it to the clients using AWS, i.e., Amazon Web Services. IoT used leads to more efficient solar energy.

Nalamwar et al. (2017) have come up with a system that monitors and controls the solar panel simultaneously in an automated behavior. They have used IoT as their base idea. They have used devices such as sensors, block management modules, and electronic software to store the electrical details of the photovoltaic plant into management modules. The idea can completely monitor the solar panel by showing faults, sending messages for maintaining the panels, rotating panels when sun rays changes direction. The system rightly monitors the solar panel and reduces hassle for humans. Rao et al. (2021a) have introduced a cleaning system for the solar panels under the roof of Internet of Things. They have come up with a smart monitoring system in order to remove the dust on the solar panels. The use of Arduino UNO, different sensors and actuators, helps with control system and analysis of the process. The process of removing the dust enhances the efficiency of photovoltaic solar panels.

Spanias (2017) develops a new IoT-based system in order to elate the efficiency and working of solar array farms which helps to monitor the solar energy. Many countries have also contributed to solar array farms, for instance, Japan developed a first-generation smart monitoring device, which can be called as SMD. This development is installed with panels which are already IoT equipped. Figure 19 shows the overall layout of the proposed model using sensors and PV arrays. This development solely depends on the amalgamation of vision and fusion algorithms. This method claims for a generationally new solar array farms. This results in the installation of mobile—analytics, the faults are determined which is beneficial for the user, and regular optimization is done which enhances the quality of the work. This helps in prediction of power and monitoring facilities.

Tharakan et al. (2021) focus on machine learning-based dual-axis solar tracker to enhance the energy harvesting efficiency. The model uses LDR sensors with solar panels, servo motors, and microcontroller as shown in Fig. 20. They proposed of using Naive Bayes algorithm to predict direction or solution for developing large amount of energy from solar panel than any other traditional methods. Sujatha et al. (2016) concentrate on increasing solar panel efficiency by incorporating indigenous solar tracking systems. In this work, solar tracking systems using ANN estimate the azimuth angle of the sun. An AI

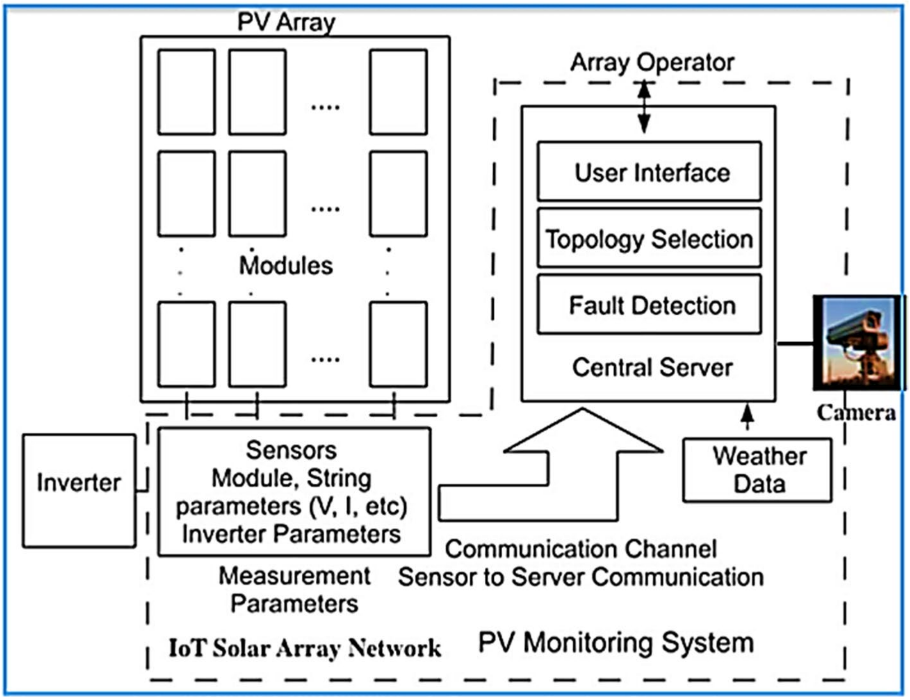

Fig. 19 Layout of the proposed operation (Spanias, 2017)

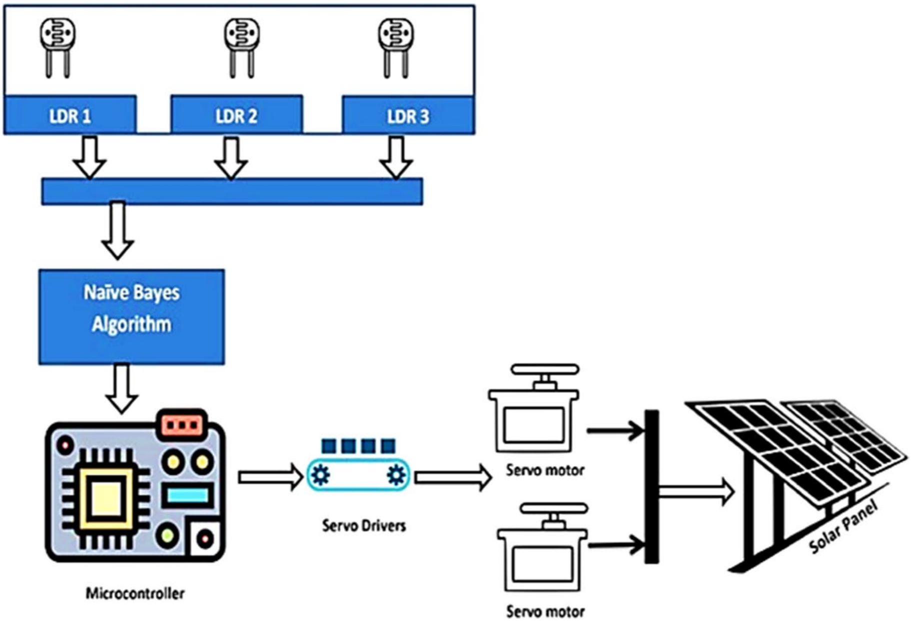

Fig. 20 Operation of the proposed model (Tharakan et al., 2021)

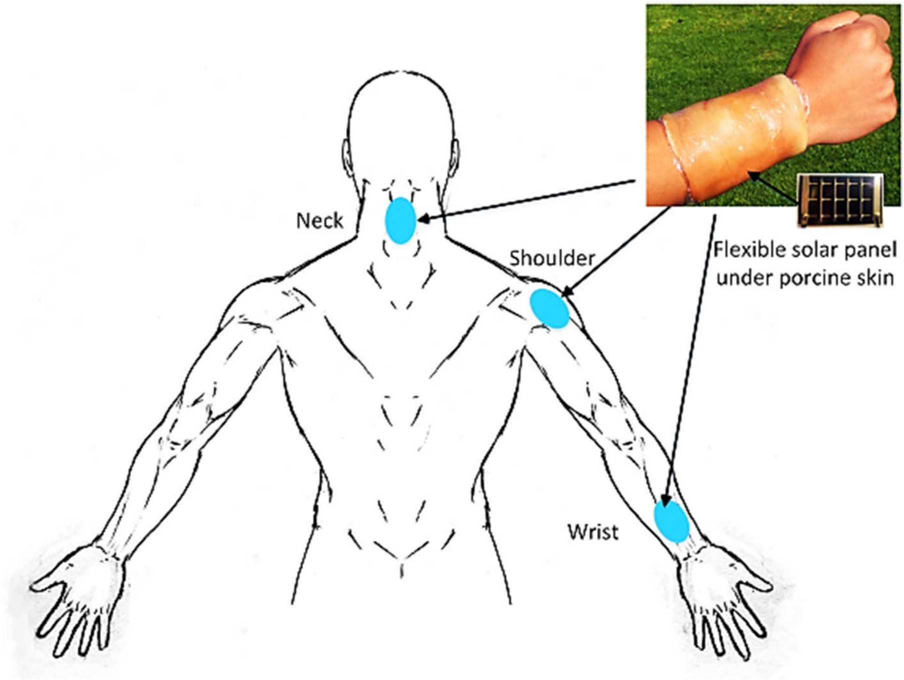

Fig. 21 The prototype of the proposed model (Wu et al., 2018)

process differentiates whether the weather condition is sunny or cloudy. With the results obtained, the solar tracking system establishes the usage of astronomical calculations.

Wu et al. (2018) have successfully proposed a prototype of sensor, as a biomedical device, having solar energy harvesting facility which can be potentially used for long-term healthcare applications. This development helps the healthcare industry based on IoT applications. To arrive at a satisfactory conclusion, various experiments have been done under natural and artificial light to examine the working of a flexible solar panel. After testing the energy harvester on different body parts, it is decided to place it between neck and shoulders for upgraded results as shown in Fig. 21. The harvester consists of different components like temperature sensor, a BLE module, and a circuit to manage power. The whole setup is kept under a silicone covering. As a result, the working of implantable sensor prototype is shown by the experiments on the energy harvester.

Yaqub et al. (2019) determine the use of IoT in a hybrid wind–solar energy-driven desalination plant that uses the network simulation tool Packet Tracer by CISCO. Power from sustainable sources is used, and the motors and the boiler are automatically controlled according to the water level/demand and by a thermostat, respectively. A web-accessible monitoring station is also housed on a server, and NAT and ACL are also used for network security and access control. Zhao and Xing (2020) propose control of hierarchy method for analysis of IoT systems cascading PFD and random system failure time. The IoT system only triggers when one system failure causes another system failure. This method applies to arbitrary types of failure time and propagation time distribution, as shown in Fig. 22. The works reviewed in this section are summarized in a tabular form in Table 1.

