Advanced Energy Forecasting Using IoT-Enabled SCADA Systems

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***Abstract*—With the substantial increase in global renewable energy production, real-time data has become essential for the efficient management of these resources particularly offshore and distant installations. A supervisory control and data acquisition system is a system that sends individual messages or directives to the external world. In this research paper, we introduce a SCADA system integrated with the Internet of Things (IoT) to monitor a hybrid system that includes hydropower, solar energy, wind, and tidal power. It provides a range of control functions for supervisors to manage and configure settings effectively. The goal is to achieve energy autonomy and promote sustainable economic growth. This technology makes it easier to administer the warning system, data logging, data monitoring and control system, and generated capacity, among other features of the station's information. Additionally, a data packet and WiFi analyzer are used to measure the communication parameters and overall performance of the Internet of Things-based SCADA system. In addition, historical energy generation data is used to evaluate and identify what factors are impacting the output of hydropower stations. This data is then utilized to forecast the production levels for the upcoming year through the application of time series analysis.**

***Index Terms*—Operation and maintenance, wind turbine (WT), condition monitoring (CM), Artificial intelligence (AI), wind farms (WFs), Master Terminal Unit (MTU), Remote Terminal Unit (RTU), and Programmable Logic Controller (PLC), HTTP (Hypertext Transfer Protocol)**

I. INTRODUCTION

The increasing worldwide focus on sustainable energy solutions has driven the development of renewable energy sources such as hydro power, solar energy, wind energy, and tidal power. As these sources become essential components of our energy infrastructure, the significance of SCADA (Supervisory Control and Data Acquisition) systems has increased significantly. SCADA systems provide extensive control and monitoring features that improve the efficiency, dependability, and safety of renewable energy operations. SCADA systems enhance the efficient use and monitoring of energy resources by incorporating advanced data analytics, real-time monitoring, and remote-control features [1]. This introduction explores the application of SCADA technology in different renewable energy areas, emphasizing its crucial role in advancing environmentally friendly energy solutions. Hydroelectric generating facilities use SCADA systems to monitor and control water flow, reservoir levels, and turbine operations. They optimize the conversion of water energy into electrical energy by altering turbine settings according to water supply and demand. SCADA systems provide real-time information on hydraulic conditions, preventing problems such as overflows or insufficient water levels. By offering precise control of turbines and generators, SCADA systems enhance the reliability and efficiency of hydroelectric power generation. In addition, they enhance environmental conservation efforts by optimizing water utilization and minimizing the effects on aquatic ecosystems [2]. On the contrary, Tidal energy systems, which utilize the energy from ocean tides to produce electricity, depend on SCADA systems for efficient functioning. SCADA systems manage the operation of tidal stream generators and adjust turbine positioning to maximize energy capture from tidal flows. They monitor variables such as tidal speed, water pressure, and generator performance to ensure optimal functioning. The capability to adapt to thecyclic nature of tides in real time aids in maintaining consistent energy production. Additionally, SCADA systems offer remote monitoring and diagnostics, crucial for maintaining tidal power facilities often located in challenging and hard-to-reach marineenvironments [3].

Wind turbines are monitored and controlled by SCADA systems, which track important parameters like wind speed, turbine blade angle, rotational speed, and power output. SCADA systems utilize real-time data collecting to maximize energy capture from fluctuating wind conditions by adjusting turbine settings. Additionally, They also play a crucial role in maintenance by predicting potential failures and scheduling timely interventions, thereby minimizing downtime and reducing maintenance costs. Moreover, SCADA systems provide remote monitoring and control, which is particularly beneficial for offshore wind farms where accessibility can be difficult [4]. SCADA (Supervisory Control and Data Acquisition) is essential for maximizing the performance of photovoltaic (PV) panels in solar energy systems. SCADA systems constantly monitor multiple factors, including solar irradiation, panel temperature, and electrical output. They gather real-time data to assess the effectiveness of individual panels as well as the overall solar farm [5].

By offering comprehensive information, these systems empower operators to quickly identify concerns such as shading, dirt buildup, or faulty panels. Furthermore, SCADA systems facilitate the anticipation of energy generation by utilizing weather forecasts and historical data, so enabling improved integration with the power grid and boosting overall energy management. Integrating SCADA systems into renewable energy sources allows operators to improve the reliability, efficiency, and sustainability of energy production, making a substantial contribution to the worldwide transition to green energy.

II. LITERATURE REVIEW

The (SCADA) system has found extensive application in various areas, including water supply, home automation, industrial control, energy power generation, and distribution. The Human Machine Interface (HMI) is currently employed as a practical monitoring method in power stations. In modern times, the majority of automation control systems and industrial control systems employ (Internet of Things) IoT devices to remotely monitor and regulate systems through the Internet from any location[7].

A. Hydropower Plant

An IoT-based SCADA system is suggested as a way to gather information and control hydropower station generators. The main objective of Internet of Things (IoT)-based SCADA systems is to create a user interface that enables users to access real-time power plant information and control them from any internet-connected location. The Master Terminal Unit (MTU) and Remote Terminal Unit (RTU) of the Internet of Things-based SCADA system are linked via a wireless network. The system's success is primarily determined by the efficiency of its data transmission and receiving process. Users utilized the packet sniffer approach, specifically the Wireshark tool, to analyze and monitor network traffic over the internet [6]. The SCADA system may experience a disruption in its operation due to a bottleneck in data traffic caused by the presence of malware threats and attacks. Hence, the Wireshark tool is employed to test the data traffic and assess the condition of the SCADA network. Tools for network performance such as analyzer Wi-Fi, InSSIDer, Netspot, and Xirrus are used to evaluate the signal strength of a wireless network. This study evaluates and examines the efficiency of the IoT-based SCADA system through the utilization of the data packet analyzer Wireshark. Additionally, the Netspot WiFi analyzer is used to assess the RTU's position in relation to the Internet Service Provider (ISP). The historical data from the SCADA system can be used to analyze the operation of the hydropower station. In Ecuador, the ARIMA time series model is used to forecast the output of hydropower stations [7]. Most authors looked at smart technology and power consumption, gathering profiles of electricity use and evaluating the load demand for electricity. In order to obtain electricity consumption profiles—which are essential for maintaining equilibrium in developers' power purchase and sales portfolios—smart meters were utilized. The trader has a significant risk due to the estimated power consumption, as any errors in the estimation directly affect the potential gains and losses. Additionally, the accuracy of electricity output forecasts is closely tied to the progress of industrial projects in emerging countries. Consequently, understanding the condition of the hydropower station is essential for obtaining information about the station. This research utilizes an IoT-based SCADA system to gather information about the station, control the power generator, analyze the performance of the generation plant, and predict load optimization using the least square line regression method of time series analysis [8].

B. Tidal Power Plant

Tidal stream technologies use the forces of attraction of the sun, moon, and earth to control the flow of coastal tidal waters. Geographical characteristics like inlets, straits, and headlands, which restrict the flow and increase its velocity, are the source of fast-moving currents [9]. One benefit of tidal flows is that they are very predictable: the motions of the sun and moon, and consequently the tides, can be precisely determined for several centuries ahead. It is relatively straightforward to calculate the power output at any given time. It is important to acknowledge that tidal streams only occur when there is a change in tide, namely while transitioning from low to high tide in nearby areas. Additionally, these tidal streams change direction two high tides and two low tides occur four times a day. Most devices are designed to work bidirectionally, meaning they can function regardless of the flow direction. During periods of reduced flow and flow direction changes, these devices often generate little or no power [10]. This factor must be taken into account in any analysis of the economic viability of the tidal power project. Pakistan has a very long coastline of 1046 Km along with the Arabian Sea but it does not have strong tides for the generation of electricity like the Bay of fundy in Canada. Indus Delta and Makran Coast are the Pakistani coastal areas that have less potential. For the generation of electricity minimum tidal range must be 5 meters for the electricity but in Pakistani coastal areas tide range is 2 to 3 meters which doesn't have the potential for the generation of electricity. The Indus Delta and Makran coastal areas have a maximum of 4 feet high tides but it is not constant. Canada is playing a crucial role in the generation of electricity by tidal energy due to its being the best coastal area in the world for having the highest tides which is more than 16 meters. Bay of Funday can produce 2500 MW which is enough to supply 70000 houses with electricity, but currently, Canada produces 40 MW from tidal energy. Tidal power facilities require automated control to be managed and protected. To accomplish this goal, a Programmable Logic Controller (PLC) will be used [11]. The American auto industry had special requirements; thus, the Programmable Logic Controller (PLC) was created to suit those needs. General Motors' automatic transmission business, GM Hydramatic, issued a request for ideas in 1968 regarding an electronic substitute for the traditional hard-wired relay systems. A programmable memory is used by the system to store instructions and perform specific tasks like on/off control timing, counting, sequencing, arithmetic operations, and data handling. PLC is a highly potent instrument employed for control in hydropower. PLC provides a convenient means of controlling and monitoring the power station [12].

