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Internet of Things (IoT) System for Diagnosing Power Transformer Faults using the IEC 60076-1 Standard: Review

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Abstract:- The evaluation of Internet of Things (IoT), which are contracted to research the adoption or acceptance of IoT technology, is deemed to be a subject of vital importance. Studying the adoption or admissibility of IoT technology is not a brand-new study area, and numerous scholars have undertaken the task. The current and upcoming generations of Internet are being shaped by the Internet of Things (IoT). The main aim of this survey, contrasted with previous surveys, is to systematically evaluate the IoT technology research in condition monitoring of power transformers to proffer a thorough cursor that can facilitate scholars to accomplish additional research in IoT acceptance. Almost all appliances may now be remotely monitored and connected to the internet thanks to the Internet of Things. Power transformers play a crucial role in electrical distribution networks, and their reliable operation is paramount. The existing diagnostic tests outlined in the IEC 60076-1 standard are essential for ensuring transformer health but suffer from manual procedures, leaving them susceptible to human error. This traditional method not only introduces the potential for inaccuracies due to human involvement but also incurs significant operational costs and delays. The need to physically dispatch technicians to transformer sites for routine diagnostics hampers timely fault detection and preventive maintenance. Therefore, there exists a pressing need to modernize and enhance the diagnostic procedures by integrating emerging technologies like the Internet of Things (IoT). This paper will review the most recent techniques for transformer health tracking system using IoT and highlight the contemporary approaches. A total of 50 primary research literature that was published between 2018 and 2024 were surveyed in this review paper.

Keywords:- *Internet of Things, Transformers, Sensors, Systematic Literature Review.*

I. INTRODUCTION

IoT is transforming contemporary civilization. The Internet of Things (IoT) is a network of interconnected devices that communicate with one another by sending and receiving data. Approximately 500 billion gadgets will use sensors and be connected to the Internet by 2030, according to a Cisco report [1]. Prior to recently, the internet allowed people to connect and communicate with one other, but as of late, objects have been able to sense their surroundings and exchange data with one another. IoT has impacted a number of other areas, including smart homes, agriculture, and medicines. IoT has not yet achieved significant progress in one area, which is the power system environment. Integrating communication capabilities into a network of widely scattered, heterogeneous, and closely spaced objects is the aim of the Internet of Things.

These smart devices generate data that is compiled, assessed, and dispersed for use in subsequent processes by IoT services and applications. Various data formats and protocols are carried by the Internet of Things network for various applications utilizing various technologies. IoT technologies develop and change as a result of the shifting demands of people's daily lives. Because of its limited or lossy identification, the Internet of Things (IoT) environment presents a number of issues, making data security and confidentiality crucial. Every owner of a transformer wants to maximize the efficiency and use of this vital equipment in order to maximize their return on investment. Transformer owners have historically used predictive and corrective maintenance techniques for this equipment. Corrective maintenance ensures that transformer parts are used without reservation in practice, but it comes at a cost to the utility in terms of labor, downtime, and non-routine maintenance requirements. By carrying out preventive maintenance, which involves determining the lifespan of specific parts and carrying out maintenance before the actual breakdown occurs, a number of utility owners have been able to advance. Although the high costs of labor, planned downtime, and underuse of the component during its operational lifespan persist, this strategy prevents unanticipated and catastrophic failures. Utility owners are now leaning toward developing a predictive maintenance model that improves the maintenance cycle and counteracts a corrective and preventative maintenance approach, thanks to the development of the Internet of Things (IoT) technology. Just-in-time component replacement is a strategy used in predictive maintenance. By reducing unplanned maintenance and labor expenses, this technique extends component lifespan in addition to replacing components that are closer to failure. A detailed examination of the primary research elements of digital twin technology in transformer condition monitoring, including

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the kind of transformer or physical item, the examined transformer aspect, the digital model platform, the communication channel, the cloud, and the type of digital twin, is conducted.

II. LITERATURE SURVEY

The work in [8] examined the current, voltage, temperature, moisture, and oil level of a 3-phase oil immersed power transformer. Node-MCU was used as the microcontroller which was embedded with 4 sensors namely: Temperature & Humidity sensor, Current sensor, Voltage sensor, IR sensor.

[9] Examined the current, voltage, temperature and oil level of a power transformer using ESP32 as the microcontroller with the 4 sensors embedded. Blynk App was used as the cloud and GSM was used to send SMS's of abnormal conditions to the operators.[10] designed a health management system of a distribution transformer. ThingSpeak was used for examining the graphical signatures of ambient temperature, winding temperature, oil temperature, Current, Voltage and Oil level. This was done by 7 sensors embedded to a microcontroller and ThingSpeak used for, storage, processing, and display.

[11] Examined graphical signatures generation tool to monitor 5 power transformer parameters viz: Current, Voltage, Oil level, Winding temperature, and Ambient temperature. This was done by enabling early fault detection measurements. Pushing Box was used to notify operators of any parameters exceeding pre-defined values. Wi-fi was used for wireless communication and LPC2132 module as the main processor.