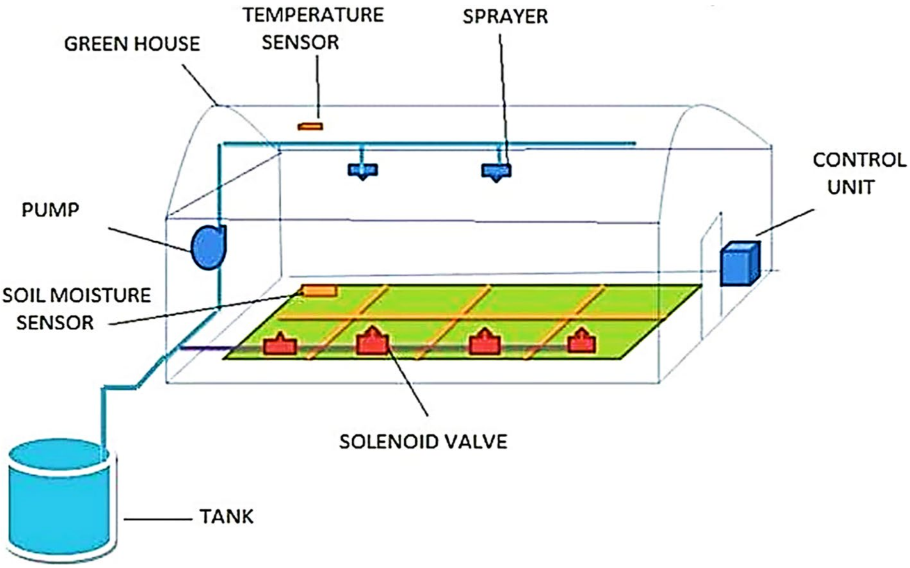

Fig. 22 Layout of the proposed model (Malarvizhi & Venkatesan, 2014)

2.2 Hybrid sources of energy

The hybrid source of energy comprises solar energy assisted with wind, ocean, geothermal energy, and integrated with IoT. Systems like irrigation were operated using solar energy, which was further smartly operated using IoT in many works. Fuada et al. (2015) aimed to design a smart greenhouse that contains the automatic opening of the canopy, watering of plants and crops, and monitoring of temperature. To reduce the cost of power supply, they will use PV cells with a solar panel to develop the electric energy. Shakya (2021) proposed a system that can provide a constant maintenance alert using the current and voltage data from the solar panels. The retrieved data are compared with the enumerated data from the solar panel based on different solar radiations. If there is any large imbalance in the power which is generated by the solar panels, the system constantly warns the maintenance team. Figure 23 explains the block diagram with the error estimation feedback, which notifies of any disturbance that occurs during the process. The experimented model can be enlarged with a standard system for controlling some other minute maintenance work which is on the connected solar panels.

Vaghani et al. (2019) have developed a solar system cleaning robot that would remove any dust/dirt and foreign particles from the panel. This cleaning system would help increase efficiency by 32% hence becoming cost-effective, efficient, and provide better performance. This system would also help reduce labor and any other labor-related costs. Katyarmal et al. (2018) proposed an IoT system that can be used to develop solar power monitoring systems to store and analyze data on the cloud. This data would help in maintaining the solar system and prevent faults and problems in the solar system and also facilitate real-time monitoring. Moretti and Marucci (2019) came up with a potential prototype of a greenhouse with variable shading by panel rotation which is used for powering the greenhouse. The rotatory panels are used to create variable shading inside

Table 1 Overview of works on MPPT-based solar energy application

Author's name [Ref.]	Hardware/ components used	Software/operating system used	Concept used	Microcontroller/technology used	Parameters measured	Application
Singh et al. (2019)	Rain sensor (FC37) Temperature sensor (DHT11) Humidity sensor OLED LDR sensors Solar panel	N/A	Solar Tracking System	NodeMCU Arduino	Humidity Temperature Rain Light Intensity	A system has been developed to track the sun stability and accuracy with different weather conditions
Wu et al. (2017)	MPPT circuit Pulse sensor Flexible solar panel Piezoelectric Transducer Supercapacitor	Smartphone Application	MPPT	BLE pioneer Base board PSOC4 BLE module	Pulse signal output efficiency Charging	The author has proposed a system to monitor people's health conditions in the form of smart wearables
Adila et al. (2018)	Temperature Sensor Pressure sensor PV Transducer Piezoelectric Transducer RF Transducer	N/A	Power Management IC (PMIC)	MCU/PSoC RF/Bluetooth/Zigbee interface	Temperature Pressure Power	A System to prolong the battery life of IoT devices
Dinesh et al. (2021)	LDR (Light Dependent Resistor) Temperature sensor Humidity sensor Rain drop sensor Solar panel DC motor Voltage Sensor Pump motor LCD display	IoT application	Dual-axis sun tracker system	ATmega 328P	Light Intensity Humidity Temperature Efficiency	An IoT system has been developed to lessen the control catastrophe to many extents

Table 1 (continued)

Author's name [Ref.]	Hardware/components used	Software/operating system used	Concept used	Microcontroller/technology used	Parameters measured	Application
Hisham et al. (2020)	Light Dependent Resistors (LDR) Solar panel Servo motor	N/A	Sun Tracking	Arduino Uno NodeMCU ESP8266	Light Intensity Efficiency	The author proposes a system to reduce carbon footprint, can be controlled manually, increases the efficiency
Divakaran et al. (2021)	Light Dependent Resistors (LDR) Solar panel DC motor	Arduino IDE Blynk app (for output)	Single-axis solar tracker Closed-loop tracking	Arduino Mega ATmega 2560 microcontroller	Light Intensity Solar panel Voltage Efficiency	A tracking system has been developed for remote monitoring of solar plants for high power generation
Gupta et al. (2021)	Inverse Sepic converter Lead acid battery PV module	MATLAB/Simulink	Incremental conductance (INC) in MPPT technique	The microchip PIC KIT 3 burner for microcontroller	Duty cycle Solar power Load current Irradiance	The author proposes a system to deal with the rapid changes in weather conditions
Soonsawad et al. (2021)	Solar panel Handler (mounting solar panel) Multimeter Supercapacitors	N/A	BLE Beacon Markov Decision Process (MDP)	N/A	Light irradiance Illuminance (lux) Light intensity Inclination angle Voltage Current	A system has been developed which ensures the operation of a beacon in the unavailability of both indoor and outdoor light sources

Table 1 (continued)

Author's name [Ref.]	Hardware/ components used	Software/operating system used	Concept used	Microcontroller/technology used	Parameters measured	Application
Khujamatov et al. (2019)	Solar tracer system Motor driver LDR sensors Current sensor Voltage sensor LCD display Solar panel Servo motor Digital Oscilloscope	Proteus simulation	Automatic Sun Tracking system	Arduino UNO ATmega328	Temperature Voltage of PVpanel Illumination Azimuth angle Tilt angle	A system has been proposed for disconnecting the defective device and timely reporting emergency case
Shaw et al. (2020)	PV panel Voltage and current sensor	N/A	maximum power point tracking technique	IoT-based controller Charge controller PV Solar module	Maximum Power Efficiency of solar panel	A PV and IoT governed system which provides a reliable, high quality and more efficient power to the user has been developed
Gunasagaran et al. (2016)	Solar panel Pyranometer	N/A	Solar power generation under a closed forest canopy	Libelium node	Solar Radiation Total solar power	The author develops a system which can power IoT devices with solar power in forest canopy
Shapsough et al. (2020)	PV panels IV Tracer Digital relays RC circuit Isolated wattmeter Capacitors Bleed resistor	N/A	Current–Voltage (IV) Tracing	Cloud-based server	Charging time Maximum Power Soiling ratio	The author proposes an IoT-based solar monitoring system for city-wide, large-scale, and distributed solar facilities

Table 1 (continued)

Author's name [Ref.]	Hardware/components used	Software/operating system used	Concept used	Microcontroller/technology used	Parameters measured	Application
Soonsawad et al. (2019)	Solar panel Rotatable solar panel holder Movable arm BLE beacon chipset holder	N/A	BLE beacon, one-time adjusted solar panel	N/A	Light sources Optimal Solar panel angle Charging rate	The author develops a system for an environment with multiple light sources
Spanias (2017)	Solar Panels PV cells SMD sensors	N/A	Solar panel array with IoT Machine Learning	N/A	Array Output	Concept is to integrate the solar panels with SMD sensors and can analyze the different analytics, control solar farms, and can detect the faults
Tharakan et al. (2021)	Mini breadboard Micro Servo SG90 LDR Solar panel Photo-resistor	N/A	Dual-axis solar tracker Naïve Bayes algorithm	Arduino UNO Tracker Control Unit	Light Intensity Output Power Efficiency	The author develops a system to automatically rotate the solar panel based on sun light
Sujatha et al. (2016)	Solar panels Filters LDR Digital sensor Sim card	Intel Galileo Gen2 Thingspeak cloud	Artificial Neural Network (ANN)-based Image Processing Technique (IPT)	Arduino	Light Intensity Output power Azimuth angle	The author proposes a system which is useful to evaluate the sun's position to obtain maximum output
Wu et al. (2018)	Temperature sensor BLE module Battery Solar panel Porcine flap Supercapacitor	Mobile application	Implantable sensor system with subcutaneous solar energy harvesting	Power management IC, BQ25505 from Texas Instruments Microcontroller (ARM Cortex M0)	Average power consumption Output power	The author develops a system which can be used for IoT-based healthcare applications

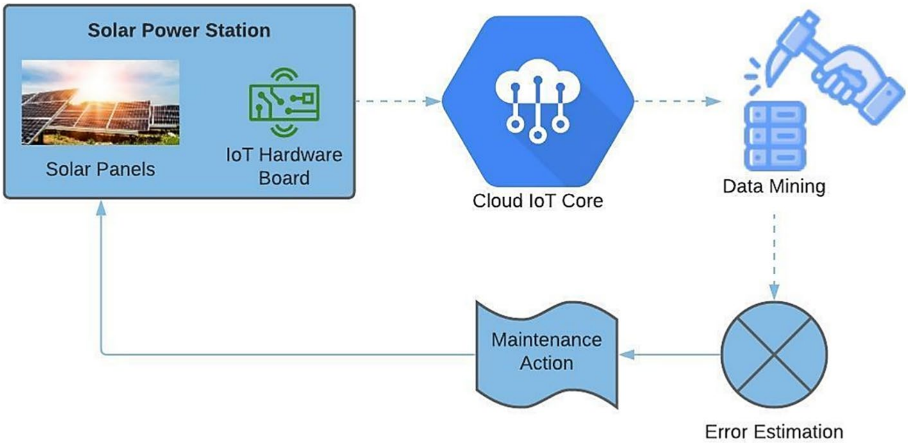

Fig. 23 Block diagram of IoT integrated with solar panel (Shakya, 2021)

the greenhouse that is matched in relation to climatic conditions outside. Solar energy is the cleanest source of energy and, if harvested efficiently, can solve several energy requirements globally. It does not have any toxic discharge on harvesting and hence can be extremely dependable. Solar energy requires photovoltaic cells, which have to be maintained properly. Any amount of dust or dirt settling on the panel would drastically affect the efficiency of the panel and hence reducing the amount of energy harvested.