C. *Wind power plant*

In response to the challenges posed by global warming, scientists are searching for alternate energy sources, and renewable resources are demonstrating promise as a potential replacement for traditional energy produced from fossil fuels. Among the various renewable energy sources, wind energy stands out because of its unique characteristics. Acknowledged as the ”fastest growing renewable energy source worldwide,” it has grown at an average yearly pace of thirty percent over the previous two decades. A recent report published by the international agency Global Wind Energy Council states that the generation of electricity from renewable energy sources will be increased by almost 98 percent which is 2,518 TWH by 2025 and in this 130 percent is offshore. In China, 300 offshore wind energy will be installed, while in Europe, 100 offshore wind energy will be installed which will decrease the energy crisis in the world. From 2023 to 2025, 60 GW of offshore wind will be included globally, pivotal in optimizing electricity generation worldwide, and 68 GW from 2026 to 2028. According to BloombergNEF (BNEF), the wind energy will be reached at 1 TW by the end of this year. It took 33 years for the completion of 1 TW. GWEC has the intention to install another 1 TW wind energy by the end of 2030 (Figure 1).

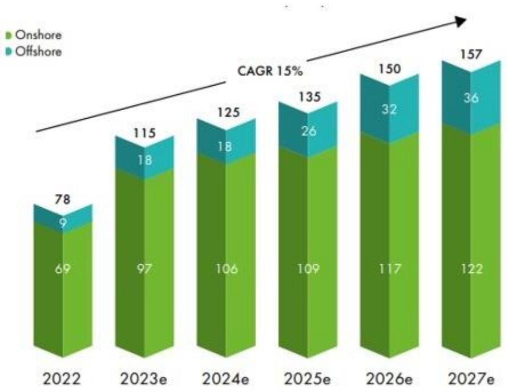

Fig. 1. GWEC report install onshore and offshore wind energy from 2022 to 2027

As the wind industry expands, the technology will advance and the costs of wind project installation will decrease. Offshore wind farms (WFs) have distinct advantages over onshore ones, including more consistent and powerful wind speeds. However, it is evident that these WFs operate under challenging settings, namely in remote marine environments. Nevertheless, specific land-based wind farms can also be located in challenging intricate landscapes, endure severe temperatures (either extremely low or very high), cope with high levels of humidity, and are situated in remote locations [13]. Consequently, additional difficulties arise in the transportation, installation, and functioning of these wind turbines (WTs). As previously stated, the challenging accessibility of WFs and their distance from control centers result in elevated operation and maintenance (OM) expenses. Various criteria for the expenses of operation and maintenance for wind farms have been proposed in the scientific literature. According to the authors, offshore wind farms have operational and maintenance expenditures that make up 30 percent of the overall expenses over a 20-year lifespan. Operational and maintenance (OM) tasks are estimated to make up to 23 percent of the overall expenses for offshore wind farms. According to the information provided, the operations and maintenance (OM) costs accounted for around 20 percent to 25 percent of the entire cost of electricity generation for offshore wind farms and between 10 percent and 15 percent of onshore wind farms' overall cost of production, respectively. The writers concluded that between 25 and 35 percent of the total cost of electricity generation may come from the operation and maintenance of wind farms. The OM cost percentages may be elevated due to frequent failures in various componentsof a wind turbine [14]. Hence, it is crucial for owners and operators of wind farms to promptly identify probable wind turbine failures and develop a suitable maintenance plan to make informed decisions. Therefore, ensuring proper condition monitoring (CM) of the WT is crucial. CM, or Configuration Management, can be defined as the process of manually or automatically observing the current state of a component. Therefore, during the first phase of a component, condition monitoring (CM) can effectively serve as a dependable indicator of the existence of a failure, enabling proactive planning and minimizing downtime. Several scholars have attemptedto identify the most crucial elements in a WT. There have been limited reliability studies undertaken to address this issue. The most important parts, according to the research are the hub and blades, generator, gearbox, electric system, and control system [15]. Thirteen tests of reliability, comprisinga breakdown of the downtime and failure rate for thirteenWT sub-assemblies, were presented and analyzed in a recent review that was published. The figure displays the average of these investigations, which has been calculated 2 down below. According to Figure 2, The equipment with the highestfailure rates is the electric and control systems. When it comes to downtime, the gearbox is the most important component, followed by the generator, electrical system, and brake system.

With the help of a variety of sensors and different types of data (parameters or signals), condition monitoring systems (CMSs) collect information about different wind turbine (WT) components. Multiple studies have thoroughly examined the technological solutions, applications, approaches, benefits, and other aspects of CMSs. The majority of these studies have found that their use is limited due to cost and technical complexity [16]. Recently it has been proposed that monitoring wind turbine conditions with SCADA data is an attractive option.

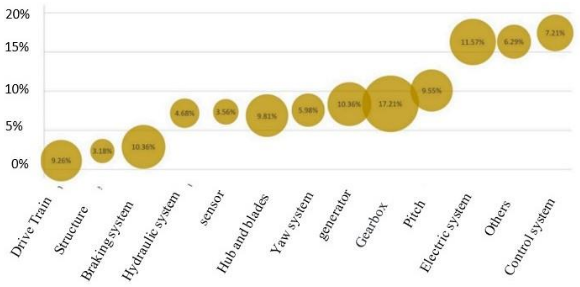

Fig. 2. Average component failure rate of wind turbines (WT)

Contemporary wind turbines typically capture over 200 different variables at 1–10 intervals in minutes through their SCADA systems, resulting in a wealth of historical data. By employing suitable data processing techniques, the dataset can be transformed into valuable information for condition monitoring (CM) and, consequently, wind turbine (WT) fault prediction [20]. The current study involved conducting a systematic literature review (SLR) which uncovered a significant number of works on condition monitoring (CM) and early failure prediction in wind turbines (WTs) utilizing SCADA data. This work’s contributions can be summarized as follows: 1. A systematic literature review (SLR) is conducted to evaluate the prevalent methodologies and algorithms employed in condition monitoring (CM) and predicting wind turbine (WT) failures using SCADA data. The suggested approach for the systematic literature review (SLR) can be extended to additional domains within wind energy research. 2. The SRL process involves posing and answering four research questions to produce a classification for the most relevant research papers. The classification is based on the following criteria: • The problems of the present WT CM are highlighted and categorized based on the specific technique and type of data utilized. • The various components or subsystems of WT that have been subjected to CM are recognized and categorized using different methodologies. • The analysis and classification of the most frequently used SCADA variables for condition monitoring of wind turbines are based on their quantity and sample frequency. • The text includes the most important studies published in the past three years that discuss the use of artificial intelligence (AI) approaches in content management systems (CMSs) to identify and categorize faults in wind turbines (WTs). Additionally, the authors discovered a requirement for easily obtainable SCADA data from functioning wind turbines for the purposes of study and the establishment of data standardization [17]. The wind power plant’s next sections are structured as follows: They also feature the conceptual mind map, research questions, and semantic search structure in addition to a comprehensive description of the SLR approach.