[12] Examined optimal protection of a power transformer using IoT. ESP32 microcontroller was used with 2 sensors embedded on it. The 2 sensors used were temperature and flow sensors. [13] examined voltage, current, oil level, and oil temperature of a power transformer using ESP 8266 microcontroller which was embedded with 4 sensors viz, voltage, current, oil level and oil temperature sensors. [15] Used long range communication protocols to effectively monitor transformers and their real time parameters. GSM was used to send notifications for any parameters exceeding pre-defined values. From the literature it was ascertained that papers conducted excellent work in monitoring electrical parameters for transformers. However, it was discovered that not a single paper used this data to perform electrical routine tests outlined in IEC60076-1 standard. This remains a research gap that can be explored further.

III. INTERNET OF THINGS

The term "Internet of Things" (IoT) describes a group of gadgets that are linked to the internet in order to send and receive data [22]. With the advancement and simplification of daily tasks, IoT has now permeated human existence. Up until recently, only computers, laptops, and cellphones could connect to the internet. Almost any equipment may be remotely monitored and connected to the internet thanks to the Internet of Things. IoT is a significant advancement in artificial intelligence and a step toward integrating into contemporary culture. Due to their widespread application in digital systems, electronics, and equipment, they also grew to be a significant component of the engineering sector. IoT consists of a large network of interconnected devices. These digital technology tools gather information, process, and evaluate it, and then do the tasks in accordance with the configurations of the programs, as illustrated in Figure 1. The sensors, which are covered in more detail below, enable this. Wireless networks abound on IoT platforms. An Internet of Things (IoT) environment is made up of networked devices with sensors, CPUs, and other complex hardware that are connected to the internet and use that data to transfer, gather, and act upon it. IoT sensors take measurements of physical quantities, sending the data to an MCU for processing and analysis. The MCU then sends the data to the cloud for additional processing and storage. The IoT system responds to any anomalies it detects by executing program configurations.

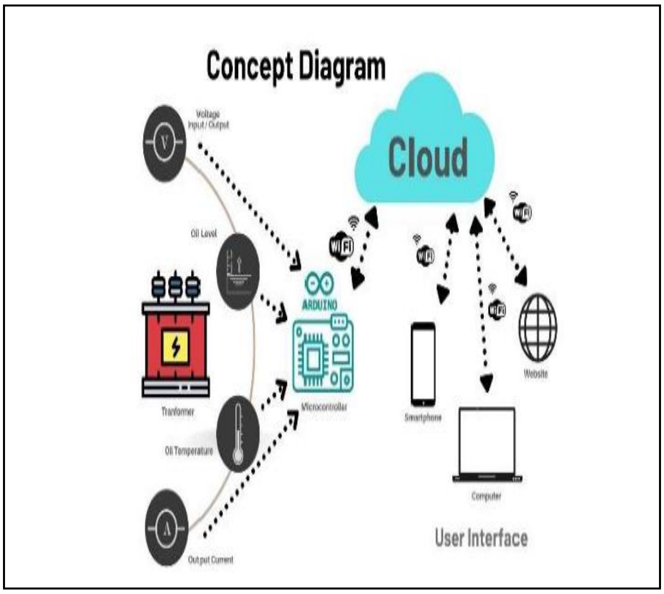

Fig 1 IoT System Layout Diagram. [17]

IV. METHODOLOGY

The present systematic literature review (SLR) has established inclusion and exclusion criteria. The four methods used to complete this review were data coding and analysis, quality valuation, search strategies, and scholarly work sources. The first step of laying the groundwork is included in the systematic literature review (SLR) created in this work, while the survey procedures consist of designing, carrying out, and assessing the survey. The steps in the procedure were picking the search query, assessing the caliber of the academic literature, identifying the most important research, gathering information, recording the review, and, finally, carrying out validation. Furthermore, since the research subject immediately sets the reference framework for the study, it is a crucial step in the systematic literature review process. It is stressed to combine a search approach that prioritizes conducting the preliminary

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investigation. After this process is finished, more effort needs to be done in order to create a plan for determining the search criteria and making sure that the preliminary study is linked to the SLR.

➢ *Proposed Inclusion and Exclusion Criteria*

For this survey investigation, only academic works that meet the suggested inclusion and exclusion criteria listed in Table 1 will be looked at. This table guarantees that the literature choice is in line with the goals and parameters of the study.