Narang and Sharma (2019) have reviewed several cleaning robots for solar panels using IoT. The review talks about how the overall efficiency has improved, and maintenance of these solar panels has become comparatively easier. Herdiana and Sanjaya (2018) developed a solar home monitoring system with the application of IoT technology. The solar panels used in the study are able to produce electric loads, which can be monitored and controlled using the proposed system. The system uses current and voltage sensors to measure the power produced by solar panels. The study results in power generation up to a maximum amount of 5.2 Watts in 10 h of energy charging. In Table 2, the overview of works on IoT and solar energy utilization in combination with other energy sources is mentioned.

2.3 Smart lightning and PV systems

Díaz et al. (2020) described the panel detection and automated diagnostic methods which are used to examine the solar plants and to spot the abnormality in the photovoltaic panels, which are accomplished through unmanned aerial vehicles (UAV) using thermal imaging sensors. The primary step is to examine the solar panels in images and in case, due to complex background, cheap contrast, and structures that are similar to solar panels or shades of power lines could slow down this process or even obstruct the automated detection process. In this paper, for the detection of the panels, two self-intellectual methods with a common post-processing step are compared, i.e., the primary one is a classical technique that is based on edge detection and classification, and the other one is based on deep learning, which is based on training a region-based convolutional neural network to identify a panel. So in the first method, using edge detection, segment classification, and segmentation, the contrast of the thermal image can get correct also with the preprocessing techniques. A

Table 2 IoT with combined solar and other source of energy

Author's name [Ref.]	Hardware/ components used	Software /Operating system used	Microcontroller/technology used	Parameters measured	Application
Marhaenanto et al. (2021)	Solar panels Temperature sensor Humidity Sensor Voltage sensor	Esp_basic_flasher	IoT ESP8266	Temperature Humidity Voltage	An IoT system for the Greenhouse to measure the parameters for growth of the plants
Ariffin et al. (2017)	PV panels thermoelectric generator semi-transparent thin film solar panel	N/A	hybrid photovoltaic MPPT	Power Voltage Thermal Output	It's an automated greenhouse system in which hybrid photovoltaic and thermoelectric generator modules have been used to achieve the high energy output
Fuada el al. (2015)	Photovoltaic Cells Solar panels	N/A	Photovoltaic	Water level Temperature Humidity Light control	A Glasshouse farming system has been introduced which is a kind of greenhouse made up of glass or polyethylene so that sunlight can be easily trapped in the greenhouse up to 85% so that it can increase the quality of the production up to 5 to 15 times
Moretti and Marucci (2019)	Photovoltaic panels Glass	N/A	Passive Cooling system	Air Temperature Relative Humidity Lighting level Co2 Concentration	Iron and glass are being used to developed the greenhouse with a transverse vertical polycarbonate wall where the solar panels can vary the angle according to the sunlight
Selmani et al. (2019)	PV system Climate Computer	N/A	Raspberry pi Fuzzy Logic	Temperature Humidity Soil Moisture	Embedded System and Fuzzy Logic has been used here to control the different parameters of the greenhouse

help vector machine is prepared with an upgraded surface descriptor vector. In the second method, deep learning has been used with images with three different preprocessing operations. Panels that were not easy to examine were detected using a post-processing technique by selecting the contours from detected panels which are established on the angle of rotation and panel area. To process the detection methods, eleven UAV flights over three solar plants capture 100 random images. Classical techniques approach a precision of approximately 0.997, a recall of 0.970, and an F1 score of 0.983, whereas the deep learning approach has a precision of approx. 0.996, a recall of 0.981, and an F1 score of 0.989.

Gupta et al. (2021) have researched on Maximum Power Point Tracking (MPPT) system in which the photovoltaic system characteristics have been studied. The variable step size (DVS) and fixed step size (DFS) have been extensively studied and analyzed. The setup has been simulated on MATLAB/Simulink, and the data were analyzed accordingly. Kumar et al. (2018) describe IoT as being used for photovoltaic systems for control and time-bounded monitoring systems. The need for systems like IoT and its justification with PV systems is considered majorly. This results in easier control of PV systems in places like remote areas. Islam et al. (2019) propose a home automation system that is based on the applications of IoT. The HAS, as shown in Fig. 24, can be used to control various parameters like the operation of home appliances via computer or mobile application. The proposed model uses different sensors like temperature sensors, LDR sensors, etc., to control the appliances of the home over the Internet. The wireless monitoring method used is cost and user-friendly. The utilization of solar energy has become significant in recent years, where renewable energy sources have been preferred over conventional fossil fuels. Irfan Danial Hisham et al. (2020) have proposed a solar tracking system that would track the rays of the sun as per the relative angle of the sun from the solar panel. This system would help in increasing the efficiency of harvesting solar energy using LDRs which would give the exposure angle for the solar hence increasing the efficiency of the solar system.

Nizam Kamarudin et al. (2021) developed an integrated IoT facility real-time automated monitoring cooling system for a solar panel. Two main factors are sun irradiation and surrounding temperature, which decrease the efficiency of the solar panel. A consistent state of charge (SOC) is obtained by harvesting consistent energy and directing it efficiently to the battery. IoT helps the user to measure the efficiency of solar panels and SOC from any location. The analysis is done to find the effect of active cooling on efficiency, and the result is tabulated. An automatic active cooling system has been developed to improve the efficiency of the solar panel.

Aslam et al. (2020) described the importance of DSSCs for IoT, its performing factors, and its commercialization for it in which indoor solar cells have the capability to modify the IoT system, which contains remote actuators, distributed sensors, and communication devices. Sensors have the ability to mass monitor executive control systems and require very less electrical power and can be feasible with an indoor power gathering system. The concept of dye-sensitized solar cells has influenced a very big impact on the photovoltaic sector due to numerous advantages like roll-to-roll compatibility, easy availability of materials, and cheap methods of fabrication. Limpid, multi-colored dye solar panels/cells can exert enough energy for indoor light-harvesting and IoT applications. This paper comprises four parts, i.e., the significance of solar energy with the advantages of photovoltaic technology. The second part describes the progress of DSSCs from laboratory to commodification. The third part describes the ability of DSSCs for IoT applications, and the fourth part describes the obstacles and future outcomes. Here, Fig. 25 represents the application of IoT in every field aspect like infrastructure, health field, industrial, transportation, etc. Table 3 provides a brief view of the smart lighting system from solar energy integrated with IoT, where many prototypes were developed and tested.

Phoolwani et al. (2020) proposed the idea of monitoring solar panels under different physical conditions to maintain the efficiency of the panel. They used a PV analyzer for generating PV graphs, a solar power meter, and a thermal camera to generate results that can be compared to different physical conditions. All the data generated are transferred to the cloud using NodeMCU. The data generated help the user to monitor the solar panel for different physical conditions and ensure proper efficiency. Efficiency λ is calculated using the formula below where E_{oc} is the open circuit voltage, I_{sc} is the short circuit current, η is the fill factor, and P_{in} is the input power (Shaikh et al., 2018; Vieira et al., 2019).

$$\lambda = \frac{E_{oc} I_{sc} \eta}{P_{in}}$$

$$\eta = \frac{P_{max}}{E_{oc} I_{sc}}$$

2.4 Solar monitoring system

The objective of Shirbhate and Barve (2019) was to develop a smart solar system so that it could be used to capture the optimum amount of solar energy and generate it using the metrological data and predict several other factors. The hidden Markov model has been employed for the prediction, and it takes into consideration the probabilistic correlation between past and future values in the time series. The evaluated result shows that a single panel dead state is deployed, and solar energy prediction based on time series can reproduce the actual power generation.

Priyadharsini et al. (2021) studied the positioning of solar panels and found the energy losses while removing the dust particles. From the sunrise, the position of the sun is calculated and automatic panel adjustment is made to increase the efficiency of the panel. Here, Fig. 21 shows the calculation of and Azimuth and Zenith angle for sun tracking to increase the efficiency of the solar panel. The performance of the panel is improved by automatic cleaning. A smart meter is installed to control the energy loss. IoT devices that sense dust depositions on the panel are installed, and cleaning is done in a semi-automated way.

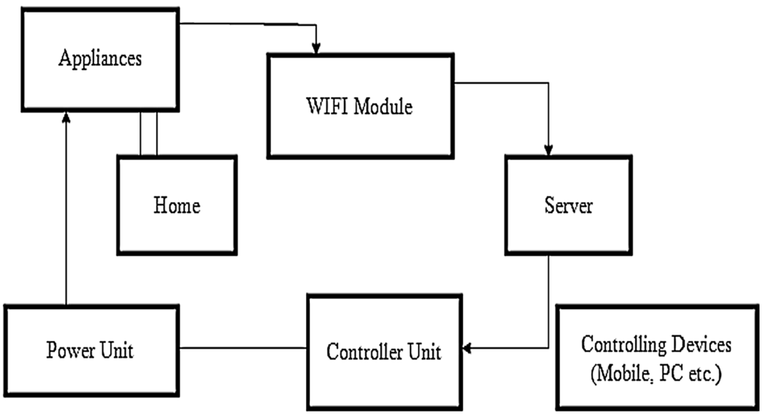

Fig. 24 The proposed design of HAS (Islam et al., 2019)

Ifiok et al. (Archibong et al., 2020) proposed an idea to develop a stand-alone anti-vandalization solar-powered street lighting system that concentrates on energy efficiency, power conservation, intelligence, and automation. It has a vandalization tracking and monitoring system. It consists LDR sensor so that it can turn street lights ON and OFF with power-saving ability, as it also consists IR sensor with a microcontroller. To increase the life span of the lighting module, it can increase and dim the LED. This user interface system is developed with ESP8266MOD Arduino Wi-Fi module and has a vandalization tracking and monitoring mechanism so that a street light can directly contact the control station whenever required, and for the lighting purpose, it has a 32-bit LED array module. The system can turn on the light to the full brightness when the LDR senses darkness or whenever a vehicle passes, and as it consists of the motion sensor so when the traffic gets reduced from 11 pm the light switches to the dim state. So, to find the distance (L) for the security purpose from the baseline (B), Eq. (1) has been formulated below,

$$L = B\frac{\mathrm{Sin}\beta\gamma\mathrm{Sin}\zeta}{\mathrm{Sin}(\beta + \zeta)} \tag{1}$$

For security, it consists of an alarm system that can get turned on and inform the control room and can track the vandal using the triangulation concept using Wi-Fi and GSM module.