D. Photovoltaic plant

In order to achieve effective monitoring, the PV plant requires both accurately calibrated equipment and a range of supplementary devices. These auxiliary systems need to integrate with measuring components in order to optimize their performance. Both systems would form the SCADA of the plant. SCADA systems frequently encounter complex difficulties that are difficult to resolve using conventional solutions:

• Interoperability: PV plants require enhanced horizontal and vertical integration, as well as efficient system interoperability [18]. An enormous inventory of devices and manufacturers makes up the monitoring infrastructure. These devices are precisely adjusted for a certain set of measurements and are capable of communicating using various protocols, which may be legally mandated in some cases. When multiple plants need to be monitored, vertical integration becomes essential, even when different installation companies or different technologies result in different SCADA systems [19]. • Management: monitoring and upgrading of industrial infrastructure or devices, proactive maintenance methods can be implemented in place of reactive solutions. In order to fulfill this objective, effective communication technologies are essential, as the plants are typically expansive and secluded, necessitating remote supervision. Communications are necessary for video surveillance and are commonly used by energy providers to remotely view the plant’s meter. The overall network load is quite high, and the connections often suffer from insufficient quality due to the plant’s isolation. • Processing: The SCADA systems and monitoring infrastructure must have the ability to deliver reliable data. For a reliable Real-Time analysis, it is necessary to collect data at a frequency of 1 s or higher. If the monitoring devices do not provide relevant metrics, the data can be utilized to build metrics that are important for the monitoring system, like the plant’s power ratio or the total amount of energy produced. Additionally, the scalability of the system is highly flexible, allowing for the creation of PV installations ranging from small-scale self-consumption setups to large-scale plants with hundreds of MW of installed power. A photovoltaic monitoring solution must be able to accommodate these use scenarios without oversizing. In order to address the difficulty of interoperability, the infrastructure must be future-proof. This means that it should be capable of facilitating interaction between both legacy and new systems. Failure to do this could limit the scalability of the infrastructure. • Cost: The expenses associated with industrial deployments are always taken into account, including both the original and ongoing maintenance expenditures. Since most monitoring devices must be used outside in hard, isolated conditions and are exposed to the sun and dust, the maintenance costs must also account for the equipment's endurance. The requirement for low-power systems is another. This need is not imposed for reasons of autonomy, but rather because consumption has a direct impact on the PV plant's overall output. These difficulties would probably require a specialized and scarcely expandable development. This is the situation with a few of the newest monitoring systems out there. Under these systems, industrial PCs gather data locally, and providers' applications are used to access it. The entire platform lacks external system integration and is proprietary. Additionally, they can require specific. The levels of the Internet of Things (IoT) architecture are shown in Figure 3. Depending on the particular implementation, the Platform and Gateway's functions may be distributed differently [20]. Sometimes visualization tools and the measuring components and sensors are quite basic or hardly adjustable.

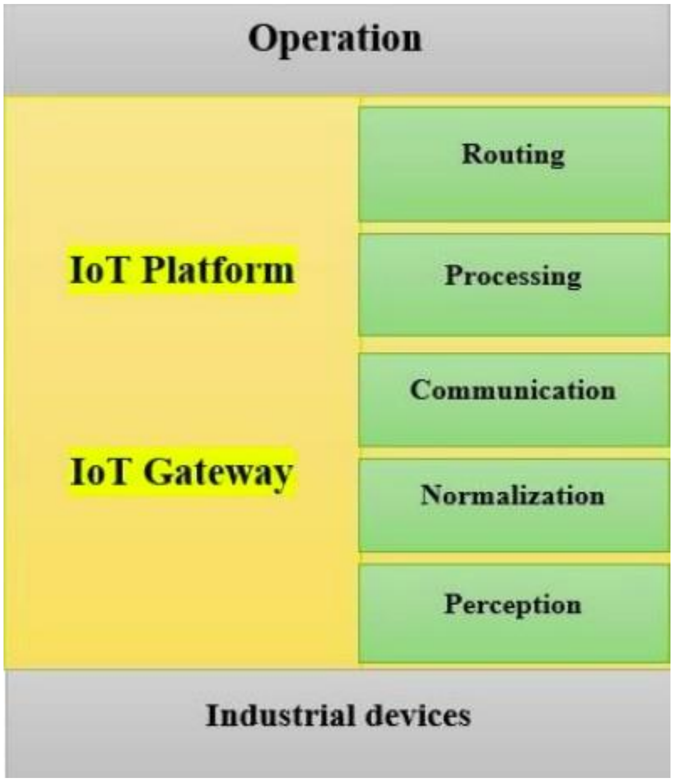

Fig. 3. Layers of IoT architecture. Gateway and Platform have different functionalities depending on how they are implemented

However, a more general approach can still be customized for certain applications inside IoT design structures. They can use IoT technology to solve problems like reducing electrical use. Utilizing single-board processors that retain the required high level of computing for an ideal solution can help achieve this. There are other advantages that will be discussed later.

III. METHODOLOGY

A. HydroPower Plant

An Internet of Things (IoT)-based SCADA system's hardware and software implementation seek to use a mobile wireless network to manage a hydropower plant and collect historical data remotely. By using electronic sensors, communication between RTU and MTU is possible. A conceptual image is shown in Figure 5, of how the SCADA system based on IOT might be used in controlling and monitoring. This system consists of four levels: lower level, middle level, communication equipment, and upper level (refer to Figure 4). The lowest level of the power station consists of a variety of measuring transducers and electromechanical components, including generators and transformers [21]. The intermediate level consists of controller devices, such as programmable logic controllers and microcontrollers, which are responsible for controlling the operation of numerous electronic components in a hydropower plant. The upper-level server is used as a client's server, which works as a file server on the same network for monitoring and storing data files. Communication equipment is a crucial component of the SCADA system. This research utilized an IoT device to create a modernized SCADA system known as IoT-based SCADA systems.

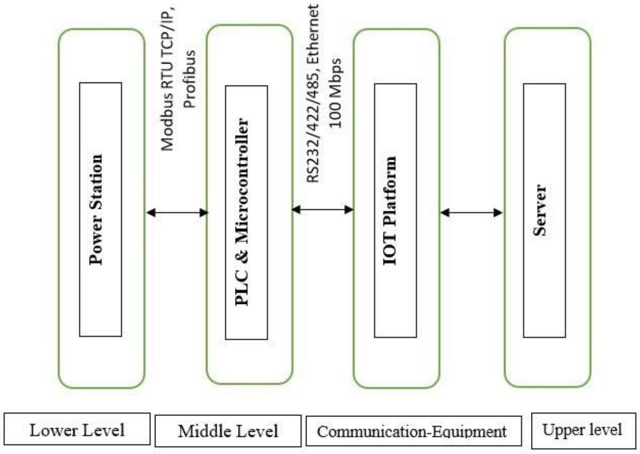

Fig. 4. SCADA system block diagram.

B. Hardware Implementation

The hydropower station's IoT-based SCADA system hardware implementation comprises many key electrical devices, such as the AT Mega Arduino controller, ESP WiFi Module, programmable logic controller, and multiple hydropower station-related sensors, as seen in Figure 5. The microcontroller unit made use of the real-time clock (RTC).One very reasonably priced, standalone System on a Chip (SoC) with a TCP/IP protocol stack is the ESP WiFi Module.It enables the establishment of a WiFi network on any microcontroller [22].

The AT Mega 328 microcontroller is a single-chip microcontroller that belongs to the Advance Virtual RISC (AVR) family. It is utilized in diverse initiatives and self-governing

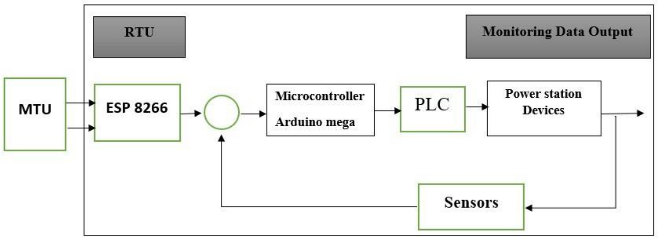

Fig. 5. Design of an IoT-based SCADA system for a hydropower station

S No	Collection of Data	In the case of subjective items
1	Voltage	Transformers, Generators, and Power Line
2	Current	
3	Active Power(w)	
4	Power Factor	
5	Frequency(Hz)	
6	Pressure	Penstock is the water output, while the draft tube is the water output
7	Temperature(C)	Transformers, stator coil, turbine guide bearing, higher guide bearing, lowering guide bearing, thrust bearing
8	The level of Water(m)	The upstream and downstream
9	Water flow rate(m/s2)	Shaft seal and all bearing cooling water systems
10	Vibration rate(m/s2)	Rotor

TABLE I
Principal Data of the Hydropower Station

systems. An industrial computer known as a programmable logic controller (PLC) stores instructions and specific functions in programmable memory to enable control systems in various machinery to be executed. PLC is predominantly utilized in hydropower plants to regulate various systems such as generator start/stop, excitation, synchronization, water supply, and firefighting [23].