Table 1 Proposed Inclusion and Exclusion Criteria

Criteria	Inclusion	Exclusion
Topic	Must pertain to Internet of Things technology in electrical transformer condition monitoring or fault diagnosis	Articles unrelated IoT technology for transformers
Research Framework	Must include a research framework or methodology	Articles lacking clear research. framework
Language	Must be written in the English language	Articles published in languages other than English
Publication Period	Must be published between 2014 and 2024	Articles published outside the specified timeframe

➢ *Scholary Work Sources*

A comprehensive search of published academic publications was done using Google Scholar (GS), IEEE Xplore (IX), Science Direct (SD), Emerald Insight (EI), Springer Link (SL), Wiley Online Library, Taylor & Francis Online (TFO), and ELSEVIER repositories in order to gather the literature for this SLR. The search phrases used to find relevant information were derived from the terms created in Table 2.

Table 2 Proposed Keyword Search

Keywords search
Internet of Things (IoT) "Transformer Monitoring" or "Electrical Transformer Condition" or "Transformer Maintenance" or "Transformer Management". "Condition Assessment" or "Transformer Health" or "Transformer Diagnostics" or "Transformer Data Analysis". "Predictive Maintenance" or "Transformer Performance" or "Transformer Reliability".

V. RESULTS AND DISCUSSION

The current SLR looks at 50 research projects that were carried out between 2018 and 2024 and use IoT technologies to diagnose transformer faults. The analysis of the published sources in Figure 2 shows how widely the literature on IoT technology for electrical transformer status monitoring is distributed. Journal papers make up most of the landscape with 26 publications, whereas conferences only account for 24 publications.

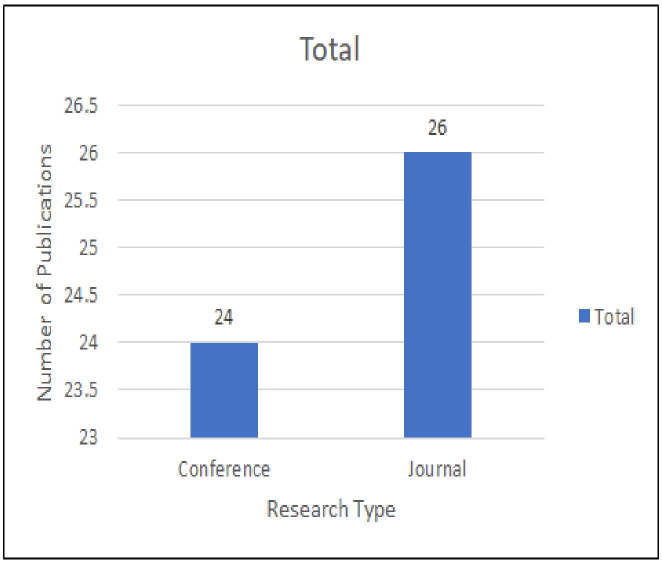

Fig 2 The Primary Research Publication Sources

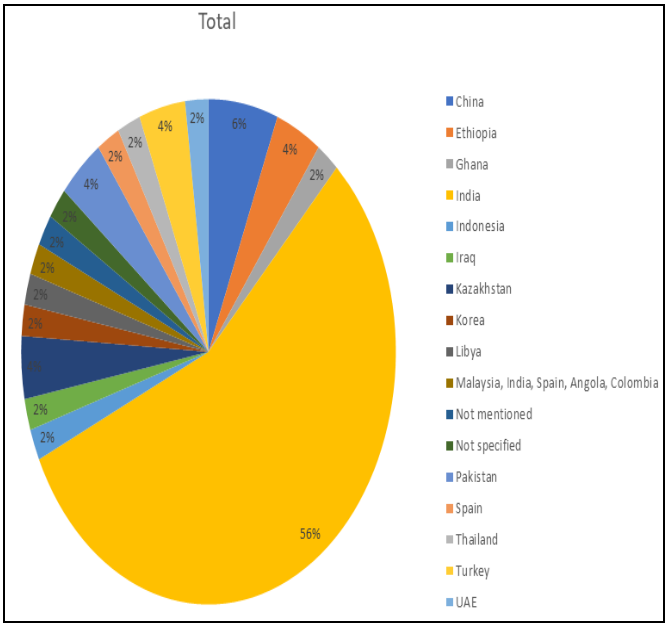

Fig 3 The Primary Countries of Represented Publication Sources

The regional distribution of research contributions in the field of Internet of Things technology for electrical transformer status monitoring is depicted in Figure 3. Of these, India accounts for 56% of the total donations, suggesting a substantial concentration there. India has made significant research efforts and has actively contributed to the growth of this technology, as evidenced by its dominance. Even though India leads by a large margin, other countries make substantial contributions as well, albeit on a smaller scale. China shows a strong interest in this industry as seen by its 6% contribution and the 5% contributions from Ethiopia, Indonesia, and Kazakhstan.