IoT is a revolutionary breakthrough in our regular life as it has decreased the living cost by automating physical work. So, Mubashir Ali and Mahnoor Khalid Paracha (2020) have proposed an idea to automatically control and observe the parameters like voltage, current, power consumption, etc., and send data about real-time information to users. In this paper, the authors have enabled users to monitor and control solar panels through their mobile gadgets. This idea can make the users effectively control their procedures from

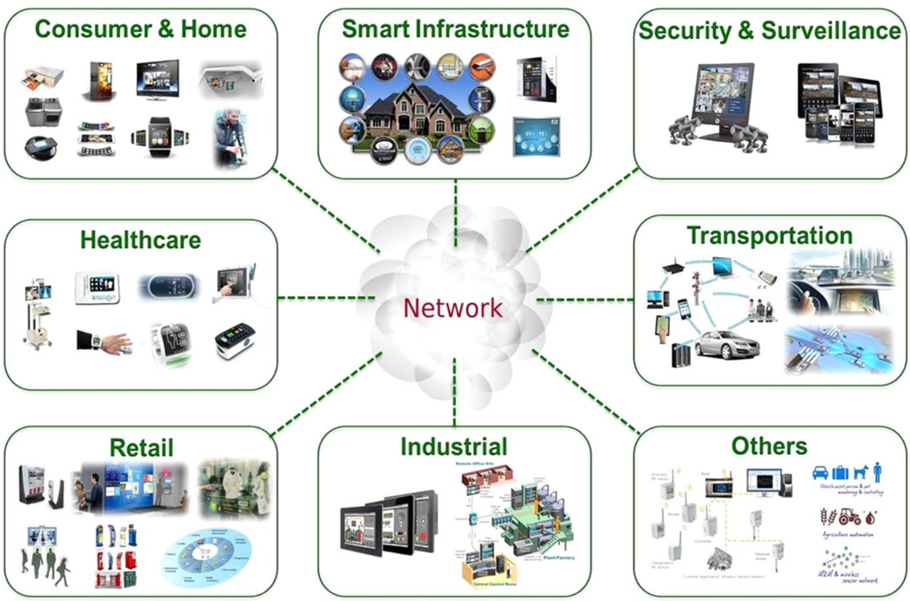

Fig. 25 Application of IoT (Dinesh et al., 2021)

Table 3 Smart lighting system from solar energy energy

Author's name [Ref.]	Hardware/ components used	Software /operating system used	Concept/ mechanism used	Microcontroller/technology used	Parameters measured	Application
Archibong et al. (2020)	LDR IR Sensor Motion sensors Lithium batteries	N/A	Vandalization monitoring/tracking mechanism, Triangulation	ESP8266MOD Arduino Wi-Fi module, 32-bit LED array	Light Intensity Object distance	A system for providing general security for the environment
Rahman et al. (2019)	Solar panel Vertical-Axis Wind Turbine (VAWT) Inverter Converter	N/A	Internet of Things	IoT-driven controller, MPPT charge controller, microcontroller and battery	Temperature Wind speed Power Tolerance	IoT system improves battery performance in highway lighting system
Gunawan et al. (2021)	Relay Solar panel Lead acid Battery LED Lamps Converter Voltage Sensor	Blynk application	green energy usage in household application The IoT connectivity with a renewable energy production from Solar PV	NodeMCU ESP8266 Solar Charge Controller (PWM20-10)	Charging current Solar power Capacity	Author proposed this system to cope with lightning consumption in a typical household application
Karthik and Gandhi (2020)	Solar panel Inverter DC motor Step-up transformer Rectifier	IoT Blynk application	Photovoltaic technology Solar energy and IoT for controlling the DC drives	NodeMCU	Motor running time Motor off time	A system developed for using the energy for industrial and low-energy applications
Kjellby et al. (2018)	Temperature Sensor Light level sensor IoT server Transceiver	Wireless sensor network (WSN)	MPPT IoT	N/A	PV Module Load condition Temperature	An IoT system has been developed which is maintenance free and self-powered

any location. Sun is the transcendental energy source, so it is very important to retrieve the maximum efficiency from solar panels. But it is not easy to obtain the maximum efficiency from a fixed solar panel and to obtain a great amount of efficiency, the area of the solar panel has to increase. Singh et al. (2019) have designed an all-weather solar tracking autonomous system integrated with solar trajectory tracking and photoelectric detection to inspect variation in the solar position. This system also consists of a sunlight intensity sensor to appropriately examine the weather condition. So, Fig. 26 describes how the sun-tracking solar panel system actually works.

This procedure could effectually inspect the stability of the sun and can gain the maximum amount of efficiency from the solar panel. Teng et al. (2019) have proposed a method by which conventional honeycomb aluminum panels has substituted with 3D metal printing formation for microsatellites that can focus on manufacturing restrictions and the cost of conventional aluminum honeycomb plate. To enhance the compression strength, shear strength, temperature difference, and solar panel structure for the new solar panel plate structure, a multi-objective optimization method has been used in this paper. After the replacement of the panels with the new structures, the efficiency of the panels has been increased, and using Eq. (2) the performance of honeycomb solar panel could be observed, where μ represents the performance:

$$\mu = \frac{|pi - xi|}{xj} \times 100\% \tag{2}$$

The results have been confirmed via experiments and simulations.

The main drawback of wearable IoT devices is the finite battery technology. So, energy harvesting is the solution for these wearable devices. Wu et al. (2017) have researched energy harvesting for IoT for wearable sensor applications integrated with the MPPT algorithm. Only output current is enough for the MPPT circuit to retrieve the maximum power from the flexible solar panels. Figure 27 describes that the wearable device is integrated with IoT and MPPT technology to retrieve the maximum power. The efficiency of solar harvesting is 66.5% which is enough for transmission with a BLE module and for the pulse sensor. Non-renewable energy is getting vanished day by day, whereas renewable energy is the most likely source of a nonconventional type of energy.

The limited life period of rechargeable batteries is an obstacle for IoT devices and their applications as they cannot provide a lifetime constant battery power supply. So, to tackle this problem, Adila et al. (2018) have proposed an idea about energy harvesting with an interconnected network of devices from the surroundings. This paper explains how energy harvesting could be so efficient that it could provide a constant battery power supply even for low-powered devices. So, Fig. 28 describes the protocols of wireless communication with the help of the measured distances.

Karthik and Priyanka (2020) came up with the innovation of systems operated by IoT to analyze the environment and identify or find objects for solar-operated cities. It deals with the reformation of the network structure that has been established for a long period of time and adding technological control strategies. The same is achieved using solar panels, batteries, transformers, rectifiers, and filters. The overall system design shown in Fig. 29 proposes the flow of the process. This results in the complete rejuvenation of existing things with Internet-operated structures that result in higher efficiency with low human—interference (Fig. 30).

Harvesting renewable energy sources is more efficient, for which proper methods have to be adopted to capture their full potential. However, currently, India is only able to capture 100 GW of energy. The infrastructure and capacity to capture such large amounts of energy are still not available due to several factors (Ginley et al., xxxx; Mekhilef et al., 2012). The gap also is prevalent due to improper management of already existing solar resources. Solar energy, if harvested efficiently, can meet several global energy needs while helping several countries to achieve their global carbon footprint minimization targets. Gunawan et al. (2021) have proposed a system to increase the efficiency of solar lamps with the integration of IoT-based technology to reduce AC power consumption from the city's main power line. The setup uses two solid-state relays that would help decide which power supply to use. The system is connected to the Internet using NodeMCU ESP8266 and can be turned ON/OFF with a smartphone. The setup can power a 12V–18Ah battery for about 3 h. The block diagram of an integrated solar lamp is shown in Fig. 31.

Hadi et al. (2019) proposed a solar inverter that is based on IoT using blockchain technology. This system would improve maintenance, cybersecurity, connectivity, and easy control of the photovoltaic solar system. This would help to send data and analyze it when required. Sharing of the same data between other devices and systems also becomes easier. Blockchain technology and cloud computing integration in the solar panel grid and monitoring can be seen in Fig. 32.

Shaw et al. (2020) have monitored the performance parameters of solar panels using MPPT and interfacing of IoT with PV cells for partial shading conditions. They have worked on incorporating MPPT for PV systems. The MPPT used under partial shading conditions helps to procure the maximum amount of energy for PV cells. This enhances the maximum energy generating system, and the efficiency increases. Kjellby et al. (2018) propose the proof of an IoT device that is self-sustainable and maintenance-free. They merely need indoor lights (for a solar panel) and a gateway range for functioning as they can run for 5 months on coin-size batteries during the downtime of the year. Sensor nodes contain low-power sensors for temperature, humidity, and light levels, with the possibility of adding more sensors. Saravanan and Lingeshwaran (2019) developed a monitoring system for solar power using the concept of IoT in a very economical path. The approach depends on the direction of the sun. They have used basic electrical

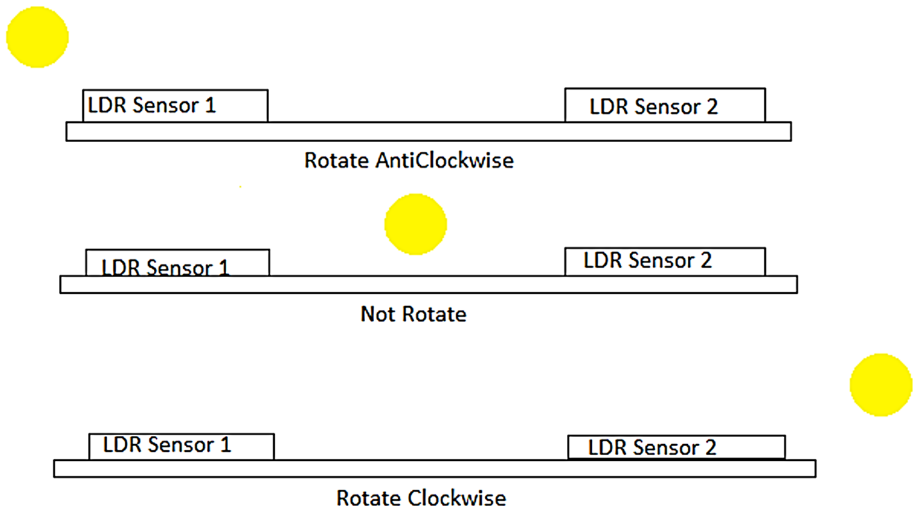

Fig. 26 Sun-detecting solar panel system (Singh et al., 2019)

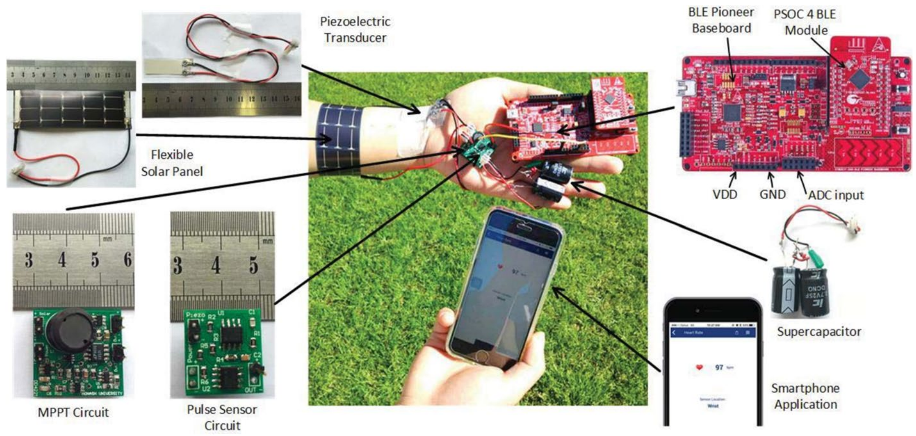

Fig. 27 Wearable device is integrated with MPPT technology (Wu et al., 2017)

components, including sensors of low range and a stepper motor, as shown in Fig. 33. This way, solar tracking and monitoring are done for solar power.