The PZEM 016 AC communication module, along with other sensors, is employed to gather data about hydropower stations.The primary function of this research is to utilize the PZEM module to collect electricity data, including Active Voltage (V), Current (A), Power (W), Frequency (Hz), and Power Factor. This information only relates to the hydroelectric power station equipment such as the generator, transformer, and power distribution bus bar. Temperature sensors will be used to keep an eye on the thermal state of the generator, stator coil, and bearings in a hydropower plant, including the thrust, upper, lower, and turbine guides. A pressure sensor is crucial for monitoring the water flow in the intake and outlet of a hydropower system, namely in the penstock and draft tube.Additionally, a water level sensor is employed to obtain data on the water levels in both the upstream (headwater) and downstream (tailwater) areas. A vibration sensor is requiredto assess the state of the rotor in a hydropower plant. Table 1 presents the fundamental information regarding the primary components of hydropower plants [24].

C. *Software Implementation*

Reliable measurement equipment will be used in place of human operators in network architecture to administer control systems for hydropower plants. This research focuses on the utilization of Industrial Internet of Things (IoT) devices in SCADA systems for hydropower plants.

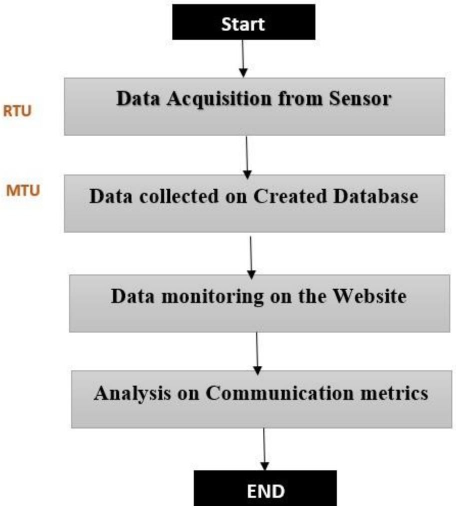

Fig. 6. Flowchart of performance analysis for IoT-based SCADA system

These devices facilitate communication between various electronic devices, enabling the acquisition of data from sensors and the control of electronic equipment. The HTTP (Hypertext Transfer Protocol) protocols are employed for this purpose. An IOT device wifi Module ESP8266 Node MCU can be used as an Arduino mega controller in the SCADA system, in this device we can use programming and upload programs in the module. PLC is used for the excitation system, and synchronization system and checks the conditions of transformers, and generators, and also used in the opening and closing of the dam gate in the hydropower plants. In the PLC we used the ladder diagram which is the graphical programming language. the language is designed to control the process of hardware by giving them commands. A SCADA system consists of hardware and software, it collects data from devices then monitors the devices and controls them. The main task of the SCADA system is to give commands to the automatic control devices and communicate them on behalf of the human operator [25]. The microcontroller obtains the data from the sensors to manage the power station implemented for the remote terminal unit. MySQL databases are utilized in MTU systems to store data at the back end specifically for hydropower stations. A website is developed using the hypertext preprocessor (PHP) scripting language to analyze the back-end data. The efficacy of Internet of Things (IoT)–based SCADA systems is evaluated using the software Wireshark. In addition, the WiFi analyzer, referred to as Net spot software, can be used for locating a hydropower station’s Remote Terminal Unit (RTU). Figure 6 depicts the flowchart that shows how this specific system’s communication metrics were examined [26].

D. Network architecture

It refers to the design and structure of a computer network. A SCADA system, sometimes referred to as a centralized control system, consists of two primary systems: the RTU and MTU. These systems are comprised of various components such as Human-Machine Interface (HMI), Input/Output (I/O) devices, controllers, net-working infrastructure, software, and other related elements. Distributed network protocol (DNP) is commonly employed in various industries to gather data. Basically, DNP’s purpose is to serve as a protocol that is simple and itinerant based on the IoT. In this mechanism, the transmission and distribution used a Master/ Slave polling which used different ports such as Rs-232 protocol whose purpose is serial communication transmission of data, RS-422 protocol commonly known as TIA/EIA-422 whose operating voltage is -6 to +6 the purpose of this to minimize and bear the noise, RS-485 protocol used to communicate for a long distance. These protocols are widely used as a physical layer in industries for the recognized and established standard for data. Only the application, data connection, and physical layers are supported by DNP. It is based on the telecontrol applications’ enchanted protocol architecture (EPA), which allows for enhanced functionality including managing messages longer than a Remote Technical Unit’s (RTU) usual frame length [27]. Communication technology is essential for quickly rapidly driving force in the IoT-based SCADA System. The Master Terminal Unit (MTU) relies on LAN (Local Area Network) technology as a crucial element to ensure both high reliability and rapid transfer speeds for improved response time. The data transfer rate of a Local Area Network (LAN) typically ranges from 10 Megabits per second (Mbps) to 100 Mbps. For a master terminal unit as non-vendor-specific open standard interfaces, we used a wireless network in RTU-like satellite spread spectrum and fiber optics. In this research paper, ESP 8266 node modules as a wireless router are necessary to construct an IOT-based SCADA system. This module is a wireless router device for data transmission in the SCADA system. As seen in Figure 7, these devices help users (operators) and the station’s Remote Terminal Units (RTUs) transmit the essential data.

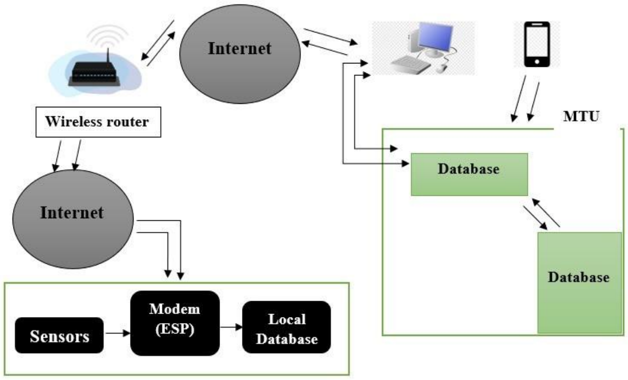

Fig. 7. Network topology of SCADA system

E. STATISTICAL ANALYSIS OF GENERATED ELECTRICITY RESULT

Based on the monthly report of generated electricity, performance is evaluated in hydropower station. The system examined the collected data then monitored the data and analyzed the variation that happened during the generation of electricity. Multiple techniques exist for forecasting electricity usage. Annual load curve asymmetrical conditions can be implemented through the use of differential and integral features. Using monthly data for every year, the integral evaluation of the yearly load curve may be calculated. On the other hand, the average yearly load curve’s differential evaluation can also be carried out using a high number of data points. The resulting capacity statement’s integral calculation can be performed using the following parameters: a) The load curve form factor (kf) b) The root mean square deviation (n) represents the average load value each year. c) Annual energy production

A) The Load Curve Shape Factor The load curve shape factor demonstrates the fluctuation in load demand within a certain period of time. Therefore, a power station operator must carefully assess and plan the amount of power to create within a specific time period, utilizing (1).

$$K_f = \frac{\sqrt{\frac{1}{n}\sum_{i=1}^{n} N_i^2}}{\frac{1}{n}\sum_{i=1}^{n} N_i} = \frac{\sum N_{rm}}{N_{avg}} \qquad (1)$$

This is the expression: where n is the total number of points on the annual load curve, Nrm is the root mean square for the load (in GWh), Navg is the average annual load (in GWh), and Ni is the monthly value of the ith point on the annual load curve (in GWh). B. Annual Load Mean Square Deviation from Mean by Root Mean Square The amount of variation between the observed and expected values is expressed as the root mean square deviation (n)). In this study, n the deviation from the average yearly load value, as expressed in equation (2),

$$\sigma_n = \sqrt{\frac{1}{n}\sum_{i=1}^{n} (N_i - N_{avg})^2} \qquad (2)$$

C. Annual Energy Generation Period The efficiency of a power station can be determined by calculating the amount of electricity it generates and the duration of its operation. The period of generated energy can be estimated as an integral evaluation in equation (3).

