Clean Energy Management Based on Internet of Things and Sensor Networks for Climate Change Problems

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1 Introduction

Since the beginning of the industrial revolution [1], it has been abundantly clear that human activities have hastened the progression of climate change. Since the beginning of industrialization, there has been a roughly fifty percent rise in anthropogenic carbon dioxide in the atmosphere. The primary contributor has been the use of fossil fuels for the generation of energy, the operation of transportation networks, and the processing of industrial goods [2]. The residential building industry and the commercial construction industry are major consumers of energy. In 2018, the built environment was responsible for around 40% of the world's total energy consumption and 40% of the planet's greenhouse gas emissions. The annual emissions from the building sector reached a new high in 2018, having climbed by 2% from the previous year. This took place even though overall energy usage was increasing by 1%. Guidelines 14 and 15, the International Performance Measurement and Verification Protocol (IPMVP), the Federal Energy Management Program (FEMP), and

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the Uniform Methods Project of the Department of Energy (DOE) (UMP) [3]. They establish guidelines for determining how much energy is used, how much energy is demanded and how much water is used [4]. However, the programs do not target any metrics relevant to reducing the effects of climate change. It could be a game-changer if the building sector were to transform energy savings into pollution reductions. It is possible to do so by locating a generally accepted method to which all relevant parties agree and which can provide trustworthy auditable reporting and verification in 2017 and 7% higher than in 2010 [5]. These concerning figures are attributable, to a significant degree, to the expansion of both the floor space of worldwide buildings and the human population. Although there is the continued implementation of energy-efficiency methods in buildings, these strategies are insufficient to keep up with the demand for energy [6]. As a result, energy-efficiency methods for buildings and management strategies for those buildings are vital to the process of mitigating the effects of climate change. The building industry launched several auditing schemes to keep track of how much energy was being used. The American Society of Heating, Refrigeration, and Air-conditioning Engineers is one example of such an organization (ASHRAE).

The carbon credit market [7] relies heavily on the measuring, reporting and verification (MRV) system. An important application area for MRV technology is building energy performance (BEP) monitoring. The existing BEP MRV, on the other hand, cannot provide a reliable solution to the issues. The use of Blockchain technology can enhance this system's reliability. Blockchain is a distributed database that is instantly accessible to all participants in a network. Data recorded in a blockchain system are unchangeable, shareable, and traceable after they have been recorded. The BEP MRV system benefits from Blockchain's transparency, traceability, and affordability. As a result, the Emissions Trading System (ETS) design characteristics and MRV for carbon emissions [8] are great possibilities.

Human actions, particularly in the last half-century, are largely to blame for the rapid shifts in global climate [9, 10]. As long as heat-trapping gas emissions in the atmosphere and Earth's climate sensitivity remain high, the climate change expected to continue [11]. A rise of 1.3–1.9 F in average temperature has been recorded in the United States from 1895 to 2020 [12–14], with the greatest increase occurring after 1970. An 8-inch rise in global sea levels has been seen in this century since 1880, with a projected increase of up to 4 feet by the end of this century. Climate change has decreased the amount of ice covering the sea, land, and lakes. In recent years, the summer month on record has been broken on a regular making it impossible to effectively estimate climate change. As a result, the length of the growth seas growing risen and will continue to increase due to the interdependence of the growing season on the frost-free time [15–24]. There has also been an increase in the average amount of precipitation, as well as an increase in the intensity of the most extreme downpours and precipitation. The frequency of cold waves has decreased, but their strength has increased [25–31], as have other variations in extreme weather occurrence patterns. Carbon dioxide emissions from the atmosphere are being absorbed by oceans, and this is causing ocean acidification (a fall in ocean changes pH values) [32].

IoT is being hailed as a powerful weapon against climate change [33]. It can detect the amount of CO_2 and other greenhouse gases in the atmosphere and use that information to help uncover the underlying causes of climate change [34]. Real-time monitoring of greenhouse gas emissions from fossil fuel combustion is possible. So, monitoring carbon sequestration processes and rates can help to offset emissions by increasing the amount of carbon stored in forests. Climate IoT can be used to develop new atmospheric "things" and technology that can be used to permanently reduce CO_2 levels in the atmosphere.

Climate IoT can also be used to anticipate and prepare for climate change. Uncertainty in climate change can be reduced by using advanced sensors, communication networks, and models. Forecasts of climate change and ecosystem response can be made using IoT-enabled decision-making tools incorporating sensors' data. Increased greenhouse gas emissions may be empirically studied thanks to IoT technologies [35]. Additionally, it can simulate how an ecosystem will respond to various climates (both current and future). Environmental and atmospheric management procedures can now be better adapted, and new management approaches can be devised as a result of this new information being gleaned. Climate IoT can address short-term and long-term goals and application needs by exploiting current scientific and technical breakthroughs. This architecture supports improved knowledge and insight into global ecosystems. As we learn more about the Earth's system on a broader scale, we'll be better able to estimate water resources, forecast weather patterns, and assess the health of ecosystems. As a result of these reasons, we need to design applications that are useful to our community.

This chapter is organized as follows. Section 1 represents the ng introduction. In contrast, Sect. 2 contains greenhouse monitoring, Sect. 3 includes challenges related to energy use, Sect. 4: The IoT for sustainable energy, is also divided into a subsection, and Sect. 5 sensors for the transmission system, Sect. 6: Meters with Internet-enabled functions, Sect. 7: sensing of the solar and wind fields and conclusion.

2 Greenhouse Monitoring

Plants that need carefully controlled temperatures and humidity levels are typically grown in a greenhouse since it is an enclosed structure with walls and a roof composed primarily of transparent material, such as glass. These buildings can be as small as sheds or as large as factories, and their sizes range. A cold frame is like a tiny greenhouse in appearance. The temperature inside a greenhouse exposed to sunlight will become noticeably warmer than the temperature of the surrounding environment, which will shield the contents of the greenhouse from the cold. There are a lot of commercial glass greenhouses and hot houses out there, and many are high-tech production facilities for growing flowers and vegetables. The glass greenhouses are outfitted with various machineries, such as screening installations, heating and cooling systems, and lighting, which a computer may manage to provide the ideal environment for developing plants. After that, various methods are utilized to assess the optimality degrees and comfort ratio of the micro-climate within the greenhouse (i.e., air temperature, relative humidity, and vapor pressure deficit) before cultivating a particular crop. This is done to lower the production risk. The conversion of chemical energy into electrical energy is the primary function of an electrical device known as a battery. Batteries can be broken down into various subcategories determined by their intended function; these subcategories are then utilized in various electronic and electrical products. Electrical batteries include a variety of substances, including mercury and lead compounds, among others; lead is one of the most toxic elements found in nature, and batteries do not contribute to environmental health [36].