Prasetyani et al. (2020) have worked on an energy monitoring system for a solar panel. They have researched the use of solar panels in laboratories to assist the teaching process. Halogen lamps are used in place of sunlight. The control system is backed up with microcontrollers and PLCs. They have also incorporated the use of LoRa system. A prototype is a design that tells about the optimum angular orientation for maximum energy generation from renewable sources. This supports the user in monitoring the energy regularly.

Supachai and Kamon (Puengsungwan & Jirasereeamornkul, 2019) have put forth a hydronic system for the farming of lettuce using the mighty concept of the Internet of

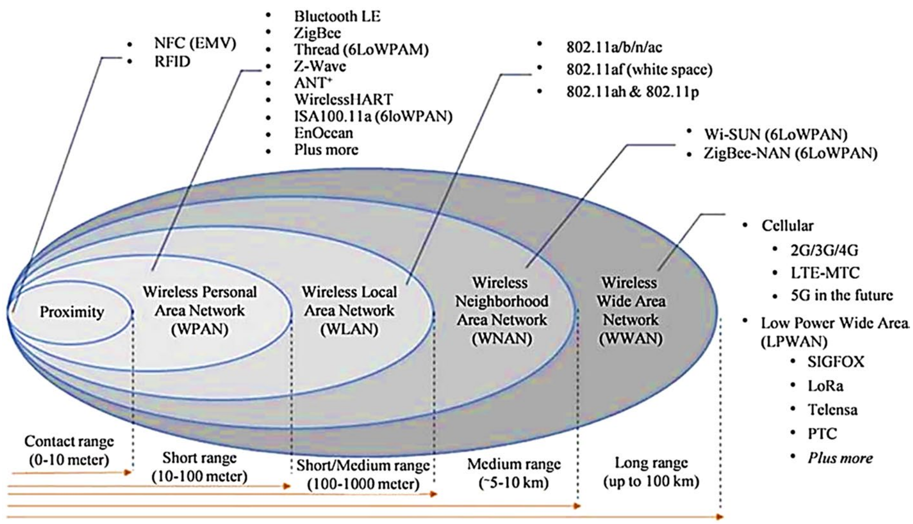

Fig. 28 Wireless communication protocols with measured distance (Adila et al., 2018)

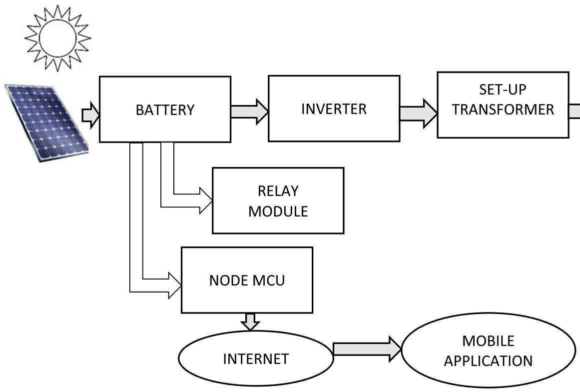

Fig. 29 System design proposed (Karthik et al., 2020)

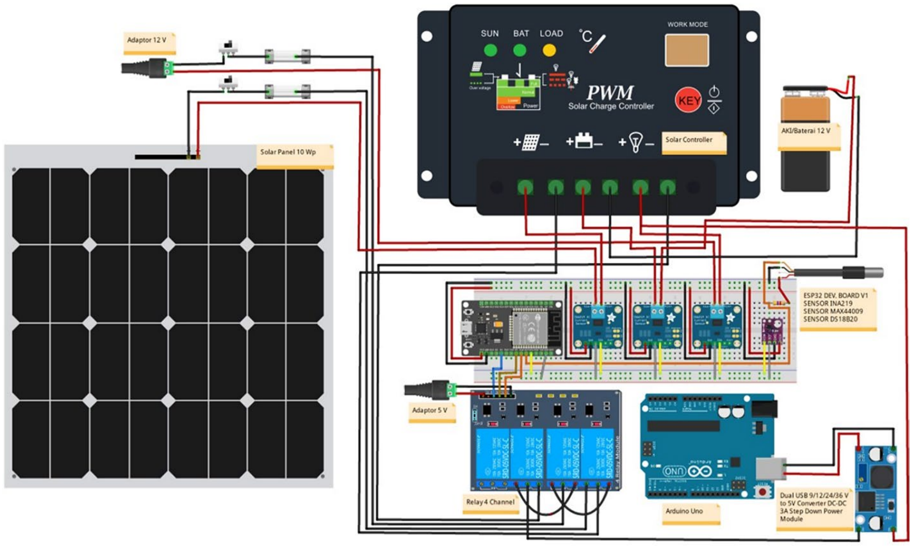

Fig. 30 Solar panel integrated with IoT Battery Charging System (Hermansyah et al., Mar. 2020)

Things. They have used a transpiration leaf sensor which works on the principle of IoT. This optimizes the advantage of solar panels. The sensor is highly useful for determining the changes inside the lettuce plant with respect to real-time operating conditions. They have used a temperature sensor and 30 solar panels for a farm with 800 square meters of the area as shown in Fig. 34. This system tells us the duty cycle in real-time conditions and increases the overall efficiency.

Soonsawad et al. (2019) proposed an algorithm to compute the optimal angle for a solar system that maximizes the energy harvested. The model proposed by the author involves solar panels with adjustable angles having a movable arm, as shown in Fig. 35. The designed BLE beacon can accelerate the energy storage charging rate by 570% under different lighting conditions.

Solar energy has still not been harvested to its maximum potential, and hence, with the help of the dual-axis solar tracker setup, which uses Arduino as the microcontroller, Said et al. (2020) have been able to track the sun efficiently, which would then accordingly guide the solar system to face the sun directly to harvest maximum solar energy possible. The setup would help increase efficiency by capturing the maximum possible solar energy throughout the day. Figure 36 describes the working and functioning of a solar tracking system which is used for increasing the efficiency of the solar system. Two-axis solar trackers were used in the setup, which was controlled using Arduino Uno as the primary controller. The solar tracking was done using light-dependent resistors (LDRs). The solar panels were rotated along the position of the sun by integrating two servo motors, and the NodeMCU ESP8266 module was used for monitoring the system and storing data. The setup proved to be more successful than the single-axis solar tracking system, which harvested more solar energy throughout the day.

Motlagh et al. (2020) have studied the use of IoT-based systems in renewable sources of energy and how it can help in increasing efficiency, make analyzing data easier, and help in the transmission of energy. This would improve the energy requirement and utilization by efficiently providing energy as per the requirement. The growth of plants is facilitated by greenhouse gasses which can be controlled by controlling solar energy. As studied by Marhaenanto et al. (2021) in industry 4.0, IoT can be used to facilitate the growth of plants. Data can be controlled using a microcontroller and a WiFi module ESP8266, which can be stored on the cloud/edge and analyzed accordingly for monitoring the solar system and maintaining it accordingly.

Kholifah et al. (2019) have challenged the contemporary irrigation system and put forth a drip irrigation method that operates on IoT with the help of solar panel energy. They have

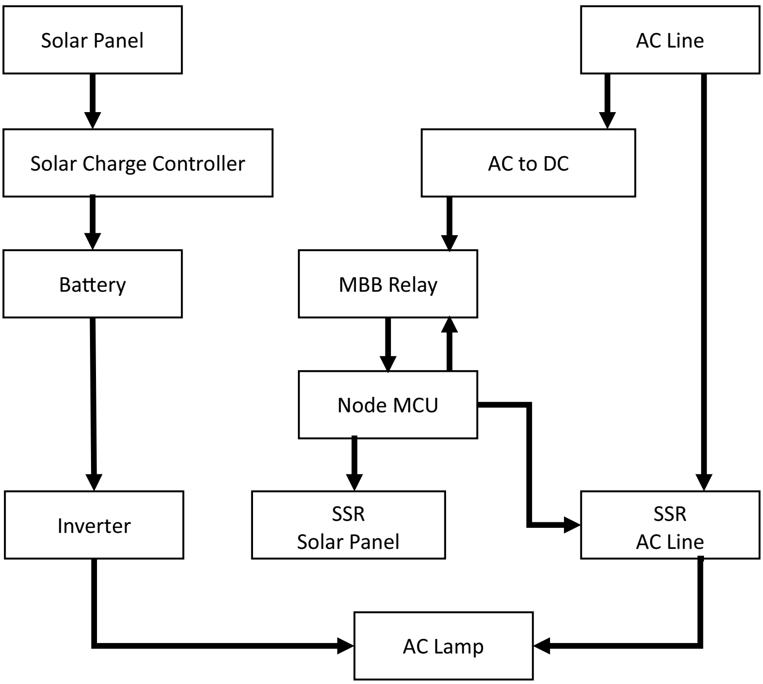

Fig. 31 IoT integrated solar lamp (Gunawan et al., 2021)