The examination of the tools used in the research on IoT technology for electrical transformer status monitoring reveals a wide range of IoT platforms and software solutions. Among the solutions that are used more commonly is the

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Arduino IDE software. This program is well renowned for its capacity to set up third-party microcontrollers and Arduino boards. Researchers seem to prefer it because of its adaptability and ease of usage. Figure 4 shows that the communication channel that was most popular was Wi-Fi. Due to the current infrastructure's ideal application for close-quarters communication. Figure 5 showed that the researchers' top choice for an IoT cloud was ThingSpeak, most likely because it is an open-source program that lets users aggregate, visualize, and analyze real-time data streams on the cloud. Finally, as Figure 6 illustrates, the Arduino Uno board was the microcontroller of choice for the majority of researchers.

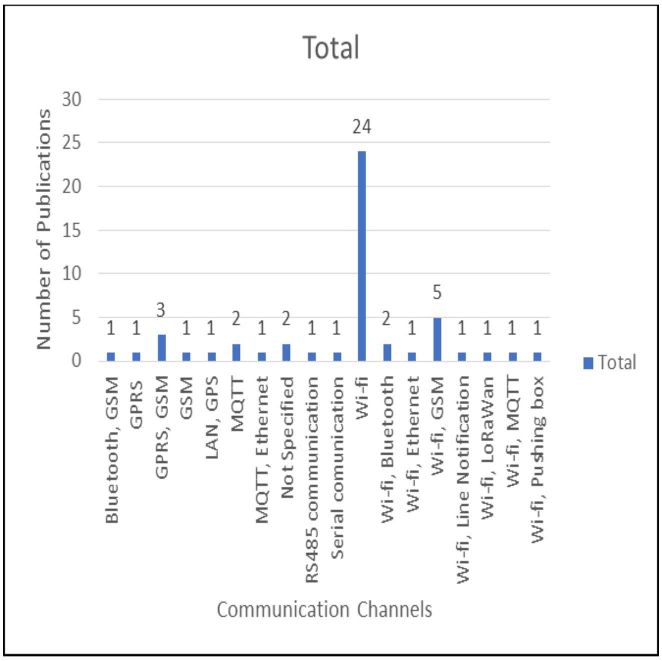

Fig 4 The Communication Channels

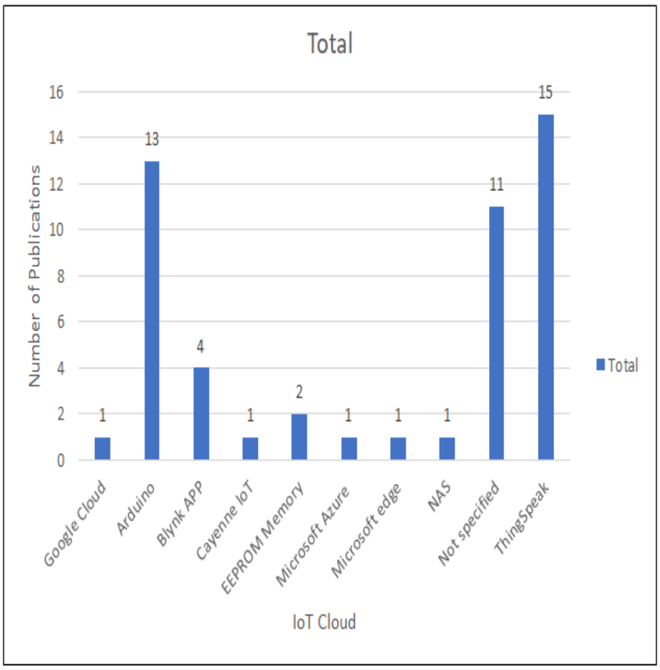

Fig 5 The IoT Cloud Platforms

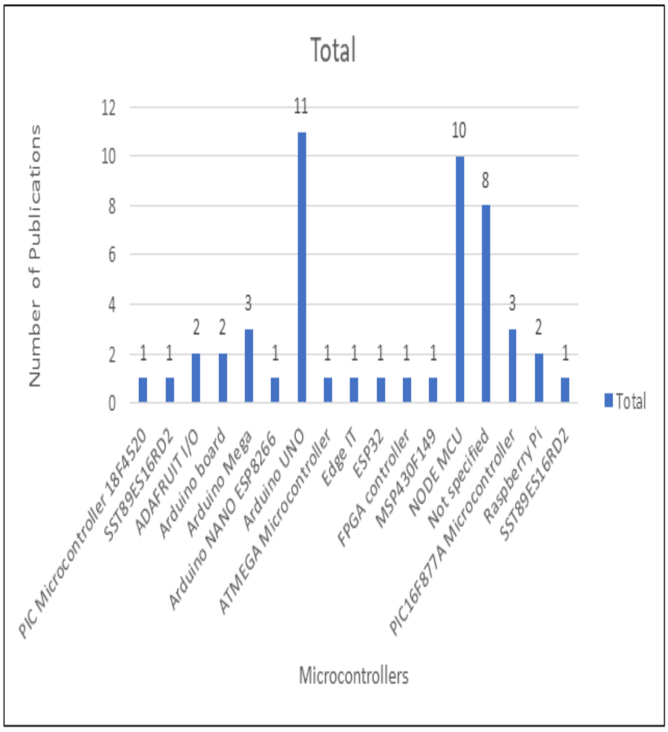

Fig 6 The Microprocessors

VI. DIAGNOSTIC TESTS

The existing diagnostic tests outlined in the IEC 60076-1 standard are essential for ensuring transformer health. Only four diagnostics from the standard are briefly discussed below viz:

➢ *Winding Resistance*

A transformer's DC resistance can reveal a great deal about itself when measured from one external terminal to another. More subtle issues can be found in addition to the obvious faulty windings (such as an open winding or shorted turn). Apart from the winding, the on-load tap changer and multiple welded and mechanical connections also need to receive the DC current. Direct current shall be used for the measurement [23].

➢ *Voltage Ratio and Phase Displacement*

The primary purpose of voltage ratio test is to find any shorted turns in any of the transformer windings due to insulation failure. This test is also used to detect any problems between the connection of windings and the selector switch of the tap changer. The voltage ratio shall be measured on each tapping [23].

➢ *Short Circuit Impedance and Load Loss*

Only short-circuit impedance is used to estimate voltage regulation, short-circuit current, and load distribution when transformers operate in parallel. To find the copper losses in a transformer at full load, perform a short-circuit test on the transformer. It can also be used to get the parameters needed to roughly represent a transformer's equivalent circuit. Load losses: These losses are often referred to as short circuit or copper losses.

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➢ *No Load Loss and Current Measurement*

Every time the transformer is activated, even when the secondary circuit is open, these losses take place in the transformer core. They are constant and also known as core losses or iron losses. They consist of hysteresis losses, which are brought about by the frictional movement of magnetic domains in the core laminations that are magnetized and demagnetized by changes in the magnetic field.

VII. IOT SENSORS

IoT sensors are hardware components that gather data and identify environmental changes. They are members of an Internet of Things family that connects the virtual and real worlds [24]. IoT sensors can be used to measure variables like motion, pressure, and temperature. They also share data with networks when they are connected to one [24]. Sensors are input devices that provide outputs concerning physical quantities. Sensors are classified as active and passive. Passive Sensors are those sensors that does not require power supply to operate whilst active sensor requires power supply to operate. IoT sensors related to the transformer health management system are discussed below-:

➢ *Voltage Sensor*

A voltage sensor is a sensor that monitors, calculates, and determines the supply of voltage. Voltage sensors are often applied to control power demand, detection of a power failure and for sensing loads. As secondary voltage of distribution transformer is single phase 230V, so it can be easily measured with the help of ZMPT101B AC voltage sensor [9]. ZMPT101B has a high accuracy, good consistency for power measurement up to 250V AC as shown in Figure. Easy to use and comes with a multi turn trim potentiometer for adjusting the ADC output [9].

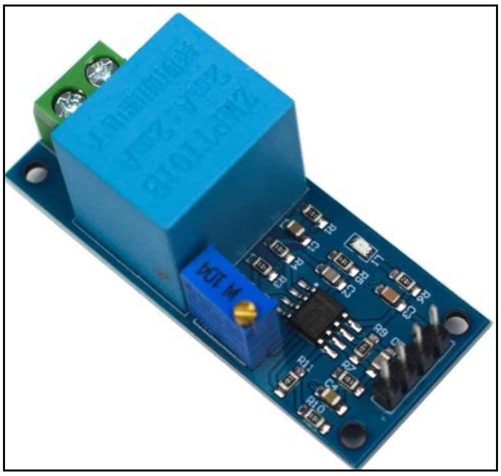

Fig 7 AC Voltage Sensor ZMPT101B [24]

➢ *Current Sensor*

Current Sensors are devices that can be used to detect electrical current in a circuit. Current sensors are often used for the metering of power, controlling of complex loads from power transformers, integration charge and monitoring batteries. The Allegro ACS712 provides economical and precise solutions for AC or DC current sensing in industrial, commercial, and communications system [9].

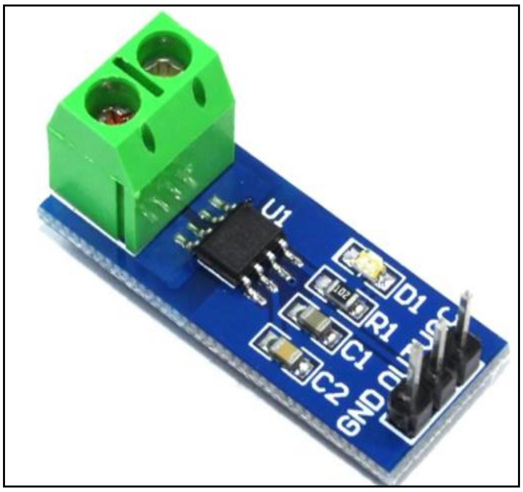

Fig 8 Current Sensor ACS712 [24]