Several researchers developed a new kind of battery called the bio battery. This battery draws its power from various organic compounds, including carbohydrates, amino acids, and enzymes. The sugar-digesting enzymes and the mediator make up the anode, and the oxygen-reducing enzymes and the mediator make up the cathode. These batteries have the potential to function with as many types as possible of energy sources within the greenhouse monitoring system. In addition to these dangers, there is also the possibility that the battery could explode or that there will be a leak of chemicals. Bio-battery have been developed as a solution to this issue. This battery lessens the effect these chemicals have on the environment and thus confers a significant benefit to humans.

Since the 1990s, many monitoring systems for greenhouses and the environment have been developed. However, these monitoring systems have been left behind due to a lack of knowledge and cost and implementation constraints. The use of this technology has the potential to assist in the expansion of agriculture within a managed procedures like increasing crops yield, rationing water use and other resources, it is required for plants to have the necessary environmental conditions, such as respiration. Plants' ability to absorb water might be hindered when soil temperatures are low. The amount of sunshine a plant receives can influence its rate of development. Low relative humidity causes an increase in transpiration, leading to a water shortage in plants. By automating the data collection process regarding the soil conditions and the numerous environmental parameters that influence plant growth, it is possible to collect information with fewer requirements for human labor. Automatically controlling all the factors that affect plant growth is also difficult because it is expensive, and some physical factors are interrelated. For instance, temperature and humidity are related so that when temperature increases, humidity decreases; therefore, controlling both together is difficult because they are interrelated. It is possible to utilize a wireless sensor network to gather the data from one place to the next in a greenhouse, which is necessary since the temperature and humidity levels inside the greenhouse need to be constantly monitored [36].

The sensor will measure the data coming from the greenhouse and then transfer the data it has acquired to the receiver. The construction of greenhouse monitoring systems is getting further along as each day passes. When utilizing this system, the monitoring process is simplified, and additional savings are realized in the areas of installation cost and ongoing maintenance cost.

3 Challenges Related to Energy Use

One of the fastest-growing fields of study is energy management, which is a rewarding career choice. The economic and environmental benefits of proactive energy system assessment and management can be realized. An energy manager's job is to evaluate how much energy is being used and then make modifications to make the system more efficient. Regarding planning for efficiency, it's common for energy management to focus on machinery, equipment, buildings, and other physical structures and processes[37].

Energy managers are responsible for evaluating and enhancing the efficiency of a company's present plans and processes to reduce environmental impact while simultaneously increasing profits. These include hydropower, solar battery storage and energy conversion, electrical networks, and petroleum processing and utilization.

Energy management is becoming increasingly vital as the world's natural resources are depleted. Making use of valuable resources more effectively requires the adoption of efficient systems. Emissions are a problem throughout the entire energy supply chain, including extraction, conversion, transportation, and distribution. Increasing a system's energy efficiency makes sense because it lowers costs and maximizes the inherent value of the resources being used.

Technology that considers environmental impact first and seeks to lessen it is a rapidly expanding industry. Changemakers are required in this industry to produce better energy management systems and invent new ways of processing, extracting, transporting, and so on.

We must think beyond the box for both your career advancement and that of our planet. We aim to show that climate protection and energy efficiency can also be commercially beneficial, and we hope to increase awareness in other companies. On top of that, we have close ties to the political sector and can give our expertise and experience to the legislators.“ Our current climate change dilemma can only be solved if we improve our energy management systems [37].

There are new emerging difficulties that future energy systems should handle by making use of the modern breakthroughs in energy technology [38, 39]. This is because these advances are developing simultaneously as the modern advanced energy technologies. The following discussion will focus on the past, present, and potential future difficulties that the community faces regarding energy. These difficulties affect the power-producing system's capacity and cause interruptions in the energy distribution system.

The current energy system relies substantially on water to function. However, due to the inconsistent supply of water (both in the short term and over longer periods), innovative energy production methods are required. There are no safety precautions in place for the high-voltage transmission lines. These likewise operate excessively and are not being used for their intended purpose. In addition, transmission loss is a significant problem that can result in power interruptions and blackouts. Because there is greater water availability in coastal areas, many energy plants are situated there.

Nevertheless, coastal infrastructure and energy facilities and infrastructure are being impacted by rising sea levels and high tides, heavy downpours, and flooding caused by storm surges [40–44]. Loss of productivity in urban and industrial locations, where the power outage lasted for an extended period, is related to a decline in the number of businesses and the overall economy. High energy demands and a commensurate increase in electricity usage are caused by the intense heat waves and temperatures prevailing this summer. It is anticipated that the energy demand will rise as a result of peak loads [45].

Increasing greenhouse gas emissions is one of the challenges of increased energy usage [46]. Carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) are some of the gases that are released as a result of these emissions [47]. After the transportation sector, responsible for the vast majority of emissions, these are the second highest. The energy consumed by information technology, mobile devices, and computers is expected to rise [48]. The production of electric vehicles (EV) is leading to an increase in the demand for energy, which is necessary to meet the requirements of EVs [49]. A mismatch between the demand and capacities of energy systems and the complicated energy needs of businesses and communities is another difficulty tied to energy infrastructure [38].

4 The Internet of Things for Sustainable Energy

It is abundantly clear from the discussion of energy and sustainability that universal access to energy cannot be achieved without the implementation of appropriate technological measures. The application of technology can make it possible to design resilient solutions for reliable, low-cost energy access, which can improve the performance and operation of the energy systems that are now in place. Because of this, the requirement for the community to have access to low-cost energy can be satisfied by utilizing the sensing and communication technologies of the next generation [50]. To satisfy this fundamental requirement of human existence, IoT must be developed into a system that can effectively deliver economic and efficient services.

Regarding sustainable energy systems, the IoT is envisioned as a way to connect all of the electrical grid's energy objects, service supply chains, and human capital using cutting-edge technology to meet the century's future needs and access challenges to clean energy sources. This paradigm is essential to connect a wide range of energy technologies and new solutions on a global scale. IoT for sustainable energy has the potential to make the current energy infrastructure more sustainable and resilient. Energy infrastructure and technologies that are safe, inventive, and efficient are among the capabilities that it possesses. By easing the implementation of large-scale renewable and clean energy solutions, IoT offers a variety of ways to provide low-cost energy sources to people worldwide [50].

Sustainability IoT is all about smart grids, a 21st-century technological marvel. Combining IoT autonomy with efficient grid management can increase production and consumption in the long term. Solar and wind power efficiency can be improved via real-time monitoring of renewable energy supplies and environmental monitoring. To increase supply, these can be connected to the grid. To reduce the use of fossil fuels, distributed and low-loss smart microgrids will be implemented, and included in sustainability are.

1. Generation wind, solar, natural gas, water, renewables, and coal.
2. Phasor measurement unit, transmission, and phasor measurement. Data collection and monitoring under supervision (SCADA).
3. Control of voltage, distribution, and smart and microgrid systems.
4. Work order and invoice management are also included in this category.
5. Providers of goods and services to the general public include the management of loads, bulks, and outages.