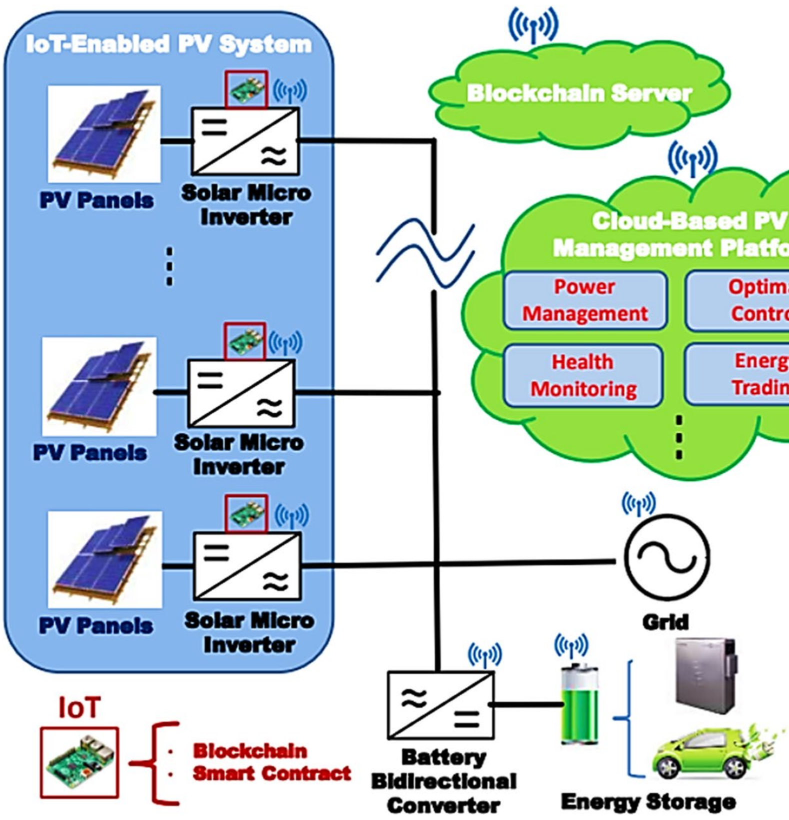

Fig. 32 Application of blockchain technology in solar power management (Hadi et al., 2019)

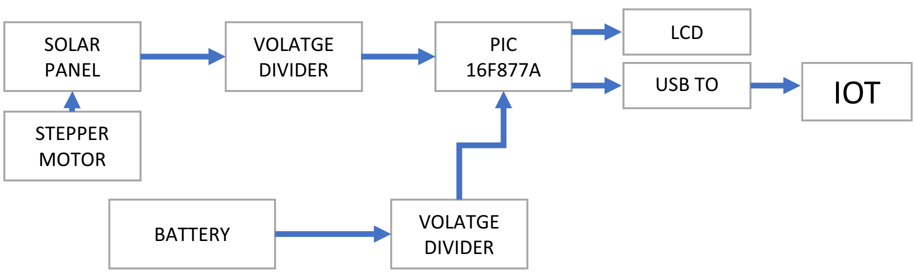

Fig. 33 The overall architecture of the proposed model (Saravanan & Lingeshwaran, 2019)

used NodeMCU to communicate with the system, which tells the farmer about humidity in the soil and helps them to control the water supply to the agricultural fields. The devoted idea enhances the efficiency of the use of water in agricultural fields. Khujamatov et al. (2019) focus on modeling solar panels, which are both automated and IoT based. They used Proteus software to model a solar tracking system which is automated. The sun tracking system used here is automated and inclined toward IoT, which depends on the angle which rays of the sun make. Maximum energy for the output is attained by installing self-propelled driving equipment. The illuminance and output voltage are also calculated using the formula below. E_{out} represents output voltage, E_{in} represents input voltage, and Z_3 represents resistance (Gubbi et al., 2013; Madakam et al., 2015)

$$I = \mathrm{MAX}(I1, I2, I3), [\mathrm{lux}]$$

$$E_{out} = E_{in}\left(\frac{Z_3}{ZI\mathrm{d}r + Z_3}\right)$$

Sahraei et al. (2017) developed a solar power system that works for persistent outdoor conditions using the applications of Internet of Things. The design of the power system is dependent on the performance the user wants from the system. In order to achieve the data, sensors are employed that measure the performance parameters. The system performance is determined in each situation, and design parameters are achieved along with the constraints for each case. Azhar et al. (2019) developed a system using Arduino Mega 2560 to collect certain data like temperature, humidity, and soil moisture. An android application has been developed to keep monitoring the various parameters of the environment. Also, this android application can control the actuators also. Various combinations of LEDs like red and blue are used to improve and maintain the growth of the crops.

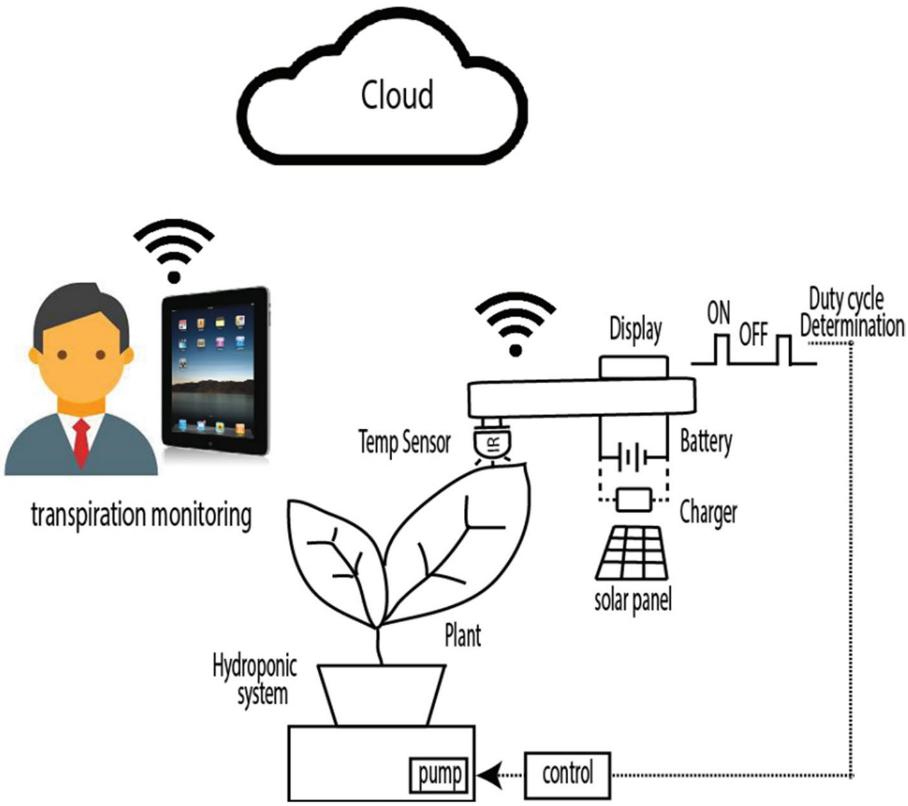

Fig. 34 Operation of the proposed model (Puengsungwan & Jirasereeamornkul, 2019)

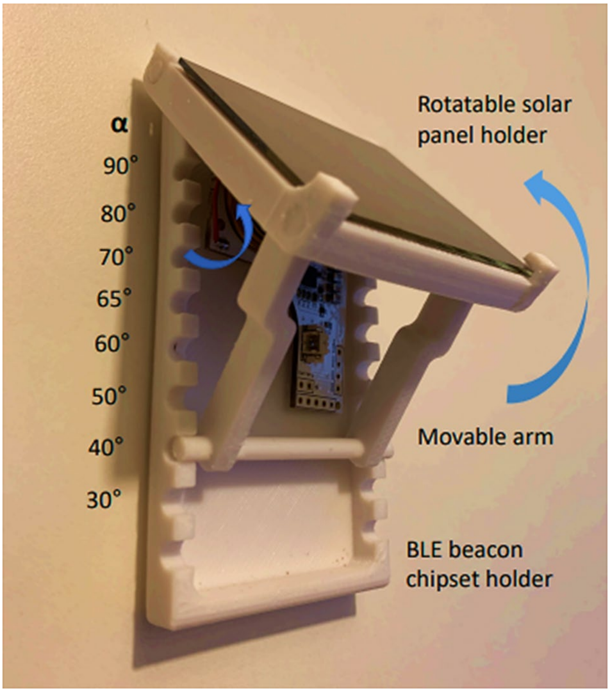

Fig. 35 The prototype of the proposed beacon (Soonsawad et al., 2019)

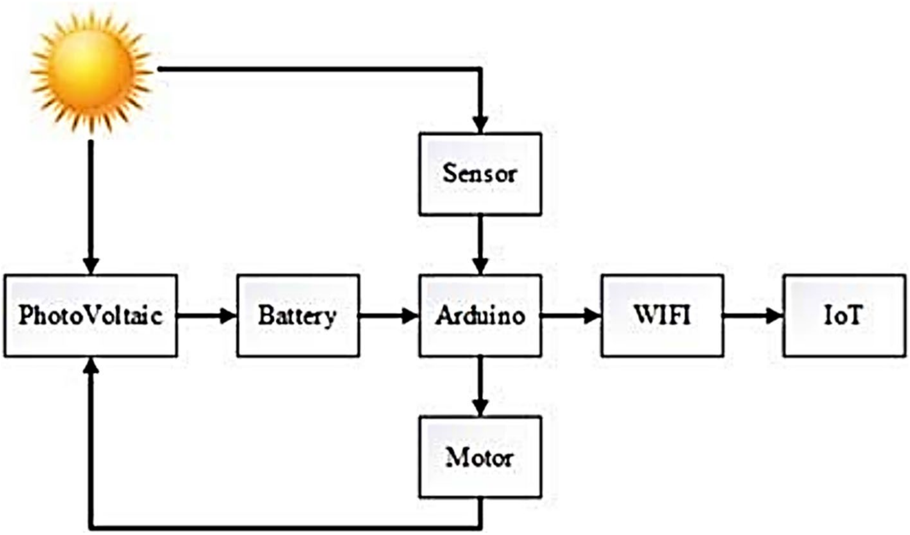

Fig. 36 Block diagram of the working of solar tracker setup (Mohd Said et al., 2020)