$$\Delta t_{\max}^{\Sigma} = \sum_{j} \Delta t_j \qquad (3)$$

where $\Delta t_{\max}^{\Sigma}$ is the total time for a year, and j is the time segment value for each month's power generated capacity. The differential evaluation can be performed using the following parameters. a) The maximum load curve coefficients (kmax); b) the annual peak load (Np). c) The coefficients of the minimum load curve (kmin) d) The ratio () between the kmax and kmin e) Variations in load (kd) f) Peak load ratio (kr) for the dry and wet seasons D. Peak Load Annually (Np) Peak load (GWh) is the maximum load demand for electricity consumption; for hydropower plants, on the other hand, peak load is also the maximum generating capacity. As a result, peak load, which is defined as the very highest point over the yearly load curve's maximum and minimum points,

$$N_p = \max\{N_{\max}^{i}\}, i = 1, 2, \ldots., n \qquad (4)$$

E. Coefficients for the maximum load curve (kmax) The maximum load curve coefficient is defined as the ratio of the peak load to the average load, as shown in equation (5). Hence,the kmax value is invariably bigger than 1 and is defined as: Coefficients for the minimum load curve (kmin);

$$K_{\max} = \frac{N_p}{N_{avg}} \qquad (5)$$

F. The minimum load curve coefficient (kmax) is defined as the quotient of the minimum load and the average load, as seen in equation (6). The result of kmin is perpetually below 1 and is characterized as such.

$$K_{\min} = \frac{N_{\min}}{N_{avg}} \qquad (6)$$

G. The ratio between the maximum value (kmax) and the minimum value (kmin) In order to determine the ratio between kmax and kmin, it is necessary to understand the peak and off-peak conditions for power generation in the power station mentioned below (7). is described as;

$$\lambda = \frac{K_{\max}}{K_{\min}} \qquad (7)$$

H. Load Fluctuation (kd) During the peak internal load, fluctuations occur as a result of the high current being drawn and the significant voltage drop in the system. To prevent damage to the power station's equipment, operators reduce load fluctuation. Kd can be defined as follows:

When kd is equal to 0 and is equal to 1, the load curve will evolve in a totally smooth horizontal manner. Peak Load Ratio (kr) Every day, there are two instances of high demand: the morning peak, known as N1max, and the evening peak, known as N2max. The load curve will exhibit N1max and N2max at specific time intervals, T1max and T2max, respectively. These peak load ratios can be determined using equation (9). While this equation is applicable for a daily load curve spanning 24 hours, it is not suitable for calculating the yearly load curve of a hydroelectric station. kr is also characterized as;

$$k_d = k_{\max} - k_{\min} = \frac{N_p - N_{\min}}{N_{avg}} = \frac{\Delta N}{N_{avg}} \qquad (8)$$

$$k_r = \frac{N_{1\max} - N_{2\max}}{N_{1\max}} \qquad (9)$$

IV. TIDAL POWER PLANT

A. I. NEED FOR AUTOMATIC CONTROL OF TIDAL POWER PLANT

a) The installation cost and control of protection equipment in tidal plants are prohibitively expensive. Automatic control systems offer continuous protection at a considerably lower cost. b) Tidal plants have the ability to start and stop more frequently. c) Enhance operational efficiency and ensure seamless performance. d) Because tidal plants are usually found in remote places, manual operation might be difficult. Automation is a very practical solution in these situations. e) The running cost will be reduced significantly.

B. II. AUTOMATED CONTROL OF TIDAL POWER PLANT

Previous study indicates that a cascade structure can be used to manage the tidal power-producing system. There are two control loops in it. The inner power control loop regulates the field excitation current, while the outside power control loop adapts to changing operating conditions by maintaining the generator input power. Different relays, switches, contactors, timers, isolators, and logic components are used to control the fluctuating condition. To ensure ease of control, the tidal plant is separated into three components [28]. The independent control of this section creates a fully managed and resilient system that operates autonomously. In the event of a serious fault, it triggers an alarm or sends a message to the main control room while simultaneously initiating a secondary system to ensure the continuity of operations.

C. Controlling the Barrage or Dam using a Programmable Logic Controller (PLC)

The Barrages are essential components of tidal power plants. Water waves possess kinetic energy as they flow. This kinetic energy can be used to rotate turbine blades. Simultaneously, a barrage is employed to store the water, which has significant potential energy. Sluice gates and slip locks, which are connected to the shore by embankments, are the standard components of a barrage. The sluice gates open when tidal forces cause a sizable difference in the water levels on each side of the dam. The water flows through the turbines. To produce power, a generator is rotated by the turbines [29].

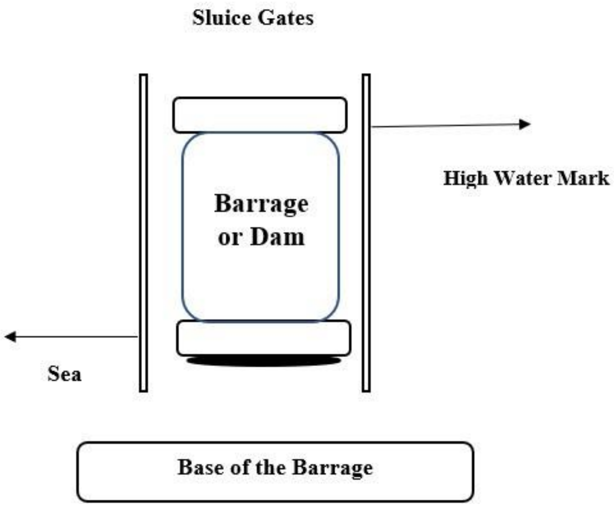

Fig. 8. Tidal Barrage

Here we make use of two sensors and a Programmable Logic Controller (PLC). One of these sensors is positioned near the sea and is responsible for detecting the water level in the sea. We can use capacitance level sensors, radar level sensors, optical sensors, or ultrasonic water level transmitters to accomplish this goal. The sensor's output serves as the input for the logic circuit in the PLC ladder diagram. This will determine the operation of the sluice gates, causing them to open and close. In Figure 10, the value 1001 represents the output of the sensor located inside the dam. This sensor is responsible for measuring the water level of the dam. Similarly, the value 1002 represents the output of the sensor located on the sea side, which measures the the dam's water level. The input of the Sluice gates is 0001. When the input signal 0001 is in a high state, the motor controlling the sluicegate will activate, causing the sluice gate to open. When the water level in the dam is low (0) and the water level in the sea is high (l), the barrage's motor will only turn on (1) and allow water to flow into the dam [30].

Sensor output (Controller input)	1001 1002 (Mw1) (Mw2) S1 S2	0
Inverter Comparator	Mw2¡Mw1	0
	Mw2=Mw1	0
	Mw2¿Mw1	1

TABLE II
ADAPTABLE LADDER STRUCTURE

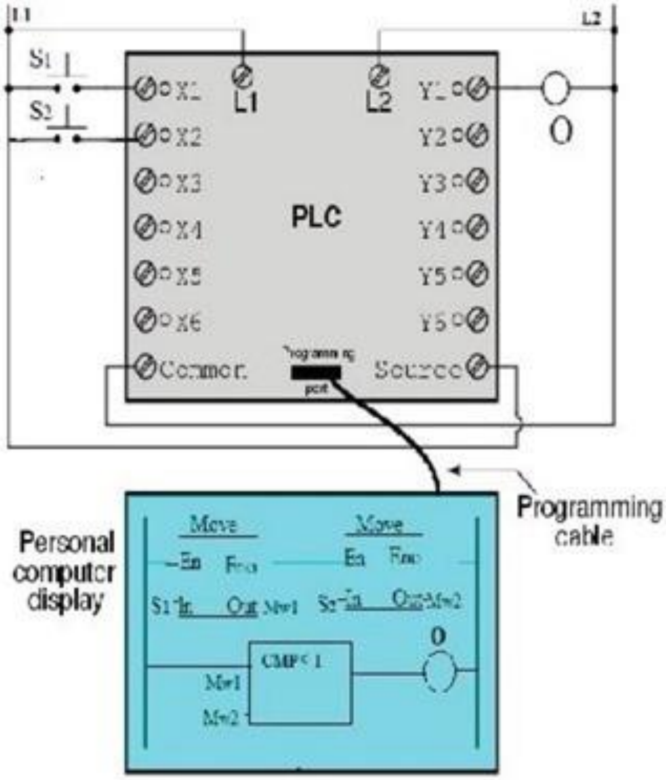

Fig. 9. Logic Model for Open and Close the Barrage Gate

D. III. Control of Generation System Utilizing PLC (Programmable Logic Control)

The generation system's turbine is either directly connected to a generator or through a fixed ratio gearbox, which is a less complex and costly gearbox alternative than a variable ratio gearbox. A diode bridge rectifier, which is less costly and more dependable than active power conversion, is used to convert the generated AC power to DC. Using a high-voltage (HV) generator can eliminate the need for AC transformation in the nacelle; but high-voltage transmission on land is still required. Tidal stream turbine generators' rectified outputs are connected to one another via a shared sub-sea DC connection, eliminating the need for complicated AC synchronization. Every turbine generator has a field excitation that may be changed to control the output power, enabling either maximum power extraction or power limitation. Control is mostly needed for the gearbox, cooling system, circuit breaker, and auxiliary power supply of the generating system. To achieve this control, electrical sensors such as current transformers and potential transformers can be used. The output of these sensors can be used as input for a logic circuit. Depending on the specific requirements, a ladder diagram of a programmable logic controller (PLC) can be created using various PLC components such as switches, counters, timers, and contractors [31]. The output voltage is determined by the field excitation, which in turn is influenced by the excitation voltage. The excitation voltage is controlled by the firing angle of the PWM converter. By manipulating