4.1 Coal-Plant Sensors

To meet the ever-growing demand for ecologically friendly, reliable, and adaptive power generation. Coal power plant control systems have experienced continual improvement. It has become necessary to use online monitoring technologies and more advanced algorithms to optimize the combustion process to manage multivariable systems. Coal and airflow sensors, along with imaging and spectral analysis of the flame, can help improve stoichiometric management. It is also possible to map the furnace's hot zones using in-situ laser absorption spectroscopy. One of the current plant control strategies that modern plant control systems can use is artificial intelligence, which mimics the behaviours of expert operators and uses complicated empirical models created from operational data to identify the optimum control response. These advanced plant control systems can use a wide range of computational methods. New sensor technologies are being developed to improve control further and ensure that these sensors can withstand the harsh conditions of advanced coal plants and gasifiers.

Since optical fibre sensors may produce highly sensitive, distributed, and low noise measurements even when subjected to high temperatures, an increase in the use of optical technology is of particular importance. Microelectronic fabrication techniques and newly discovered high-temperature materials are currently being used to build miniature devices that provide a reliable and cost-effective solution for in-situ gas and parameter monitoring. The development process incorporates the use of several techniques and materials. Wireless communication and self-powering systems can make it easier to install distributed sensor networks and monitor inaccessible places with the help of these newly created sensors. In the future, self-organizing networks may play an increasingly essential role in future control systems [51].

Coal-fired power stations are essential to IoT-based systems for long-term sustainability as a source of fluctuating power. Monitoring in these facilities enhances combustion efficiency and permits self-optimization through sensors. It is possible to improve the performance of coal-fired power plants by employing modern stoichiometric control systems. various materials, including coal, flame, carbon, oxygen and flow sensors have been used in furnaces [52].

4.2 Oxygen Sensing

The amount of oxygen remaining after burning is a critical variable in combustion management, and oxygen sensing is essential for combustion monitoring in fossil-fuel-fired power plants [53]. Combustion air intake and distribution adjust this oxygen signal to an oxygen set point. On the other hand, changes in the rate of firing or other disturbances may need a change. Lowering the oxygen set point while avoiding incomplete combustion can improve combustion efficiency and reduce NOx emissions. The residual oxygen controls the process of burning. The rate of fire and the amount of air being drawn into the chamber can be altered—incomplete combustion and oxygen set-point optimization [54].

The voltage generated by platinum electrodes covered in catalytic platinum in the electrolyte is directly proportional to the gradient in oxygen concentration across the cell [51]. Ionic conduction can only take place at temperatures above 300 °C. Hence a special electric heater is needed to keep the zirconia between 700 and 750 °C.

Oxygen sensors can be found in various forms, but the most common is an electrochemical zirconia-based sensor. Zinc oxide is used as a solid electrolyte between the sample gas and the air as a reference for this device's oxidation detection [55].

Using probes, it is possible to install Zirconia sensors directly into the flue gas. Ceramic or stainless-steel casings protect these sensors from high temperatures and fly ash diffused through a filter. The use of temperature-resistant ceramic shielding can withstand temperatures as high as 1400 °C, making them suitable for the furnace's higher temperatures [51]. Due to the lack of a heater, these sensors from Rosemount can operate at extremely high temperatures. A hermetically sealed metallic reference is used as a substitute for air to ensure that measurements are free of drift. Zirconia sensors have many benefits, including that their inverse logarithmic response increases accuracy as oxygen concentration decreases. As a result, zirconia sensors are ideal for use in environments with low amounts of oxygen following burning [51]. Only one or a few sensors are used in most coal boilers. Temperatures of 300–400 °C are common between the economizer and the air preheater, where these sensors are frequently installed. Because of its proximity to the furnace and distance from the probe, this location necessitates materials that can tolerate high temperatures to regulate combustion. This can make it difficult to distinguish between the flue gases produced by distinct burners due to air incursion in convective passes. When attempting to optimize the furnace's oxygen set point, it's typical to run across problems like an inaccurate picture of the furnace's actual oxygen levels due to improper monitoring. In addition to paramagnetic analyzers, which make use of oxygen being pulled to a magnetic field, extractive oxygen analyzers can also use zirconia sensors [51]. Oxygen movement can be detected in several ways, such as with flow sensors or by the torque exerted on a revolving pair of nitrogen-filled glass spheres after exposure to an intense magnetic field [51]. Servomex and Yokogawa developed these methods. Unlike zirconia sensors, this measurement method is unaffected by combustible gases, which are known to artificially reduce the signal by interacting with oxygen. One of the advantages of this form of measurement is that it provides a more accurate picture of the situation. An additional layer of complexity and slower response times are incurred by installing a gas sampling system.

Air preheater and economizer were employed in zirconia-based electrochemical sensors. These sensors use platinum electrodes capable of separating and absorbing oxygen into electrons and ions [56].

Paramagnetic sensors can measure oxygen because of the strong magnetic field. It uses two nitrogen-filled glasses to cause suspension rotation, which photocells sense. It's less sensitive to combustion gases [57].

4.3 Carbon Monoxide Sensors

The carbon monoxide (CO) concentration in the flue gases can serve as an extremely helpful control variable within the furnace. It should ideally be maintained at a level lower than 200 parts per million (ppm). CO is the most sensitive and accurate indicator of incomplete combustion [58, 59]. Suppose an unwanted rise in CO levels, sometimes known as a CO "breakthrough," is detected. In that case, the excess oxygen set point can be lowered to a more appropriate level, and the extra air can be adjusted accordingly. Alternatively, a CO sensor that is more sensitive could be used as a control variable for the furnace itself, particularly in regards to optimizing the oxygen set point.

In most cases, CO detection in coal furnaces relies on either infrared absorption or electronic sensors that rely on catalytic combustion as their primary method of operation. This latter group uses a conductive element covered with a catalyst that encourages combustion, such as platinum. The conductive element is heated, which raises its resistance, as CO and other combustibles are oxidized on the catalyst. In coal boilers, the other combustibles are often negligible compared to the CO [60]. The most prevalent use of this technique is found in catalytic bead sensors, which involve coating a conductive filament with a bead of catalyst. These sensors can be found in GE, ABB, and Emerson/Rosemount devices. These devices are too sensitive to be used in situ and require sample extraction; nonetheless, they are capable of being "close linked," in which sample conditioning consists merely of the filtration of particulate matter [61, 62]. Although the Rosemount sensor promises to be resistant to sulfur, the sensitivity of catalytic bead sensors in applications involving coal plants to catalyst poisoning by SO_2 is one of the sensors' weaknesses. Servomex produces a thick film thermistor, which is an alternate application of the idea of catalytic combustion. This type of thermistor consists of thin conductive tracks formed on a ceramic substrate and coated with a layer of CO-sensitive catalyst. This design is also applicable in a close-coupled arrangement, and it boasts a high degree of precision as well as resistance to the poisoning of catalysts [63].