Maximum Power Point Tracking of solar panels is often achieved using IoT in ongoing research. Al-Ali et al. (2019) developed a feasible IoT system that is established on a solar system for smart irrigation, which can detect water scarcity and power shortage issues. The system consists of a chip controller and has built-in WiFi and a connection to the solar cell to provide the essential controlling power. The system can analyze the level of soil humidity, temperature sensor, water level, and some actuation command to control irrigation pumps. Figure 37 shows the design of a system for smart irrigation using the above method. Equation (3) describes the power which is required to be generated by the solar (photovoltaic) panel (Eo_{PV}) to meet the total of 369 W h/d, which is calculated as Eq. (3), where Eo_{pv} indicates the power generated by a photovoltaic panel, $Q_{d\mathrm{tot}}$ indicates energy required per day, D_{rc} indicates de-rating factor of the charge controller, $S_{3\mathrm{D}}$ describes constant bright sunshine a day, and v indicates usable power. The system can consist of 3 modes, viz. local control mode, mobile monitoring mode, and fuzzy logic model. The proposed design has been outlined and tested.

$$Eo_{\mathrm{pv}} = \frac{Q_{d\mathrm{tot}}}{S_{3D} v D_{rc}} \tag{3}$$

Hamdani et al. (2021) have developed a system using Blynk applications and Visual Basic that can monitor the output parameters of the solar panels to examine their efficiency in real time. In this system, IoT has been used which is based on a wireless sensor network with a data logger to send and receive the real-time output parameter data of the solar panels. The system has been developed for the solar panels to evaluate the output parameters like voltage, current, position, light intensity, which are presented in the form of tables and graphs in a real-time environment. Implementation of this system has resulted in tracking and reading the output parameters like current, voltage, position, and light intensity. A data logger has been used to store the data in the database and retrieve it in the form of an excel sheet. Rekha et al. (xxxx) have discussed the use of sun-tracking systems in order to use sun—power, which is a renewable source of energy. They dealt with the conversion of solar power to electrical form with the help of installed solar panels in combination with the PV effect. The solar panel has to rotate via a servo motor with the sun's rays falling in order to track the power. This is achieved using microcontroller ESP32, sensors, blower, and relays. This results in the use of solar power in a convenient and efficient way.

Yakut and Erturk (2022) propose the idea to counter the drawback of the row-to-row shading effect of solar panels using the IoT approach. They have achieved a backtracking method with IoT-STS installed in the solar panels. The data about the position of the panel are transferred between two different IoT-STS via a wireless communication method. This method is time-bounded, and it enhances the efficiency to procure solar energy. This results in an increase of annual yield to 5%. Hema et al. (2021) have proposed a system for cleaning solar panels to maintain the efficiency of the solar system. The power output of the solar can reduce by up to 50% if the panels have not been cleaned for about a month. The dust layer and other foreign particles may limit the panel from harvesting maximum solar energy as per its capability. Patil et al. (2017b) have worked on monitoring the use of the power of one of the renewable sources of energy which is solar energy. To follow the same idea, they worked with flask framework via Raspberry pi. This also deals with the electricity issues followed by continuous use of the energy. The proposed model is shown in Fig. 38. The energy dissipated can be monitored on a regular basis by smart monitoring displays, which in turn helps the user to have control over the usage of this renewable form of energy. The output voltage is also calculated using the formula below where E_{out} is the output voltage, E_{in} is the input voltage and Z_1 and Z_2 being resistance 1 and 2. Table 4 is added to provide a summary of

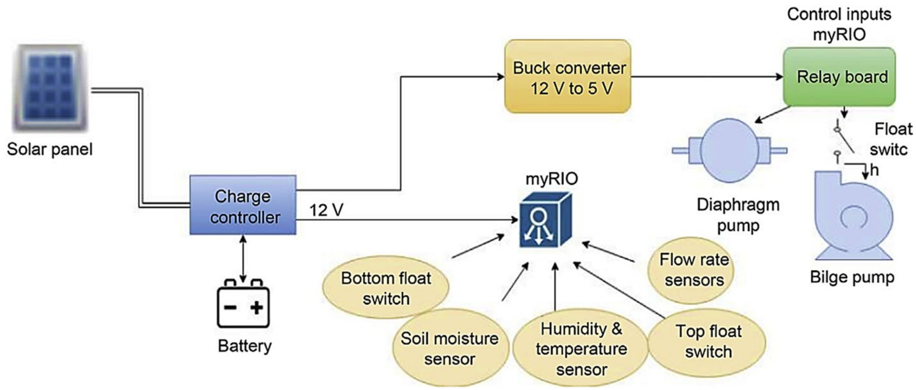

Fig. 37 System design proposed (Al-Ali et al., 2019)

research analysis pertinent to the use of PV panel defect detection, energy monitoring, maintenance, etc., using IoT (Shafique et al., 2020).

$$E_{out} = \left(\frac{Z_2}{Z_1 + Z_2} \right) E_{in}$$

3 Summary, conclusions, and future scope

The primary motive of an IoT system is to increase efficiency and decrease the workforce, whether in the field of smart irrigation systems, smart homes, or any other technically involving resources. An IoT system is so customizable that it can measure various parameters at the same time. Applications such as the examination of water scarcity and power shortage issues in smart irrigation systems are easy using IoT. Similarly, the condition of solar panels can be maintained wirelessly as the data like voltage or current can be measured through the sensors and can be directly monitored on smartphones or any other gadgets. Smart solar energy systems have been developed, which are integrated with IoT, to capture the maximum amount of solar energy and predict the various parameters.

The prospect that solar brings to the energy grid is immense. Solar energy in many countries has the capability to cater to the energy needs of the country if harvested in the right way efficiently. The efficiency of solar panels is disrupted heavily by the formation of dust and dirt on the surface, which block or reflect the sun's radiation, not allowing the panel to absorb the irradiation. This problem is solved using smart cleaning systems, which with the help of IoT detected any dust on the surface and immediately warned the concerned authorities. This warning would also trigger the automatic smart cleaning system that was deployed, which would wash or wipe the panels. This system is very helpful in countries where dust is predominantly present and also due to adversity and unpredictability of the weather. In middle eastern countries, where dust storms occur very frequently, this setup also proved to be extremely helpful in maintaining the efficiency of the solar system. Along with cleaning, another problem with countries near the equator is excessive heat during summers which cause the system to overheat, and researchers found that this overheating costed the efficiency of the system. This problem was overcome by using IoT to automatically cool the panels by installing a cooling system that would trigger an overheating warning using temperature sensors. Solar parameters monitoring system was also deployed using IoT to monitor the parameters and study and analyze them when needed. The data are stored in the cloud, which is then used to study the parameters of the solar panel system and its proper working of it. The parameters could also be used in the future for reference and can be easily accessed via the cloud.

Solar energy, if harvested in the right way using IoT, can prove to be an extremely powerful tool to fight global pollution and help reach environmental targets. Sun is a replenishable energy source; hence, we would never run out, and the resources put into harvesting it would never go in vain. Climate conditions could change drastically by reducing the carbon emission produced from burning fossil fuels for energy. Efficient and intelligent ways of harvesting renewable energy sources are the only way forward, and it has a large prospect ahead in terms of advancement and enhancement.

One of the applications of solar panels is the smart solar lighting system in which solar panels are used to light up the streets. The solar panel would generate electricity which would be stored, and at night the lights would light up with the energy that was produced. This would save electricity by a large margin and also reduce the usage of electricity from the grid. Many counties do not have enough resources to do so, but with the present resources, it is moving on the right path toward progress. Several researchers have proposed several ideas for solar trackers or Maximum Power Point Tracking systems (MPPT), which helped in improving the overall efficiency of the solar system by maintaining a

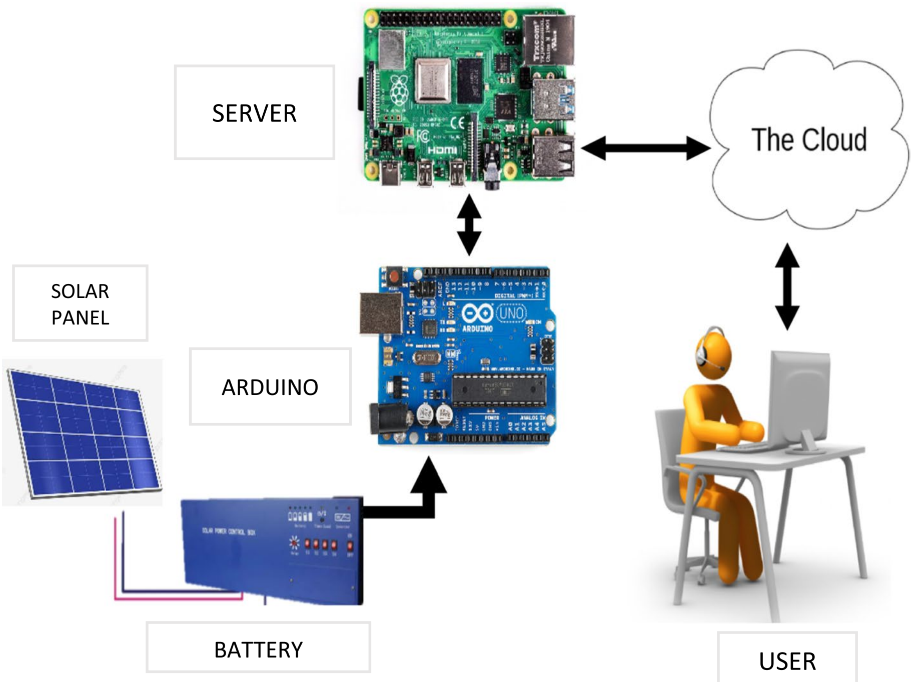

Fig. 38 Operation model of the proposed system (Patil et al., 2017b)

Table 4 Solar energy monitoring system using IoT

Author name, [Ref.]	Technology used/software	Mathematical method used	Hardware setup	Application
Priyadharshini et al. (2021)	Smart Meter System	N/A	AT89S52, Raspberry Pi, DC Motor	Improving efficiency of solar system by parameters monitoring to control the system Comment: Efficiency improvement observed is 28%
Hamdani et al. (2021)	Visual Basic and Blynk	Logger data analysis	Current Sensor, Voltage Sensors, Accelerometer Sensor, ATmega 328	Monitoring of the solar system in real time to analyze any error or abnormalities
Ali et al. (2019)	Adafruit Cloud	Cloud Computing	ATmega 2560, Current Sensor, Voltage Sensor, Heat Sensor, Temperature and Humidity Sensor	Using Cloud computing to analyze data of the solar panels and storing the data on Adafruit Cloud for monitoring
Isyanto et al. (2021)	Smartphones, Blynk Application	N/A	Power sensor, Temperature Sensor	Overheating detection setup to improve efficiency of solar panel system Comment: Efficiency improvement in the system is observed by 3.89%
Teng et al. (2019)	3D Metal printing	Regression models	3D Metal printer	3D metal printed microsatellite is used instead of the conventional style honeycomb shaped aluminum panel to hence increase the efficiency of the entire solar panel system Comment: Efficiency improvement is observed by 27.45%
Padma et al. (2017)	GSM-based Wireless Sensor Network	N/A	PIC16F1947	Efficient and easy methods to monitor the solar panel system using circuits and relays boards with microcontrollers