➢ *Temperature Sensor*

Current Sensors are devices that can be used to detect electrical current in a circuit. Current sensors are often used for the metering of power, controlling of complex loads from power transformers, integration charge and monitoring. For this study, the DHT22 temperature was chosen. This digital sensor is used to determine the transformer's temperature. This sensor has been chosen because of its low cost and ability to optionally acquire ambient humidity data. It can measure temperatures ranging from -40 to 125 degrees Celsius with a resolution of 8 bits and a 2% error margin. The DHT22 has an accuracy of plus or minus 0.5 degrees and a sampling rate of 0.5 Hz, meaning one reading every two seconds. The DHT22 sensor has a working voltage range of 3 to 5 volts and a maximum measurement current of 2.5 mA.

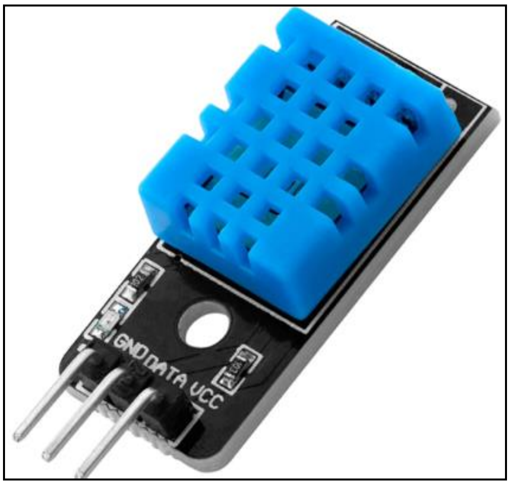

Fig 9 IoT System DHT11 Humidity Sensor [25]

➢ *Oil Level Sensor*

An instrument called an oil level sensor is used to monitor the oil level in the transformer's conservator tank. The non-contact distance sensing capability of the JSN-SR0T4-2.0 ultrasonic distance measuring module spans 20 to 600 cm with an accuracy of up to 2 mm [9]. An integrated closed waterproof cable probe is included with this sensor, making it appropriate for wet, challenging measurements.


Fig 10 Ultrasonic Sensor [24]

VIII. COMMUNICATION CHANNELS

IoT is a larger area that uses a mix of wired and wireless forms of communication as shown in Figure 11 Various IoT devices transfers and receive information, whilst some solely transfer data. Certain connections with peer devices can take place directly. It is important for remote communications to travel through a gateway before reaching their destinations. IoT communication protocols are collections of wireless networks and guidelines that link IoT devices [25]. IoT protocols enable data sharing between IoT devices. The ideal IoT communication protocol is determined by the unique needs and limitations of a given system. The following factors should be considered when choosing IoT communication protocol:

- Power consumption
- Data transmission speed
- Network and data security.
- Geographical areas These are the actual separations between two or more ecosystem-forming devices.
- Physical obstacles: These are the impediments that the IoT ecosystem's devices must overcome. For example, mountains or buildings.
- Total budget: Several protocols have varying costs.

IoT communication channels are known as pathways for devices to communicate through specific ways like servers, cables, and modules. They make it possible for devices to be implemented in communication with each other and also make it possible for different types of devices that are not the same in type to communicate with one another.

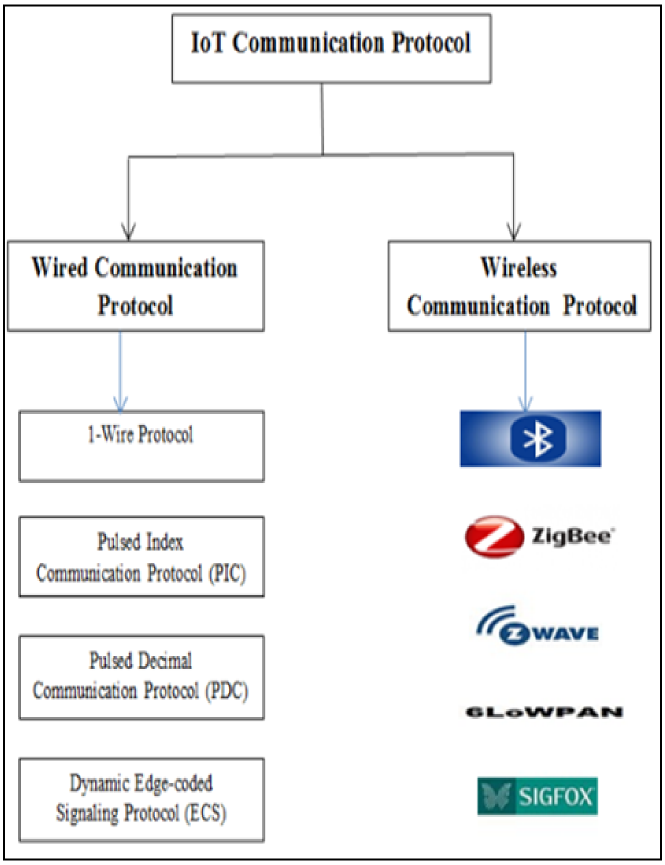

Fig 11 IoT Communication Protocols [28]