The IR analysis of the flue gas CO content can either be extractive, in which case the flue gas is removed from the furnace and placed in a sample cell for analysis, or it can be in situ, in which case an IR source and detector are placed on either side of the flue gas duct. The entire flue gas volume acts as a sample cell. In-situ devices Rosemount and SICK [64, 65] make use a technique called gas filter correlation. During this technique, a portion of the detected beam is passed through a vessel filled with pure CO. This saturates the CO absorption signal and establishes a baseline for the interference caused by the absorption of other species [64, 65]. Even though they offer a usable average over a full portion of the furnace, line-of-sight measurements are susceptible to high amounts of particles and temperatures much higher than 600 °C. There is no feasible method of calibrating the measurement, and thermal expansion and vibration are potential factors that could throw off the alignment of the source and receiver, necessitating signal filtering. A dual-pass arrangement, in which a furnace probe is utilized to reflect the beam to a combined source and detector unit, is one method that can be utilized to alleviate alignment concerns. The use of tuneable diode lasers as the source is a relatively recent development in line-of-sight infrared technology. This allows for greater accuracy and monitoring in areas with high temperatures.

4.4 Flame Detection

The safety of pulverized coal combustion depends on flame sensing in coal-fired power plants. These sensors measure the flames' infrared, visible, and ultraviolet light frequencies. These flame stoichiometry and temperature data increase combustion [66].

Optical flame detectors have been placed on each burner to ensure that pulverized coal is properly burned safely. The amplitude and frequency (also called flicker) of selected visible, infrared, or ultraviolet frequencies generated by the flame are commonly measured by these instruments. This information can be used to improve the combustion process by analysing it further [67–69].

For example, ABB's Advisor series of flame scanners provides additional information on the quality of the flame in addition to the conventional requirement of just monitoring its presence. Burners that aren't working properly can be identified with Flame Doctor®, a portable diagnostic device that uses signals from existing flame scanners to identify them. It is possible to detect different abnormalities in flame quality and optimize the air–fuel ratio based on these deviations using software that recognizes patterns and mathematics developed from the chaos theory [70].

In addition, video cameras can capture photographs of the flame in real time. With the right processing software, even a higher quantity of information regarding the quality and consistency of the flame can be derived from these images.

4.5 Sensing Coal Flow

Conventionally, the gravimetric federate of coal to the pulveriser mills is used as the sole metric for monitoring coal flow. This federates directly controlled by the boiler fire rate and the amount of load that the plant is required to produce.

It is only possible to check the distribution of coal across burners on an ad hoc basis using sample probe readings, which are not always accurate and are not carried out concurrently on different pipelines [71]. Even though the actual coal flow rate is nearly always lower, it is normal practice to draw coal from the coal pipe at the same rate as the airflow.

Online flow sensors on coal pipelines have expanded in use due to the need for better control of individual burner stoichiometry. There are currently a variety of technologies that can be used for this purpose. Coal charge is detected electrostatically by electrodes and correlated with the same data at a downstream sensor to derive the time-of-flight between two points and, as a result, a computation of coal velocity by using ABB and Greenbank's PFMaster system [51, 72].

It is used to balance the distribution of coal over a group of burners, together with information produced from the overall charge detected. The PFMaster can detect pulsed flow behavior due to its quick response time. Because the electrodes are designed to be flush with the pipe, erosion will not occur because of this feature. The PF-Flo uses electrostatic cross-correlation and the Me control coal, manufactured by Air Monitor Corp. and Protection, to determine coal velocity. To get an accurate mass flow measurement, they use a microwave resonance approach that considers coal density in the pipe [73]. Burner pipes at the Stigsnaes Power Plant in Denmark were fitted with Me control Coal sensors, which resulted in a 30% reduction in oxygen set point, 44% reduction in NOx, and an efficiency improvement of 1.3%.

Others, like EUtech's EUcoalflow and MIC's Coal Flow Analyzer, use microwave signals with an increased frequency to measure the amount of coal flowing through the system. Two or three non-intrusive microwave transceivers installed around the circumference of a pipe can be used to transform the time-dependent intensity of microwaves reflected by moving coal particles into an absolute mass flow rate. In this way, the flow rate may be determined. With these sensors, EUtech's whole air–fuel ratio optimization technique is expected to yield efficiency benefits of 0.3–1%, as well as reductions in emissions and lagged performance, according to the company [51].

Since they are non-intrusive and less affected by ambient factors, including temperature, humidity, and other charge sources, optical image-based techniques have recently challenged older methods. Due to the increasing accessibility of digital imaging equipment, this is already a reality [74]. Coal particles are lit by high-intensity LEDs using CCD digital video cameras in these devices. They can determine the particle concentration and the particle velocity by analysing the blurriness of the photographs. Deposits can build over time, making it difficult to see through the coal pipe's transparent window.

4.6 Sensing Airflow

When it comes to controlling the combustion process, one of the most important parameters to adjust is the combustion air flow rate into the furnace. Additionally, the flow of primary air into the pulverizer mills needs to be maintained within a specific range that keeps the coal in suspension while minimizing erosion and the production of NOx. Venturi flow meters, which measure the decrease in fluid pressure that occurs as air travels through a confined piece of pipe, or Pitot tubes, which measure the pressure that air builds up when it is allowed to come to a complete stop, are generally used to monitor both of these air movements ("Air Monitor Corp, Flow Measuring and Control Stations" 2015). Air Monitor Corporation's IBAM system, which uses pitot tubes in each burner's combustion chamber, is proof that this technology can be used on even the smallest of burners. Fechheimer Pitot tubes, or flow straightening devices, may be necessary to account for the non-axial flow components of turbulent air. Short or curved duct portions are common places to find these parts (Air Monitor Corp, Rosemount). Both Pitot tubes and Venturis must have self-purging mechanisms in dirty air to function efficiently. If the principal air flow is being evaluated, these changes are especially critical because the ductwork is often short and the flow is contaminated by fly ash from regenerative heaters. The velocity of entrained particulates can also be used as a proxy for the airflow, and the charge signals created by these particles can be used to get the velocity of the entrained particulates in the same manner as for coal flow [75].

Volume flow meters include devices such as Pitot tubes and Venturis. This flow meter necessitates additional temperature and pressure measurements to accurately establish the density of the air and, therefore, the total mass flow. As a result, temperature inhomogeneities, such as those caused by the attemperator of primary air, might introduce errors. An alternative to mass flow meters is thermal mass flow meters. To measure the mass flow, these meters use the convective cooling effect of flowing air on a hot object [76, 77].