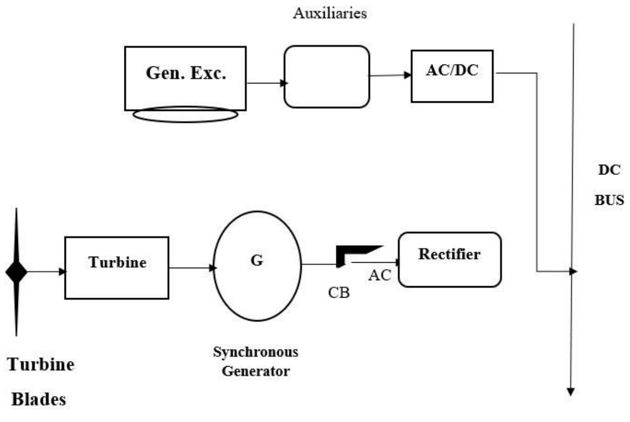

Fig. 10. Electrical Configuration Schematic

this firing angle, we may generate a specific voltage.

E. IV. Benefits of Automatic Control in Tidal Power Plants

a) $P(t) = 0.5*C*p*A*V3(t)$ is the formula for the converted mechanical power in a tidal power plant. The power coefficient, denoted as C, is a measure of the efficiency of a system. The density of water is represented by p, while A refers to the frontal area. V (m/s) represents the current velocity. velocity is the primary determinant of power generation. Typically, a tidal power plant has the capability to convert up to 59.3 percent of the kinetic energy into mechanical energy on the rotor. However, the utilization of this automated system will result in an enhanced conversion rate of kinetic energy. This is achieved by the turbine's seamless and well-balanced spinning in both inflow and outflow conditions [32]. b) Decrease in workforce and efficient operation or production. c) Minimize the processing time for control by utilizing computer-based decision-making and command execution. The reaction time is determined by the speed of the computer processor, which is far faster than any mechanical system. d) The tidal turbine is equipped with the capability to rotate in both clockwise and anticlockwise directions, allowing it to adapt to varying water level conditions. An automation system is included to enable flexibility in changing the operational mode. e) Minimize the physical area required and increase the capacity to manage a greater number of plants using a single computer system. f) Enhanced efficiency. g. Remote operation is feasible. h. Minimize the operational and maintenance expenses of the facility.

V. WIND POWER

This paper employs the Systematic Literature Review (SLR) approach introduced by Torres in, which is a modified version of the methodology developed by Kitchenham and Bacca. The procedure is illustrated in the flowchart seen in Figure 12,and the protocol is outlined below. Include a diagram or illustration.

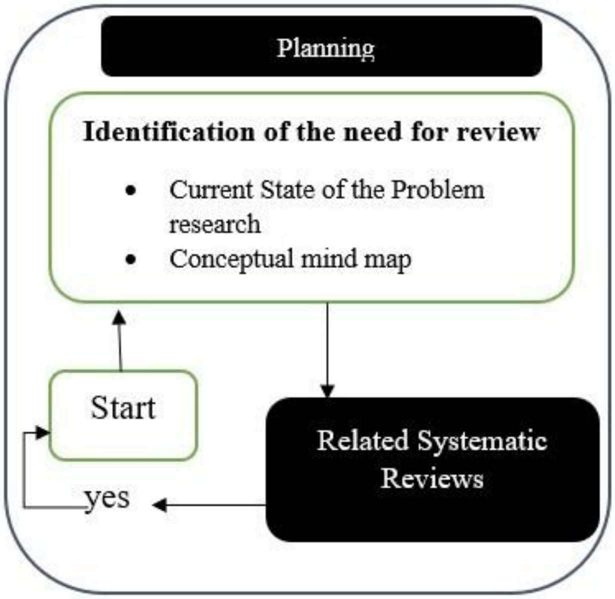

Fig. 11. Flow diagram of the methodology

A. Identification of the necessity for a review

Wind power has seen significant growth in the last decade. Unscheduled maintenance caused by unforeseen breakdowns is a significant factor in the operational and maintenance expenses of wind turbines. Hence, the ability to predict failures is crucial for minimizing operation and maintenance expenses and upholding the competitiveness of wind energy [33]. A comprehensive bibliographic search was performed in the scientific literature to find the artificial intelligence algorithms that utilize SCADA data for condition monitoring and early identification of wind turbine breakdowns. Utilizing SCADA data eliminates the need for extra costs associated with the installation and maintenance of sensors, cables, and dedicated acquisition systems. With this in mind, it was essential to understand the key components or systems of the wind turbine under analysis, employing condition monitoring methods and utilizing variables obtained from the SCADA system, which is typically used for condition monitoring in wind turbines [34].

B. Conceptual Mind Map

A mind map is a cognitive diagram that arranges and retains knowledge in a hierarchical manner, with primary concepts being represented and secondary ideas being excluded. A conceptual mind map serves two purposes: organizing propositions and preserving concepts, thereby putting them in a straightforward hierarchical diagram. As stated by reference, a conceptual mind map is essential for facilitating thorough reading and learning. Furthermore, the conceptual mind map tool is employed in teaching to represent concepts. Moreover, as stated in reference, a mind map is a visual representation or diagram that symbolizes a notion or idea, effectively simplifying and organizing complicated information. It is structured into categories as outlined below: • Supraordinate: pertains to a category of statements that completely embraces others. Its purpose is to ascertain and uncover the fundamental attributes of the concept. • Isoordinate: Proposals come before conceptions and help them to be structured; they also establish non-total correspondence, highlight linkages and links between nearby propositions, and link ideas with one another. • Infraordinate: characterized by the presence of several subclasses or derivations, and organized based on the evolutionary sequence of propositions, concepts, notions, and categories. • Exclusions These classes function by excluding or denying a connection between two neighboring classes and are mutu+ally exclusive or opposed to one another. The conceptual mind map shown in Figure 13 assisted in focusing the bibliography's search efforts on the study issue. When reading from top to bottom, the supraordinate "wind turbine" at the top helps to clarify the fundamental notion of "CM." The exclusions, which are stated on the right, are ideas that are thought to be connected to the main idea but are distinct from an operational standpoint. The concepts that assisted the bibliographic search in identifying the features of the main idea are known as the coordinates, and they are located on the left side. The infraordinates, located at the bottom; contain the main components of a WT to which CM techniques are applied [35].

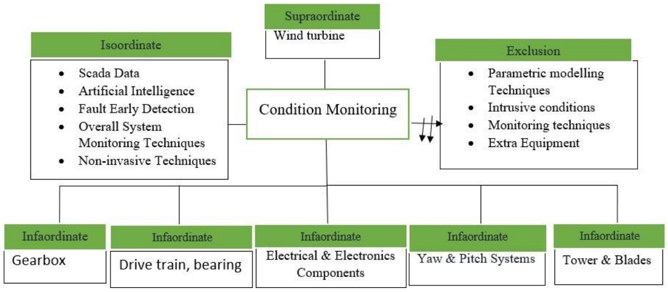

Fig. 12. Conceptual mind map

C. *Relevant Systematic Reviews*

A search script was developed to conduct precise and efficient bibliographic searches on the Scopus and Web of Science (WOS) databases. Working with a scientific thesaurus, the conceptual mind map was used to create the semantic framework. The main goal of thesauruses is to lessen polysemy and synonymy, which can affect how accurately material is indexed and retrieved. The framework for semantic search is shown in Table 3, and it consists of five layers that are described as follows:

Level-1	Condition monitoring	Condition surveillance "OR" Maintenance according to conditions
Level-2	Artificial intelligence	AND (AI "OR" the future strategies "OR" signal processing approaches) machine learning
Level-3	Fault detection	AND (diagnostic OR fault OR anomaly OR detection W/1)
Level-4	Wind turbine	AND (wind generator) "OR" wind power station
Level-5	Scada	AND (SCADA "OR" Signals "OR" real conditions")