IX. IOT CLOUDS

An IoT cloud is a huge network that supports IoT devices and applications [26. It is a technology architecture that links servers located in cloud data centers to Internet of Things devices. Better information-driven decision making, optimization, and risk mitigation are made possible by the underlying infrastructure, which consists of servers and storage that are required for real-time operations and processing. The services and guidelines required to link, control, and secure various IoT devices and apps are also included in an IoT cloud [27]. An effective, adaptable, and scalable architecture for providing the services and infrastructure required to power IoT devices and applications is provided by IoT clouds. IoT clouds enable enterprises to take full use of the enormous potential of IoT without having to start from scratch with the underlying infrastructure and services since they provide on-demand, affordable hyperscale [27].

➢ *ThingSpeak*

An open-source framework called ThingSpeak makes it possible to gather and store sensor data on the cloud [28]. It gives you access to the MATLAB software for data analysis and visualization. Data from the sensors can be sent via Beaglebone, Raspberry Pi, and Arduino. To store data, a different channel can be made. The end user can gather, visualize, and analyze real-time data streams in the cloud with ThingSpeak, an IoT analytics platform service [29]. ThingSpeak can receive data from end users' devices, visualize live data instantly, and issue alarms.

➢ *Ardiuno Cloud*

An online platform called the Arduino IoT Cloud facilitates the creation, deployment, and monitoring of Internet of Things projects [30]. It makes it easy to create, administer, and install linked apps on compatible hardware. Furthermore, it is possible to create an elegant dashboard for gathering, presenting, and modifying data from IoT devices. Three simple-to-use tools are included in the Arduino Cloud toolbox, which facilitates the creation, monitoring, and updating of linked IoT projects during their whole lifecycle. The end user can aggregate variables from linked devices using the Arduino IoT Cloud. After that, a completely customized dashboard with the variable values and aggregation results is displayed. The functionality of the offline, traditional Arduino IDE are also available in the web editor [31]. On the other hand, it makes it easy for the end user to transport all drawings and libraries and access them from any PC connected to the Internet [31]. There is a free plan available on the Arduino Cloud that can be used indefinitely. However, the end user must purchase a premium package in order to get more advanced capabilities like over-the-air upgrades.

➢ *Amazon Web Services*

With its well-established and scalable infrastructure, which can accommodate billions of sensors and trillions of IoT data, Amazon offers a comprehensive range of cloud IoT services. There are several uses for the Amazon IoT platform, including business, industrial, and consumer ones [32].

➢ *Microsoft Azure IoT*

When utilizing Microsoft Azure IoT solutions, the end-user can select from pre-customized working flows or develop a specific project according to the project's requirements. Every aspect of IoT development and design is covered by the adaptable Microsoft Azure IoT Suite, from connecting devices to giving decision-makers insights. One of its biggest advantages is the significance of security.

X. MICONTROLLERS

Typically, electronic devices are controlled by microcontrollers, which are tiny computers [33]. Its low power consumption, affordability, and ease of integration into many devices make it a popular choice for Internet of Things (IoT) applications. A microcontroller is a single chip including input/output components, memory, and a processor. The memory holds data and programs, the processor executes instructions, and the I/O components enable the microcontroller to interact with its surroundings through sensors and tools [33]. There are numerous microcontrollers on the market, each with unique characteristics and functionalities. In an Internet of Things application, programming languages can be used to provide instructions to a microcontroller. A PC, USB, or serial port connection can be used for this. Following programming, the microcontroller can interface with other devices or establish a wireless, Bluetooth, cellular, or internet connection. Microcontrollers, which are tiny computer chips, are widely utilized in Internet of Things (IoT) systems to monitor and manage various systems and objects. They are commonly found in actuators, sensors, and other electrical components. They help control the device's operation and behavior during data processing and transmission. In an IoT system, microcontrollers are essential for establishing connections with and exchanging data with other devices and systems. They gather, process, and transmit sensor data to other systems or devices via wired or wireless communication protocols. They can also understand and receive commands and control signals from other devices, which they can employ to direct the embedded device's actions and behaviors. Microcontrollers' tiny size, inexpensive cost, and low energy consumption make them ideal for use in Internet of Things (IoT) applications. They are appropriate for a wide range of IoT applications since they can be configured to do a wide variety of functions. Because they consume less energy, they are also excellent for battery-powered gadgets [33]. Commonly used microcontrollers are briefly discussed below-:

➢ *ESP32*

Due to its quick CPU, low power consumption, Wi-Fi and Bluetooth capabilities, and portability, ESP32 is a great option for Internet of Things applications [33].