Additionally, compared to pitot tubes, these are more accurate at low flows. Venturis, on the other hand, cause the duct to experience energy-intensive pressure drops; this design avoids this problem. Fouling was a common concern with early thermal anemometers, but newer designs, such as Kurz Instruments' thermal mass insertion meters that operate at far higher temperatures than the air around them, eliminate this issue.

Optical flow meters, a new type of coal flow meter, are non-invasive and less sensitive to external factors, making them ideal for monitoring coal flow ("Optical Scientific, Optical Flow Sensors." 2015). Optical scintillation happens when light is diffracted due to localized fluctuations in air temperature and density and they can take advantage of this.

It is also possible to estimate burner airflow by combining existing flow measurements with a physical system airflow model. This is one method for determining burner airflow. A "soft sensor" utilized by EUtech to monitor air flow at all points in the hydraulic network of the plant and adapt to changing inputs, such as damper position, employs this strategy. Everything can be done using EUtech's 'EUsoft air' A robust PLC generates data from the soft sensors in real-time and sends it directly to the DCS [78].

4.7 Ash Carbon Sensing

Carbon ash concentration indicates combustion efficiency [79] Less than 20% is kept. Microwaves are used to assess carbon concentration. Depending on the dielectric constant, carbon's high permittivity absorbs EM radiation. Resonant cavity sensors detect frequency fluctuations.

4.8 Temperature-Sensing Gases

In most cases, the results of gas sensing [80] performed in a particular area do not accurately represent the gas concentration. For this reason, arrays of gas sensors, both linear and planar, are utilized to obtain a comprehensive picture. Another innovation for sensing the quantities of flue gases with a very high level of accuracy is the tunable diode laser absorption spectroscopy. Monitoring the temperature of the furnace's exit gas is also very significant for controlling the furnace. The sensing of temperature can be accomplished by utilizing several strategies that are covered in the section on nuclear reactors. In addition, nitrogen oxide monitoring is carried out in the plant to detect the presence of nitrogen oxides.

5 Sensors for the Transmission System

Sensing grid transmission systems is critical for various reasons [81]. The sensing technologies are either fully developed or in the process of being developed. The following applications are discussed.

5.1 Methods for Sensing at Substations

(1) **Monitoring Potential Discharge at Substations**: To prevent catastrophic failures, it is essential to monitor any potential discharge that may occur at substations [82]. Antenna arrays are being utilized to assess, locate, and identify components that are contributing to discharge at present. In addition to that, the approaches of 3D acoustic emissions are currently being utilized for discharge

sensing in transformers. In addition to this, 3D acoustics can be used to detect bubbling sources as well as gas sources.

(2) **Video Imaging**: In this method, IR tomographic cameras are utilized to make thermal video images of substation components. This approach is known as "Video Imaging."

(3) **Metal Insulated Semiconducting (MIS) Gas in Oil Sensor**: this detects the presence of gas in the oil. In this method, a hydrogen sensor that is not very expensive is used to monitor the concentrations of H_2 and C_2H_2 in the headspace and oil of transformers. The MIS gas sensor is built on a chip during manufacturing [83]. This sense is also utilized to determine whether or not cable oil contains hydrogen and possible acetylene.

(4) **Sensing-based on fiber optic technology.** Two varieties of sense are based on fibre optics: acoustic and gas. Fibre optics cable is used to check for discharge in the stress zones of the transformers in sound. The presence of a gas at the end of the fibre optics is analysed in the second method [84] which is utilized to detect early stages of degradation and failure in high-risk locations.

(5) **Frequency Domain Analysis**: The device's functionality is based on the frequency domain analysis of the transformers as its underlying concept. In the FDR method, the configuration modifications of the transformers are identified by analysing the fluctuations in frequency response data. These measurements are obtained in a shady manner by using spontaneous transients [85].

(6) **Sensing Gas in System Load Tap Changer (LTC)**: This sensing approach can measure the LTC gas ratios without requiring individual gas measurements [86]. It can do so because it can monitor the LTC gas ratios.

(7) **Radio Frequency**: RF-based sensing technologies are utilized to detect leakages of the current levels to provide information regarding insulation washing and flash-over for a wide variety of insulation types [87]. In addition, they can perform wireless or remote identification of high-risk components (for example, acoustics-based internal discharge, current, jaw temperature of disconnect, and density of sulfur hexafluoride). For the goal of this endeavour, both the timing and magnitudes of fault currents traveling through the shield wires are utilized.

5.2 Sensing of Overhead Lines

The following is a discussion of the various techniques for sensing overhead lines.

1. The current sensing and temperature sensing methodologies are applied in overhead transmission to sense the temperature of connectors, the current magnitudes, and the compression of conductors such as dead ends and splices. As a result, a histogram is constructed to evaluate the loss and locate components subject to significant stress. These sensors can harvest energy from the considerable magnetic field in the vicinity of the line [88].
2. In an environment analogous to a substation, RF methods are utilized to assess the leakage of currents connected with overhead insulators. When pinpointing

the precise site of faults, it is necessary to measure not only the amount of current but also the amount of time it has been flowing through the shield wire. Regarding the illumination current distributions, the same measurements are taken [89].

3. The surge sensor is employed to measure and log surges and the overall charge sensed [90].
4. The transmission structure's sensing is accomplished by utilizing the sensing of the environment data and the image processing for decision support systems. As a result, various situations, such as an unknown outage and actions by birds of prey, can be identified in real-time [91].

6 Meters with Internet-Enabled Functions

In the IoT for renewable energy, smart meters can also be considered a form of sensor. The advanced metering infrastructure is built on top of smart meters, which are the primary constituents of this infrastructure (AMI).

These utilize a variety of communication channels to establish a connection between clients and service providers [92]. Monitoring power flow in both directions uses smart meters in another capacity. Consequently, using smart meters makes it possible to implement dynamic invoicing, load monitoring, and remote capabilities.

7 Sensing of the Solar and Wind Fields

Real-time sensing of these environmental factors is necessary for the effective operation of the energy generating process [93], as it is required for the reliable integration of solar [94, 95] and wind energy [96–98] resources in the IoT for sustainable energy. Solar irradiation and wind speed are both measured during these environmental sensing procedures. Sensing weather-related factors of this type in sustainable energy systems has the enormous potential to deliver a greater variety of energy sources to power systems.

8 Conclusion

Climate change is closely related to energy management. A lot of challenges were related to energy use. Still, The IoT offered solutions for sustainable energy, like the generation of wind, solar, and renewables which were performed through IoT sensing like coal-plant sensors, oxygen sensing, Co sensing, and multiple sensors or detectors. Meters with Internet-enabled functions are considered sensors. Aside from wind speed and its energy generation, it can be used as a monitor for solar irradiation. In sustainable energy systems, weather-related parameters of this type can deliver a wider range of energy sources to power systems.