TABLE III
SEMANTIC SEARCH STRUCTURE

The conceptual mind map served as the basis for the first level, research on artificial intelligence (AI) studies was the emphasis of the second level, defect detection-related work was the focus of the third level, the fourth level was focused on searching for information on wind turbines (WT), and finally, the fifth level was dedicated to searching for information on SCADA systems. The five levels have a clear correlation with the four research questions. Furthermore, it is worth noting that on each level, the thesaurus terms were considered, enabling us to encompass all terms connected by synonymy. Additionally, the search script can assist in identifying the presence of relevant Systematic material Reviews (SLRs) on the topic being studied and in collecting scientific material to address the research inquiries. During the construction of the script, some exclusion criteria were considered. Initially, the search was limited to studies conducted in the most recent years (2022–2023) and exclusively to those that were published in the English language. Furthermore, any materials that were not relevant to the specific area of interest or its associated fields were excluded [36]. This review provides a succinct overview of the current progress in the field of prognosis and estimation of remaining useful life, focusing specifically on components of wind turbines. It points out the areas where prognostic approaches used to wind turbines still need to be developed further, such the requirement for a platform to gather and distribute SCADA data, exchange information, and carry out analysis. The study also included a categorised list of references with the author, publication year, methodology, and input SCADA parameters, in addition to outlining the key components of the WTs. Ultimately, it was determined that artificial neural networks (ANN) and particle filters are the most favorable methods, considering their advanced development stage and the achieved outcomes. The evaluation cited in reference revealed a notable research deficiency in the creation of all-encompassing, economical, internet-based condition monitoring approaches for wind turbines. In this wind power comprehensive study, we review the common Level-1 Condition monitoring Condition surveillance "OR" Maintenance according to conditions Level-2 Artificial intelligence AND (AI "OR" the future strategies "OR" signal processing approaches) machine learning. Level-3 Fault detection AND (diagnostic OR fault OR anomaly OR detection W/1)Level-4 Wind turbine AND (wind generator) "OR" wind power station Level-5 Scada AND (SCADA "OR" Signals "OR" real conditions") faults that occur in wind turbines, fault diagnoses, and signal processing techniques used in condition monitoring, as well as an analysis of different techniques.

This includes fault types and reasons why they occurred types and their respective locations and the signals that need to be evaluated using various signal processing techniques [37].

VI. PV PLANT

A. IoT infrastructure

In addition to this the IoT infrastructure, Pv plants have layers of networking that allow the controlling and monitoring remotely. Telecom devices such as hubs, routers, and switches are used at this layer with industrial PCs. A highly promising field for the implementation of IoT technologies, in the networking layer presents an owing to their advanced communication and processing capabilities. The IoT collection of different devices such as modules, and signal processing offers highly adaptable and efficient solutions in various industries. The IoT Protocols and devices can be customized to work optimally in the most diverse scenarios. For industrial in pv sector, it is necessary to monitor the structure of the IoT solution before analyzing its impact on industrial monitoring.

B. Architectural layers

IoT solutions are structured in varied ways and are intrinsically diverse. As shown, there is no consensus on a single IoT architecture, and there are several viable implementations. Nevertheless, regardless of the specific methodologies used, there are common features and difficulties that any architecture must address in order to fully utilize the infrastructure's potential [38]. As depicted in Figure 3, the features are: Perception: it focuses on the exchange of data with industrial devices, encompassing both sending and receiving data. Normalization: involves standardizing data before using it across the architecture. In some cases, the data may also need to be filtered or compressed to improve communication. Communication: One of the significant advantages of IoT architectures is the diverse range of communication options they offer, which may be tailored to different environments such as areas without wiring, poor network coverage, or distributed networks. Processing: The collected data needs to be processed to generate new metrics, set off alarms, or trigger a critical response. Routing: First, the data has been successfully integrated into the architecture. It should be easily accessible for different tools for monitoring, visualization, management, and additional processing. Various IoT gateways offer these features, whichever typically controls the standardization and control of data. Moreover, an integrated Internet of Things platform that manages and routes the data for efficient use is also available. Nevertheless, Whereas IoT platforms need to address administrative and usability difficulties, IoT gateways primarily deal with the range of devices and protocols they interface with.

C. Internet of Things (IoT) gateway

The lower levels of the architecture can be implemented using a wide range of IoT gateways. Furthermore, the gateways may be equipped with a wide variety of Internet of Things (IoT) middleware. Based on several criteria such as architectural approaches, connection needs, and capabilities, gateways and middleware differ greatly in their characteristics. Nonetheless, some of the most common and noteworthy features for industrial monitoring include: • Data Management: Receive and process data, as it is necessary for industrial and Internet of Things applications. • Event Management: Create events in response to certain parameters; this is crucial for industry since processes are frequently triggered by events. • Timeliness: Ensure real-time responses, which is critical for many industrial systems. • Scalability: enables expansion in a horizontal direction. To offer a versatile and adaptable company model. • Reliability: the fundamental functionality must consistently be delivered. It is necessary for both production and safety purposes. • Security: prevent unwanted access. Additionally necessary for both productivity and safety purposes. Multiple IoT middleware platforms offer extra functionalities such as resource discovery and code management. For an industrial process, those are unnecessary. It is possible to view these advantages as extra, although they are not requirements [39].

D. IV. Internet of Things platform

The emergence of IoT platforms became necessary as the number of IoT devices grew and their diversity became too difficult to handle with individual solutions. The IoT platforms encompass a wide range of functionalities that leverage the capabilities of IoT devices. Common features include: • Software management: Facilitate the process of downloading, upgrading, and maintaining version control of the software installed on the IoT devices. • Monitoring: IoT device status should be tracked, and device information such as memory use, CPU utilization, storage capacity, execution state, etc. should be gathered. • Broker: Consolidates data from IoT devices and provides an optimal communication interface utilizing IoT protocols. • Processing: Perform computations using the data obtained from the Internet of Things devices. • Routing: facilitates the establishment of a routing interface for data, enabling a centralized model of data flow to enhance control over it. • Security: Verify the identity and protect the connection by using authentication and encryption methods for the IoT devices. Depending on the application, an IoT platform's functionalities may vary, and certain platforms may include extra features like operational reports, programming interfaces, or on-premise distribution. IoT platforms can be found as several vertical solutions, each with its own platform, or as a single horizontal platform. A natural progression from this concept has resulted in the emergence of platform ecosystems, which have evolved into platforms of platforms. Recently, these have been redefined as IoT platforms with strong integration capabilities to connect with other platforms, particularly when vertical solutions need to be integrated [40].

VII. CONCLUSION

SCADA systems are essential in the field of renewable energy, greatly improving the effectiveness, dependability, and environmental friendliness of solar, wind, hydro, and tidal power operations. SCADA systems guarantee optimal performance and rapid fault identification across various energy sources by offering real-time monitoring, control, and data analysis. The Tidal power plant utilizes SCADA, which employs sensors to monitor water levels and flow rates in order to improve the operation of the turbines. Moreover, optimizing the turbine angles and speeds according to tidal data in order to enhance energy extraction. Sensors and meters gather data about solar radiation, panel temperature, and electrical output. SCADA systems optimize the angles of solar panels to maximize sunlight exposure and identify any malfunctions in the panels or inverters. Performance Analysis: Utilizing historical data analysis to enhance performance and forecast maintenance requirements. Turbine control systems initiate, cease, and regulate the operation of turbines in order to align with wind conditions and sustain optimal performance. The turbine and generator control system regulates the speed of the turbine and the output of the generator by using water flow data. Their capacity to integrate with and manage complex energy infrastructures enhances resource utilization and maintenance planning, ultimately contributing to the overall efficiency and growth of renewable energy solutions. As the global transition to renewable energy sources progresses, the importance of SCADA systems will increasingly grow in ensuring a sustainable and resilient energy future. By upgrading and altering this IoT-based SCADA system architecture, may effectively decrease the need for human resources, ensuring the safe operation of the power station and timely collection of station information. Hence, the IoT-based SCADA system enables operators to remotely gather historical data of the station from any location through the internet. These collected data are then utilized to analyze the station's condition and predict its production capacity for the upcoming year, using the aforementioned methods.

REFERENCES

[1] Vanalakshmi, R., et al. ”Performance Assessment and Configuration Analysis in the Study of SCADA System (Supervisory Control and Data Acquisition).” Intelligent Automation Soft Computing 37.2 (2023).