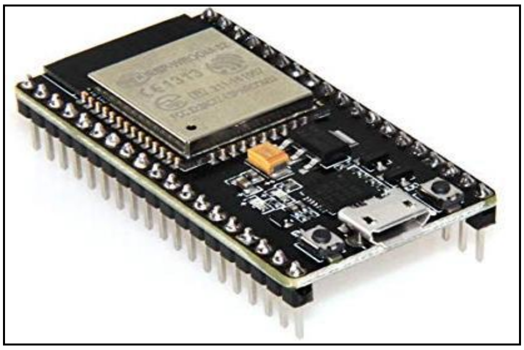

Fig 12 IoT ESP32 Microcontroller [26]

➢ *Arduino Boards*

Because Arduino boards are inexpensive and simple to use, they are a popular choice for Internet of Things projects. They accept several programming languages and offer a plethora of functionality, including digital and analog inputs and outputs [33]

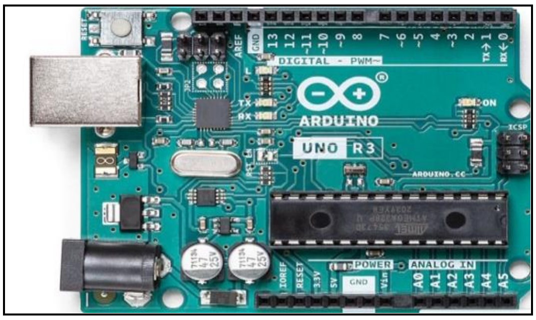

Fig 13 IoT Arduino Board Microcontroller [26].

➢ *Raspberry Pi*

Because of its adaptability and capacity to run a full operating system, the Raspberry Pi is a small, inexpensive computer that has gained popularity in IoT projects. It can construct a wide range of IoT devices, from basic sensors to intricate systems [33].

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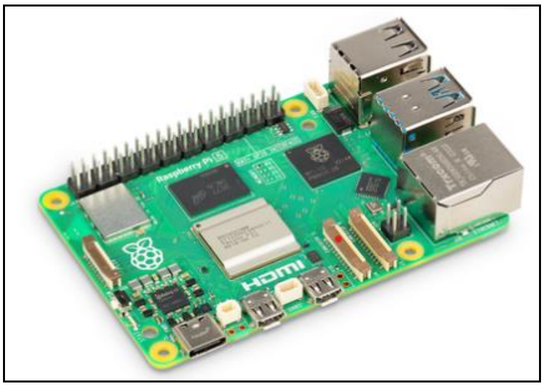

Fig 14 IoT Raspberry Pi Microcontroller [26].

XI. CHALLENGES

As can be seen, efficient connectivity and coordination between sensors, signal conditioning equipment, and internet connections are prerequisites for the full module of transformer health monitoring systems to operate well. In this case, the longevity and dependability of the sensors and linked networks are the main issues. It is established that environmental elements and underdeveloped data connection infrastructure have an impact on these factors. The fact that millions of data points from various sources are reported to the same cloud within a specific time frame raises further concerns about cloud storage. Furthermore, a negative issue could arise from a cloud data dump. Under such circumstances, it's possible that the appropriate safety signals won't be generated in a timely manner, that further safety notifications won't be generated, and that message delivery will fail. In some cases, the transformers and any linked systems could sustain significant damage because of the unreported defects. Authors are still not paying attention to the research on these concerns [5]. The following fundamental reasons are recognized as the main reasons for transformer failures based on numerous investigations and analyses of power and distribution transformers.

XII. CONCLUSION

Ultimately, this systematic literature review (SLR) provides an extensive overview of the current status of research on Internet of Things (IoT) technologies in the context of electrical transformer condition monitoring. Using a rigorous approach that involved creating inclusion and exclusion criteria, finding academic works from multiple trustworthy repositories, and undertaking quality assessments, this study looked at 50 research articles produced between 2018 and 2024. The investigation also covered the IoT clouds, microcontrollers, communication routes, and software tools used in this field of study. The most popular software for programming microcontrollers is now the Arduino IDE. A significant discovery was the way the research environment changed over time, with a discernible rise in the number of studies between 2021 and 2023. This increase points to a developing knowledge of IoT applications in transformer monitoring, motivated by the realization of its possible advantages. The above discussion showed that this study holds significance in revolutionizing the field of power transformer diagnostics by introducing an innovative IoT-based approach. By automating and optimizing the diagnostic process, the IoT transformer health tracking system will enhance the accuracy and reliability of fault detection while minimizing operational costs. The study's outcomes are expected to contribute to improved power system reliability, reduced downtime, and advancements in industry standards, offering substantial benefits to power infrastructure operators and stakeholders. From the explanation above, it was clear that using the internet to support online health monitoring yields more accurate and superior findings than using more conventional techniques. Additionally, it has been noted that detecting errors takes less time and prevents catastrophic system failures.

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