References

1. Wrigley, E. A. (2018). Reconsidering the industrial revolution: England and Wales. *The Journal of Interdisciplinary History, 49*(1), 9–42.
2. Manabe, S., & Broccoli, A. J. (2020). *Beyond global warming: How numerical models revealed the secrets of climate change.* Princeton University Press.
3. Li, M., Haeri, H., & Reynolds, A. (2017). Introduction. In: *The uniform methods project: Methods for determining energy-efficiency savings for specific measures.* National Renewable Energy Lab (NREL).
4. Woo, J., Fatima, R., Kibert, C. J., Newman, R. E., Tian, Y., & Srinivasan, R. S. (2021). Applying blockchain technology for building energy performance measurement, reporting, and verification (MRV) and the carbon credit market: A review of the literature. *Building and Environment, 205*, 108199.
5. Zhang, F., Zhang, W., Li, M., Zhang, Y., Li, F., & Li, C. (2017). Is crop biomass and soil carbon storage sustainable with long-term application of full plastic film mulching under future climate change? *Agricultural Systems, 150*, 67–77.
6. GlobalABC. (2019). *Global alliance for buildings and construction, International Energy Agency and United Nations Environment Programme.* 2019 Global Status Report for Buildings and Construction: Towards a Zero-Emissions, Efficient and Resilient Buildings and Construction Sector.
7. Singh, N., Finnegan, J., Levin, K., Rich, D., Sotos, M., Tirpak, D., & Wood, D. (2016). *MRV 101: Understanding measurement, reporting, and verification of climate change mitigation.*
8. Braden, S. (2019). Blockchain potentials and limitations for selected climate policy instruments. *Retrieved* 5(9), 2020
9. Karl, T. R, Melillo, J. M., Peterson, T. C., & Hassol, S. J. (2009). *Global climate change impacts in the United States.* Cambridge University Press.
10. Sands, R. D., & Edmonds, J. A. (2005). Climate change impacts for the conterminous USA: An integrated assessment. In *Climate change impacts for the conterminous USA* (pp. 127–50). Springer.
11. Nakicenovic, N., Alcamo, J., Davis, G., de Vries, B., Fenhann, J., Gaffin, S., Gregory, K., Grubler, A., Jung, T. Y., & Kram, T. (2000) Special report on emissions scenarios.
12. Alexander, L. V., Zhang, X., Peterson, T. C., Caesar, J., Gleason, B., Tank, A. M. G. K.. Haylock, M., Collins, D., Trewin, B., & Rahimzadeh, F. (2006) Global observed changes in daily climate extremes of temperature and precipitation. *Journal of Geophysical Research: Atmospheres, 111*(D5).
13. Rosenzweig, C., Rind, D., Lacis, A., & Peters, D. (2018). *Our warming planet: Topics in climate dynamics* (Vol. 1). World Scientific.
14. Council, National Research. (2011). *Climate stabilization targets: Emissions, concentrations, and impacts over decades to millennia.* National Academies Press.
15. Adams, R. M., Hurd, B. H., Lenhart, S., & Leary, N. (1998). Effects of global climate change on agriculture: An interpretative review. *Climate Research, 11*(1), 19–30.
16. Darwin, R. (1995). *World agriculture and climate change: Economic adaptations.* US Department of Agriculture, Economic Research Service.
17. Easterling, W. E. (2011). *Guidelines for adapting agriculture to climate change.* Imperial College Press.
18. Hatfield, J. L., Boote, K. J., Kimball, B. A., Ziska, L. H., Izaurralde, R. C., Ort, D., Thomson, A. M., & Wolfe, D. (2011). Climate impacts on agriculture: Implications for crop production. *Agronomy Journal, 103*(2), 351–370.

19. Högström, U., & Smedman, A.-S. (2004). Accuracy of sonic anemometers: Laminar wind-tunnel calibrations compared to atmospheric in situ calibrations against a reference instrument. *Boundary-Layer Meteorology, 111*(1), 33–54.
20. Reilly, J., Tubiello, F., Bruce, D., Abler, R. D., Fuglie, K., Hollinger, S., Izaurralde, C., Jagtap, S., & Jones, J. (2003). US agriculture and climate change: New results. *Climatic Change, 57*(1), 43–67.
21. Smit, B., & Skinner, M. W. (2002). Adaptation options in agriculture to climate change: A typology. *Mitigation and Adaptation Strategies for Global Change, 7*(1), 85–114.
22. Wall, E., & Smit, B. (2005). Climate change adaptation in light of sustainable agriculture. *Journal of Sustainable Agriculture, 27*(1), 113–123.
23. Walthall, C. L., Hatfield, J., Backlund, P., Lengnick, L., Marshall, E., Walsh, M., Adkins, S., Aillery, M., Ainsworth, E. A., & Ammann, C. (2013). *Climate change and agriculture in the United States: Effects and adaptation.* United States Department of Agriculture, Agricultural Research Services.
24. Ziska, L. H. (2011). Climate change, carbon dioxide and global crop production: Food security and uncertainty. In: *Handbook on climate change and agriculture*, 9–31.
25. Alexander, M. A, Scott, J. D., Friedland, K. D., Mills, K. E., Nye, J. A., Pershing, A. J., & Thomas, A. C. (2018). Projected sea surface temperatures over the 21st century: Changes in the mean, variability and extremes for large marine ecosystem regions of Northern Oceans. *Elementa: Science of the Anthropocene, 6*.
26. Diez, J. M., D'Antonio, C. M., Dukes, J. S., Grosholz, E. D., Olden, J. D., Sorte, C. J. B., Blumenthal, D. M., Bradley, B. A., Early, R., & Ibáñez, I. (2012). Will extreme climatic events facilitate biological invasions? *Frontiers in Ecology and the Environment, 10*(5), 249–257.
27. Fowler, D. R., Mitchell, C. S., Brown, A., Pollock, T., Bratka, L. A., Paulson, J., Noller, A. C., Mauskapf, R., Oscanyan, K., & Vaidyanathan, A. (2013). Heat-related deaths after an extreme heat event—Four states, 2012, and United States, 1999–2009. *Morbidity and Mortality Weekly Report, 62*(22), 433.
28. Greene, S., Kalkstein, L. S., Mills, D. M., & Samenow, J. (2011). An examination of climate change on extreme heat events and climate-mortality relationships in large US cities. *Weather, Climate, and Society, 3*(4), 281–292.
29. Kunkel, K E. (2008). Observed changes in weather and climate extremes. In: *Weather and climate extremes in a changing climate: Regions of focus: North America, Hawaii, Caribbean, and US Pacific Islands* (pp. 35–80).
30. Peterson, T. C., Stott, P. A., & Herring, S. (2012). Explaining extreme events of 2011 from a climate perspective. *Bulletin of the American Meteorological Society, 93*(7), 1041–1067.
31. Stone, B., Hess, J. J., & Frumkin, H. (2010). Urban form and extreme heat events: Are sprawling cities more vulnerable to climate change than compact cities? *Environmental Health Perspectives, 118*(10), 1425–1428.
32. Doney, S. C., Fabry, V. J., Feely, R. A., & Kleypas, J. A. (2016). Ocean acidification: The other CO_2 problem. *Washington Journal of Environmental Law & Policy, 6*, 213.
33. Khan, R., Khan, S. U., Zaheer, R., & Khan, S. (2012). *Future internet: The Internet of Things architecture, possible applications and key challenges*. 2012 10th International Conference on Frontiers of Information Technology, pp. 257–260. IEEE.
34. Tao, F., Zuo, Y., Da Li, X., Lv, L., & Zhang, L. (2014). Internet of Things and BOM-based life cycle assessment of energy-saving and emission-reduction of products. *IEEE Transactions on Industrial Informatics, 10*(2), 1252–1261.
35. Privette, J. L., Fowler, C., Wick, G. A., Baldwin, D., & Emery, W. J. (1995). Effects of orbital drift on advanced very high resolution radiometer products: Normalized difference vegetation index and sea surface temperature. *Remote Sensing of Environment, 53*(3), 164–171.
36. Saba, S., Shetty, S. R., Kulsum, U., & Vinutha, M. (2020). IoT based green house automation system with power conservation using biofuel cell. *International Journal of Engineering Research & Technology, 8*(13).
37. Audsley, S. M. (2019). *Why study energy management?*. https://www.masterstudies.com/article/why-study-energy-management/