Table 4 (continued)

Author name, [Ref.]	Technology used/software	Mathematical method used	Hardware setup	Application
Katyarmal et al. (2018)	Thingspeak, Wireless Transmission, Cloud	N/A	ATmega 328, Voltage and Current Sensor, ESP 8266	Supervising of the power produced in the solar panel system to enhance the efficiency and the performance of the system using cloud
Nalamwar et al. (2017)	Solar Energy Module (SEM), Scalable Energy Efficient Mechatronic Device(SEMD)	N/A	GSM Module	Automatic and intelligent system for monitoring the solar panels to detect any faults and discrepancies that may occur
Rani et al. (2021b)	Power Measurement, Wireless Transmission, Thing Speak	N/A	ATmega 328, Voltage and Current Sensors, WiFi module	Fault detection can be done from the errors that the power supply may generate by tracking and monitoring the data from the solar panels
Bhau et al. (2021)	Data Monitoring	Flask Framework	Raspberry Pi, Voltage Sensor, Arduino Uno	Current and voltage data are taken and stored which can be used to study and monitor the solar system and any ambiguity can be detected in the system from the above-derived data
Saravanan and Lingeshwaran (2019)	Data Monitoring	N/A	Raspberry Pi, Temperature Sensor, Gas Sensor, Vibration Sensor	Evaluating the movement of the sun to monitor the solar system even during any climatic changes
Diaz et al. (2020)	Thermal Imaging, Deep learning	99.6%	Support Vector Machine (SVM), image segmentation	Anomalies on a solar panel are detected using deep learning and thermal imaging processes to detect the panels and whether their working is in functional state

Table 4 (continued)

Author name, [Ref.]	Technology used/software	Mathematical method used	Hardware setup	Application
Suresh et al. (2018)	IoT	~95%	Wi-Fi Module, Current and Voltage Sensors	IoT architecture has been integrated to monitor and detect panels to hence increase the efficiency of the solar system
Gusa et al. (2018)	Real time monitoring	Error rate below 10%	ATmega 260, WiFi module	Smartphones and IoT system have been used to monitor the panels and any discrepancies on the panel would immediately alert the concerned authorities via a message on the smartphone
Phoolwani et al. (2020)	IR Imaging, Fault Detection	N/A	PV Analyzer, Solar Power Meter, Thermal Camera	Thermal Imaging has been implemented to monitor the system to detect overheating or any other heatrelated issue on the panels
Zainuddin et al. (2019)	Self-Cleaning, Dust Detection	Infrared emitting diode, phototransistor, wiper system	By 22%	An automatic cleaning system which would infrared emitting diode and phototransistors to detect dust and dirt and would clean the panels using the wiper system
Cho and Kim (2019)	Cooling system	Supercapacitors, Arduino Uno, Energy Storage System (ESS)	By 4.7%	Due the varying weather conditions the solar system can give varying amounts of power hence affecting the overall efficiency of the system. Hence a cooling system is installed to avoid overheating issues in the panel to increase the proficiency of the system

Table 4 (continued)

Author name, [Ref.]	Technology used/software	Mathematical method used	Hardware setup	Application
Hashim et al. (2020)	Self-Cleaning, Dust Detection, Mobile Robot	IP Camera, Voltage and Current Sensors, ESP 8266, Android control switch unit	By 60%	Mobile robots were inducted into the system which was used to detect dust and dirt on the panels. The robot would then automatically go to the panel and clean the panel removing all foreign particles
Hema et al. (2021)	Cleaning Robot	DC Motor, IR Sensors, Micro-controller	By 50%	A cleaning robot was developed for enhancing the speed and maintaining the robot control. The robot was tested and tried over inclined surfaces to map the area at high speeds
Vaghani et al. (2019)	Automated Cleaning system	Gear motors, water spray nozzle, water pump and tank	By 32%	A cleaning system which can be controlled remotely from any location is developed which feeds input to system via IoT setup

constant angle of incidence of the sun radiation. With the ideal fixed angle of incidence, the solar panel can generate a more stable and greater amount of electrical energy. The MPPT setup helped in increasing the efficiency by approximately 20–25%, depending on the conditions and environment the setup was tested in.

The rise of IoT-based systems has set an example for a sustainable future and is yet to bring about many changes to completely reform our livelihoods in a far better and more efficient way. There have been studies regarding the applications of IoT-based solar-powered systems. These systems are efficient and smart monitoring systems, but they need maintenance and can function only in specified light conditions. The developments in this field paved the path for a successful study in developing a self-sustainable IoT-based system. This system is maintenance-free and can function properly even in indoor light condition.

Sun being a vital source of solar energy is also aimed by many researches. The angle the sun makes with the solar panel is very important not just in solar tracking systems but also in power generation. A study was able to determine the optimal angle using a solar panel with an adjustable angle. The system was aimed at maximum energy harvesting. Another study used a dual-axis solar tracker to optimize the energy harvesting efficiency and development of a large amount of energy from the solar panel. This was achieved by the prediction of direction. Another solar tracking system was designed to estimate the angle of the sun. The system was also capable of predicting the weather conditions to be sunny or cloudy, which also contributed to the astronomical calculations.

The Maximum Power Point Tracking (MPPT) system has also been embedded with the solar panels so that panels can be diverted toward the face of the sun to increase efficiency. Also, actuators have been installed to clean and remove the dust particles so that the output energy can be increased. The concept of smart city is entirely resultant of IoT, as the various resources of a smart city, like smart LED pole, consist of an LDR sensor to dim and glow the LED lights to conserve the futile energy loss, and no other workforce is required. The whole system is made completely automated and is a major part of the upcoming smart city as this smart LED pole consists of a motion sensor also which can even sense when a vehicle is passing through it, which would be comfortable for all civilians.

IoT is so feasible that it can be controlled from anywhere easily with any smartphone or gadget, and the data can be retrieved in any form like—an Excel sheet so that it can be easily readable. In solar panels, there are some issues of overheating; if they are working under direct sunlight for a long durable, then panels might get heat-up and have the chances to get damaged, which may cause to decrease in the efficiency of the output. But when this system gets integrated with IoT, then the information regarding overheating can be pre-monitored and sent to the user's smartphone so that the damage to the solar panels can be avoided.

Energy harvesting has been implemented especially for IoT wearable devices so that there would be no battery discharging issues as this technology comprises MPPT technology. Components like supercapacitors or flexible solar panels play a major role in this. Also, the efficiency of solar harvesting is enough to run the major sensors of the IoT circuits. Energy harvesting is very advantageous for the IoT as this provides a constant power supply to the minor low-powered electronic devices also.

IoT-based systems have been found to contribute majorly to greenhouse systems as well. A study was developed using IoT-based system powered by solar panels to monitor the growth of the plants using a special technology using PIC controllers and various sensors. Another study based on greenhouse production was done, which resulted in increasing the electrical energy from the solar panels while reducing the cost of operation. The research was also conducted, which aimed at designing a smart greenhouse system with automatic canopy opening. The system was responsible for overall monitoring, including watering of plants, monitoring of crops and temperature, and power supply. The system uses PV cells with solar panels in order to develop electrical energy, which reduces the cost of the system.

The development in the field of IoT with solar energy is a vast field of application. Future work should aim at the losses of crops caused by weeds, parasites, and other reasons in agricultural fields. A system should be devised to identify the crops and unwanted objects using the concept of IoT and then monitor fields using the sustainable energy source of solar energy. The system needs to be farmer-friendly and low cost with optimum efficiency. Moreover, many systems were developed which were responsible for the control and monitoring of solar power. The systems designed were such that they were capable of sending messages to the user on the display screen regarding maintenance of the panels. These systems mainly focused on ensuring proper efficiency of the solar panels, generation of maximum energy, and monitoring of solar power based on the direction of the sun. A smart monitoring and cleaning system were developed to remove the dust on the solar panels. This development was successful as it increased the efficiency of the system to a greater extent.

The agriculture industry also saw various advancements. Researches included the reformation of existing systems, including the irrigation system, automated solar tracking systems, etc., with IoT-based systems for control and monitoring purposes, which also resulted in a more efficient model to carry out a process. The use of IoT-based solar-powered systems to predict the probability of forest fires can take future work. Projects like smart cities and smart villages should be taken up more for energy monitoring and control. Technology has shown exponential advancements in various fields of application. IoT is being a very vast topic, and there is still room for a more sustainable form of development using solar energy.

Acknowledgements This study was conducted with the support of the National Research Foundation of Korea (NRF-2021R1C1C1008791).

Declarations

Conflict of interest The authors declare that they have no conflict of interest.

Ethical approval This article does not contain any studies with human participants.

Data availability Data sharing is not applicable to this article as no datasets were generated or analyzed during the current study.

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Authors and Affiliations

Dhruv Chakravarty Nath[1] · Indranil Kundu[1] · Ayushi Sharma[1] · Pranav Shivhare[1] · Asif Afzal[2,4] · Manzoore Elahi M. Soudagar[3,5] · Sung Goon Park[2]

✉ Asif Afzal
asif.afzal86@gmail.com

✉ Manzoore Elahi M. Soudagar
me.soudagar@gmail.com

✉ Sung Goon Park
psg@seoultech.ac.kr

Dhruv Chakravarty Nath
Dhruvcnath@gmail.com

Indranil Kundu
indranilk2000@gmail.com

Ayushi Sharma
aayushisharma98276@gmail.com

Pranav Shivhare
shivharepranav@gmail.com

1 Department of Mechanical Engineering, University of Petroleum and Energy Studies, Dehradun, India

2 Department of Mechanical and Automotive Engineering, Seoul National University of Science and Technology, Seoul, South Korea

3 Department of VLSI Microelectronics, Saveetha School of Engineering, Saveetha Institute of Medical and Technical Sciences, Chennai, Tamil Nadu 602105, India

4 Department of Computer science and engineering, University Centre for Research & Development, Chandigarh University, Gharuan, Mohali, Punjab, India

5 Institute of Sustainable Energy, Universiti Tenaga Nasional, Jalan IKRAM-UNITEN, 43000 Kajang, Selangor, Malaysia