[2] Albița, Anca, and Dan Selișteanu. ”A Compact IIoT System for Remote Monitoring and Control of a Micro Hydropower Plant.” Sensors 23.4 (2023): 1784.

[3] Sami, Md Waliullah, et al. ”On Possibilities of Using Tidal Stream Turbine for Power Generation in Karnaphuli River.” 2023 10th IEEE International Conference on Power Systems (ICPS). IEEE, 2023.

[4] Singh, Deepi, et al. ”Modeling and Performance Enhancement of Grid Tied Tidal Energy System with Fractional Order Integral Based Incremental Conductance.” 2023 IEEE Energy Conversion Congress and Exposition (ECCE). IEEE, 2023.

[5] Gorobchenko, Stanislav, et al. ”Overview of SCADAsystems: Basic protocols, architecture and system components used in teaching students in the discipline of process control systems.” AIP Conference Proceedings. Vol. 3102. No. 1. AIP Publishing, 2024

[6] Sasitharan, Shawn Daren, and Naveeyindren Thangarajah. ”Development of SCADA photovoltaic monitoring system.” AIP Conference Proceedings. Vol. 2680. No. 1. AIP Publishing, 2023.

[7] Babayigit, Bilal, and Mohammed Abubaker. ”Industrial internet of things: A review of improvements over traditional scada systems for industrial automation.” IEEE Systems Journal (2023).

[8] Rawat, Sumit, et al. ”Environmental effects and sustainable hydropower development: A review of deployment research, environmental valuation and iot sensors integration.” AIP Conference Proceedings. Vol. 3050. No. 1. AIP Publishing, 2024.

[9] Ramos, Helena M., and Óscar E. Coronado-Hernández. ”IoT, machine learning and photogrammetry in small hydropower towards energy and digital transition: potential energy and viability analyses.” Journal of Applied Research in Technology Engineering 4.2 (2023): 69-86.

[10] Albița, Anca, and Dan Selișteanu. ”A Compact IIoT System for Remote Monitoring and Control of a Micro Hydropower Plant.” Sensors 23.4 (2023): 1784.

[11] Vijayalakshmi, S., Savita, and P. Durgadevi. ”AI and IoT in Improving Resilience of Smart Energy Infrastructure.” AIPowered IoT in the Energy Industry: Digital Technology and Sustainable Energy Systems. Cham: Springer International Publishing, 2023. 189-213.

[12] Ginanjar, Satria, et al. ”An internet of things architecture for real-time tide and wave monitoring using Heltec LoRa 32 and Kalman filter.” Journal of Ocean Engineering and Marine Energy 9.2 (2023): 219-231.

[13] Gayathri, S. P., and S. Vijayalakshmi. ”Empowering Renewable Energy Using Internet of Things.” AI-Powered IoT in the Energy Industry: Digital Technology and Sustainable Energy Systems. Cham: Springer International Publishing, 2023. 215-228.

[14] Topper, Mathew, et al. ”Enabling the Ocean Internet of Things with Renewable Marine Energy.” Proceedings of the European Wave and Tidal Energy Conference. Vol. 15. 2023.

[15] Astolfi, Davide, et al. ”SCADA data analysis for longterm wind turbine performance assessment: A case study.” Sustainable Energy Technologies and Assessments 52 (2022): 102357.

[16] Dai, Juchuan, Yayi Tan, and Xiangbin Shen. ”Investigation of energy output in a mountain wind farm using multiple-units SCADA data.” Applied Energy 239 (2019): 225-238.

[17] Pandit, Ravi Kumar, and David Infield. ”SCADA based nonparametric models for condition monitoring of a wind turbine.” The Journal of Engineering 2019.18 (2019): 4723-4727.

[18] Zhang, Fan, et al. ”Investigation of the pitch load of large-scale wind turbines using field SCADA data.” energies 12.3 (2019): 509.

[19] Khan, Prince Waqas, Chan Yeob Yeun, and Yung Cheol Byun. ”Fault detection of wind turbines using SCADA data and genetic algorithm-based ensemble learning.” Engineering Failure Analysis 148 (2023): 107209.

[20] Pandit, Ravi, et al. ”SCADA data for wind turbine data-driven condition/performance monitoring: A review on state-of-art, challenges and future trends.” Wind Engineering 47.2 (2023): 422-441.

[21] Zeng, Huifan, et al. ”Correlation investigation of wind turbine multiple operating parameters based on SCADA data.” Energies 15.14 (2022):5280.

[22] Qays, Md Ohirul, et al. ”Monitoring of renewable energy systems by IoT-aided SCADA system.” Energy Science Engineering 10.6 (2022): 1874-1885.

[23] Shafiullah, Md, Shakir D. Ahmed, and Fahad A. AlSulaiman. ”Grid integration challenges and solution strategies for solar PV systems: a review.” IEEE Access 10 (2022): 52233-52257.

[24] Kaldate, Avinash P., Amarsingh B. Kanase-Patil, and Shashikant D. Lokhande. ”Review of SCADA-based hybrid renewable energy source integration.” International Journal of Spatio-Temporal Data Science 1.3 (2021): 215-226.

[25] Kermani, Mostafa, et al. ”Intelligent energy management based on SCADA system in a real Microgrid for smart building applications.” Renewable Energy 171 (2021): 1115-1127.

[26] De Arquer Fernandez, Pedro, et al. ”An IoT open source platform for photovoltaic plants supervision.” International Journal of Electrical Power Energy Systems 125 (2021): 106540.

[27] Myint, A. K., et al. ”IoT-Based SCADA System Design and Generation Forecasting for Hydropower Station.” International Journal of Electrical and Electronic Engineering Telecommunications 10.4 (2021): 251-260.

[28] Hangan, Roberto, et al. ”Study Regarding Implementation of a Monitoring and Control System for a Small Hydropower Plant.” 2020 International Conference and Exposition on Electrical And Power Engineering (EPE). IEEE, 2020.

[29] Kesari Mary, Delphin Raj, et al. ”Energy optimization techniques in underwater internet of things: issues, state-of-the-art, and future directions.” Water 14.20 (2022): 3240

[30] Musyafa, Ali, and Agus Muhamad Hatta. ”Implementation of virtualization technology for hydro SCADA and control system to support energy efficiency of PT Vale Indonesia.” AIP Conference Proceedings. Vol. 2088. No. 1. AIP Publishing, 2019.

[31] Salahuddin, Bakhtiar, and Fadhli Yusman. ”Efficiency of AX. 25 Protocol in a Wireless SCADA Communication System for Monitoring Performance of Micro-Hydro Power Plants.”

[32] Welte, Thomas Michael, et al. ”MonitorX–Experience from a Norwegian-Swedish research project on Industry 4.0 and digitalization applied to fault detection and maintenance of hydropower plants.” Hydro 2018-Progress through partnership, Gdansk, Poland, 15-17 October 2018 (2018).

[33] Singh, Ramanjeet, and Amit Jain. ”A Study of Various Energy Efficiency Techniques in Green IoT.” 2021 3rd International Conference on Advances in Computing, Communication Control and Networking (ICAC3N). IEEE, 2021.

[34] Syed, Muslim Jameel, and Jamie Goggins. ”Structure Health Monitoring for Tidal Blades Using Trustworthy Artificial Intelligence.” Offshore Technology Conference. OTC, 2023.

[35] Gaitán, Miguel Gutiérrez, et al. ”Modeling LoRa communications in estuaries for IoT environmental monitoring systems.” IEEE Sensors Journal 22.21 (2022): 21312-21325.

[36] Kai, Lim Yee, et al. ”Current status and possible future applications of marine current energy devices in Malaysia: A review.” IEEE Access 9 (2021): 86869-86888.

[37] ONUIGBO, NNAMDI. ”POWERING THE FUTURE WITH SUSTAINABLE ENERGY.”

[38] Karad, Shivaji, and Ritula Thakur. ”Efficient monitoring and control of wind energy conversion systems using Internet of things (IoT): a comprehensive review.” Environment, development and sustainability 23.10 (2021): 14197-14214.

[39] Teimourian, Hanifa, et al. ”The potential of wind energy via an intelligent IoT-oriented assessment.” The Journal of Supercomputing (2022): 1-20.

[40] Adekanbi, Michael Lanre. ”Optimization and digitization of wind farms using internet of things: A review.” International Journal of Energy Research 45.11 (2021): 15832-1583.