38. Gui, E. M., & MacGill, I. (2018). Typology of future clean energy communities: An exploratory structure, opportunities, and challenges. *Energy Research & Social Science, 35*, 94–107.
39. Tirado, M. C., Cohen, M. J., Aberman, N., Meerman, J., & Thompson, B. (2010). Addressing the challenges of climate change and biofuel production for food and nutrition security. *Food Research International, 43*(7), 1729–1744.
40. Cutter, S. L., Solecki, W., Bragado, N., Carmin, J., Fragkias, M., Ruth, M., & Wilbanks, T. J. (2014). Ch. 11: Urban systems, infrastructure, and vulnerability. *Climate Change Impacts in the United States: The Third National Climate Assessment, 10*(7930), J0F769GR.
41. Kessler, R. (2011). *Stormwater strategies: Cities prepare aging infrastructure for climate change*. National Institute of Environmental Health Sciences.
42. Means, I. I. I., Edward, G., Laugier, M. C., Daw, J. A., & Owen, D. M. (2010). Impacts of climate change on infrastructure planning and design: Past practices and future needs. *Journal-American Water Works Association, 102*(6), 56–65.
43. Sathaye, J., Dale, L., Larsen, P., Fitts, G., Koy, K., Lewis, S., & Lucena, A. (2012). *Estimating risk to California energy infrastructure from projected climate change.*
44. Wilbanks, T. J., & Fernandez, S. (2014). *Climate change and infrastructure, urban systems, and vulnerabilities: Technical report for the US Department of energy in support of the national climate assessment*. Island Press.
45. Wilhelmi, O. V., & Hayden, M. H. (2010). Connecting people and place: A new framework for reducing urban vulnerability to extreme heat. *Environmental Research Letters, 5*(1), 14021.
46. Williams, J. H., DeBenedictis, A., Ghanadan, R., Mahone, A., Moore, J., Morrow III, W. R., Price, S., & Torn, M. S. (2012). The technology path to deep greenhouse gas emissions cuts by 2050: The pivotal role of electricity. *Science, 335*(6064), 53–59.
47. EPA. (2011). Inventory of US greenhouse gas emissions and sinks: 1990–2009. In: *US environmental protection agency.*
48. Satyanarayanan, M., Gao, W., & Lucia, B. (2019). *The computing landscape of the 21st century*. Proceedings of the 20th International Workshop on Mobile Computing Systems and Applications, pp. 45–50.
49. Luin, B., Petelin, S., & Al-Mansour, F. (2019). Microsimulation of electric vehicle energy consumption. *Energy, 174*, 24–32.
50. Salam, A. (2020). Internet of Things for sustainable Community development: Introduction and overview. In *Internet of Things for sustainable community development* (pp. 1–31). Springer.
51. Lockwood, T. (2015). *Advanced sensors and smart controls for coal-fired power plant. CCC/251,* IEA Clean Coal Centre.
52. Teichert, H., Fernholz, T., & Ebert, V. (2003). Simultaneous in situ measurement of CO, H_2O, and gas temperatures in a full-sized coal-fired power plant by near-infrared diode lasers. *Applied Optics, 42*(12), 2043–2051.
53. Tan, Y., Croiset, E., Douglas, M. A., & Thambimuthu, K. V. (2006). Combustion characteristics of coal in a mixture of oxygen and recycled flue gas. *Fuel, 85*(4), 507–512.
54. Guth, U., & Wiemhöfer, H.-D. (2019). Gas sensors based on oxygen ion conducting metal oxides. In *Gas sensors based on conducting metal oxides* (pp. 13–60). Elsevier.
55. Wang, L., Zhang, Y., Zhou, X., & Zhang, Z. (2019). Sensitive dual sensing system for oxygen and pressure based on deep ultraviolet absorption spectroscopy. *Sensors and Actuators B: Chemical, 281*, 514–519.
56. Rocazella, M. A. (1983). The use and limitations of stabilized Zirconia oxygen sensors in fluidized-bed coal combustors. In *Proceedings Electrochemical Soc (United States)* (Vol. 83). Columbus Laboratories.
57. Jordan, B. F., Baudelet, C., & Gallez, B. (1998). Carbon-centered radicals as oxygen sensors for in vivo electron paramagnetic resonance: Screening for an optimal probe among commercially available charcoals. *Magnetic Resonance Materials in Physics, Biology and Medicine, 7*(2), 121–129.
58. Qiu, X., Li, J., Wei, Y., Zhang, E., Li, N., Li, C., Yuan, H., & Zang, Z. (2019). Study on the oxidation and release of gases in spontaneous coal combustion using a dual-species sensor employing laser absorption spectroscopy. *Infrared Physics & Technology, 102*, 103042.

59. Sloss, L. L. (2011). *Efficiency and emissions monitoring and reporting*. IEA Clean Cloal Centre.
60. Yokogawa. (2008). *Carbon monoxide measurement in coal-fired power boilers*.
61. ABB. (2006). *Analytical instruments smart analyzer 90*.
62. GE. (2012). OxyTrak 390 panametrics flue gas oxygen analyzer. In *General electric measurement and control*.
63. Servomex. (2006). *Combustion analysis overview*. Servomex Group Limited.
64. Rosemount. (2010). *Model CCO 5500 carbon monoxide (CO) analyzer*. Rosemount Analytical.
65. SICK. (2013). *GM35 in-situ IR gas analyser*. SICK AG.
66. Zhang, R., Cheng, Y., Li, Y., Zhou, D., & Cheng, S. (2019). Image-based flame detection and combustion analysis for blast furnace raceway. *IEEE Transactions on Instrumentation and Measurement, 68*(4), 1120–1131.
67. Vandermeer, W. (1998). *Flame safeguard controls in multi-burner environments*. Fireye.
68. Fuller, T. A., Daw, S. C., Finney, C. E. A., Musgrove, B., Stallings, J., Flynn, T. J., Bailey, R. T., Hutchinson, D., & Lassahn, R. (2004). *Advances in utility applications of the flame doctor system*. Proceedings of the DOE-EPRI-EPAAWMA Combined Air Pollutant Control Mega Symposium.
69. Fireye. (2013). *45RM4 fiber optic flame scanner model 1001LF*. Fireye.
70. Wilcox, B. (2009). *Combustion tuning services optimize unit performance*. Babcock and Wilcox.
71. Sarunac, N., & Romero, C. E. (2003). *Sensor and control challenges for improved combustion control*. The Proceedings of the 28th International Technical Conference on Coal Utilization and Fuel Systems Clearwater, 1255. FL, USA: performance and reduced power plant emissions.
72. ABB. (2006). *Pulverised fuel flowmeter*. ABB.
73. Corp, Air Monitor. (2007). PF-FLO III. In *Air monitor power division*, 8.
74. Roberts, K., Yan, Y., & Carter, R. M. (2007). On-line sizing and velocity measurement of particles in pneumatic pipelines through digital imaging. *Journal of Physics: Conference Series, 85*, 12019.
75. Promecon, N. D., *Mecontrol air.* Promecon.
76. *Mass Flow Meter Product Guide*. (n.d). Monterey, CA, USA: Kurz Instruments.
77. Yoder, J. (2013). The history and evolution of thermal flowmeters. *Flow Control Magazine*, 22–25.
78. EUtech. (2015). *EUtech scientific engineering power generation solutions*. EUtech Scientific Engineering.
79. Dong, Z., Wang, R., Fan, M., Xiang, F., & Geng, S. (2019). Integrated estimation model of clean coal ash content for froth flotation based on model updating and multiple LS-SVMs. *Physicochemical Problems of Mineral Processing, 55*(1), 21–37.
80. Shuk, P., McGuire, C., & Brosha, E. (2019). Methane gas sensing technologies in combustion: Comprehensive review. *Sensors & Transducers, 229* (LA-UR-18–31101).
81. Muhanji, S. O., Flint, A. E., & Farid, A. M. (2019). EIoT as a solution to energy-management change drivers. In *EIoT* (pp. 1–15). Springer.
82. Yardibi, T., Ganesh, M., & Johnson, T. L. (2018). Electrical substation fault monitoring and diagnostics. Google Patents.
83. Shaltaeva, Y. R., Podlepetsky, B. I., & Pershenkov, V. S. (2017). Detection of gas traces using semiconductor sensors, ion mobility spectrometry, and mass spectrometry. *European Journal of Mass Spectrometry, 23*(4), 217–224.
84. Dong, L., Zhang, D., Wang, T., Wang, Q., & Han, R. (2018). *On line monitoring of substation equipment temperature based on fiber Bragg grating*. 2018 2nd IEEE Advanced Information Management, Communicates, Electronic and Automation Control Conference (IMCEC), pp. 1500–1503. IEEE.
85. Kurrer, R., & Feser, K. (1998). The application of ultra-high-frequency partial discharge measurements to gas-insulated substations. *IEEE Transactions on Power Delivery, 13*(3), 777–782.
86. Hoffman, G. R. (2008). Sensing load tap changer (LTC) conditions. Google Patents.

87. Shekari, T., Bayens, C., Cohen, M., Graber, L., & Beyah, R. (2019). RFDIDS: Radio Frequency-Based Distributed Intrusion Detection System for the Power Grid. In *NDSS*.
88. Lancaster, M. (2019). *Power line maintenance monitoring*. US Patent Application No. 10/205,307.
89. Deb, S., Das, S., Pradhan, A. K., Banik, A., Chatterjee, B., & Dalai, S. (2019). Estimation of contamination level of overhead insulators based on surface leakage current employing detrended fluctuation analysis. *IEEE Transactions on Industrial Electronics, 67*(7), 5729–5736.
90. Firouzjah, K. G. (2018). Distribution network expansion based on the optimized protective distance of surge arresters. *IEEE Transactions on Power Delivery, 33*(4), 1735–1743.
91. Kuang, Y., Li, Y., Deng, Y., Huang, D., & Qiu, Z. (2019). Electric field analysis and structure design of the box of bird guard used in 220 KV transmission line. *The Journal of Engineering, 2019*(16), 2860–2863.
92. van de Kaa, G., Fens, T., Rezaei, J., Kaynak, D., Hatun, Z., & Tsilimeni-Archangelidi, A. (2019). Realizing smart meter connectivity: Analyzing the competing technologies power line communication, mobile telephony, and radio frequency using the best worst method. *Renewable and Sustainable Energy Reviews, 103*, 320–327.
93. Silva-Leon, J., Cioncolini, A., Nabawy, M. R. A., Revell, A., & Kennaugh, A. (2019). Simultaneous wind and solar energy harvesting with inverted flags. *Applied Energy, 239*, 846–858.
94. DoE, U. S. (2009). Concentrating solar power commercial application study: Reducing water consumption of concentrating solar power electricity generation. In *Report to congress.* USDOE.
95. Lapo, K. E., Hinkelman, L. M., Sumargo, E., Hughes, M., & Lundquist, J. D. (2017). A critical evaluation of modeled solar irradiance over California for hydrologic and land surface modeling. *Journal of Geophysical Research: Atmospheres, 122*(1), 299–317.
96. Banta, R. M., Pichugina, Y. L., Alan Brewer, W., James, E. P., Olson, J. B., Benjamin, S. G., Carley, J. R., Bianco, L., Djalalova, I. V., & Wilczak, J. M. (2018). Evaluating and improving NWP forecast models for the future: How the needs of offshore wind energy can point the way. *Bulletin of the American Meteorological Society, 99*(6), 1155–1176.
97. Battisti, L., & Ricci, M. (2018). *Wind energy exploitation in urban environment*. Springer.
98. Bianco, L., Friedrich, K., Wilczak, J. M., Hazen, D., Wolfe, D., Delgado, R., Oncley, S. P., & Lundquist, J. K. (2017). Assessing the accuracy of microwave radiometers and radio acoustic sounding systems for wind energy applications. *Atmospheric Measurement Techniques, 10*(5), 1707–1721.