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CLOUD SERVICE AND SCADA-BASED WEB APPLICATION FOR MONITORING RENEWABLE ENERGY SYSTEMS

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Keywords: Renewable energy; Web application; Supervisory control; Data acquisition; Data analytics; Data visualization; Cloud storage service; Tracking and monitoring.

A renewable energy monitoring web application to track, monitor, and analyze the performance of renewable energy systems such as wind is presented in this paper. The main goal of this application is to provide users with real-time information on the energy production and consumption of their renewable energy systems. The application is meant to provide meaningful and easy-to-understand data visualization to users. This requires the application to have appropriate graphs, charts, and tables to help users quickly analyze the data. The application uses supervisory control and data acquisition (SCADA) for data collection and system monitoring. Amazon Simple Storage Service (S3), offered by Amazon Web Services (AWS), is used for data storage, as the application must handle large amounts of data and users. With the increase in the number of users and data points, AWS S3 helps to scale up without any performance degradation. The proposed renewable energy management system aims to develop a renewable energy monitoring and analytics web application with a user-friendly dashboard.

1. INTRODUCTION

Renewable energy systems in the form of wind turbines and solar panels have been vastly deployed in many countries worldwide. The objectives of employing such systems include a pollution-free, green environment and the installation of alternate power sources to augment the electrical power generation by conventional sources. The power generated by renewable energy systems also helps bridge the gap between the industry/domestic power consumption requirement and the power generated by traditional sources. The ever-increasing installments of renewable energy systems by many organizations on multiple sites make it imminent that applications capable of tracking and monitoring them will be available. The large amount of data generated necessitates performing analytics to provide insights to make better decisions and manage renewable energy systems efficiently. The acronyms/tools used in this paper are presented in Table 1.

Table 1
Acronyms/tools

Acronym	Description
API	Application Programming Interface
Amazon S3	Amazon Simple Storage Service
AWS	Amazon Web Services
Gin	A Web Framework written in Golang
Golang	A programming language supported by Google
GORM	Golang’s Object-Relational Mapping Tool
REST	Representational State Transfer
SCADA	Supervisory Control and Data Acquisition
Telegraf	A plug-in driven agent used for data collection

The proposed work has adapted the computational approach-based automation to reduce the personal logging by supervisors/workers and avoid monitoring the wind turbines manually. This work can reduce manpower, and wind turbines will be monitored from a remote location around the clock. Also, the site management is highly efficient and accurate. The subsequent sections are structured as follows: section 2 provides the literature survey, Section 3 covers an overview of the proposed system, and Sections 4 and 5 describe the system design and implementation, respectively. section 6 presents the conclusions.

2. LITERATURE SURVEY

Breakdown of wind turbines will result in lesser productivity. Such failures increase the maintenance cost. Wind turbine condition monitoring and fault diagnosis systems reduce maintenance and operational costs and improve system reliability. Some earlier research work on monitoring the status of wind turbines is found in the literature. A good survey of condition monitoring and fault diagnosis of wind turbine systems is presented in [1]. Various approaches to wind power curve modeling are reviewed in [2]. Multiple reasons for the failure of wind turbines are reviewed in [3]. Power curve monitoring of wind turbines based on operational conditions and data is presented in [4]. Utilizing the performance curves effectively for monitoring wind turbines is given in [5]. The use of multivariate power modeling approaches for monitoring wind turbines and analyzing their faults is presented in [6].

Analysis and validation of renewable energy systems using Photovoltaic systems are presented in the literature. Validation of the maximum power point algorithm for a photovoltaic system using the emulation approach is presented in [7]. A comparative analysis of converter topologies with maximum power point algorithms based on photovoltaic systems using simulation is presented in [8]. Sparse representation and shift-invariant K-means singular value decomposition (K-SVD) based fault diagnosis is presented in [9]. An ensemble of polynomial models for multivariate wind turbine power curves is constructed in [10] for monitoring wind turbines. Evolutionary computing-based systems for detecting faults and health monitoring of wind turbines are presented in [11,12]. SCADA-based systems for monitoring wind turbines are presented in [13,14]. A purpose-designed SCADA-based system for operating and monitoring offshore wind turbines effectively and economically is presented in [15].

3. PROPOSED SYSTEM

The primary motivation of this system is to monitor wind turbines and solar panels owned by multiple customers who are the site owners and provide maintenance experts with alarms and insights into the overall state of the power generation process, which can

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then be used to make future maintenance decisions. The dashboard displays all the information about the customer, site, turbines, and the power curve of all the turbines. The real-time data are fetched from the Influx DB and presented in the dashboard.

The customer details are displayed in the customer dashboard, the site information is presented on the site overview page, and the wind turbine details are shown on the asset overview page. A detection system that can work continuously, process data, and send data to users is required for real-time monitoring of wind energy conversion system conditions. Monitoring is carried out to determine the performance of a wind energy conversion system from a long distance. The core objectives of the proposed system are

- To take the necessary action before a breakdown occurs.
- To perform maintenance only when required.
- To decrease the frequency of breakdowns/failures.
- To reduce maintenance expenses and production costs.
- To prolong component and equipment life.
- Reduce inventory costs with effective inventory control.

The hardware and software specifications required for the implementation of this application are presented in this section. The software stack used to implement the system is presented in Table 2.

Table 2

Development environment

Function	Platform/Software
Operating System	Windows
Front end	React js and Next js
Cloud Service	AWS S3
Language	Golang
Framework	GORM and Gin
Backend	PostgreSQL, Influx DB

Telegraf is a server-based agent that collects and transmits all metrics and events from databases, systems, and Internet of Things sensors. Telegraf is written in Golang and compiles into a single binary with no external dependencies, requiring only a tiny amount of memory. Golang is an open-source programming language supported by Google and can be used to build secure and scalable systems, including cloud and server-side applications. REpresentational state transfer (REST) is an architecture used in distributed hypermedia systems. RESTful application programming interface (API) is an interface computer system used to exchange information securely over the Internet. A RESTful web service API is written using Golang, Golang’s object-relational mapping (GORM) library, and the Gin, a high-performance web framework written in Go. Thus, a Golang RESTful API that uses Gin for routing and GORM as the ORM tool for database access. Telegraf is a plugin-driven agent that collects, processes, aggregates, and writes metrics. It supports four categories of plugins: input, output, aggregator, and processor. The Telegraf allows communications over long distances. Telegraf is a server agent that collects and reports metrics, events, and logs via plugins. Input plugins collect data into the agent by directly accessing the system/OS, calling third-party APIs, or listening to configured streams. (*i.e.*, Kafka, statsD, etc.). Output plugins send the agent's collected metrics, events, and logs to Cloud Insights.

Amazon S3 stands for Amazon Simple Storage Service. It is a scalable, fast, web-based cloud storage service. This service is intended for online backup and archiving data and applications from Amazon Web Services (AWS).

A SCADA system is a combination of hardware and software. It is used to enable automation of industrial processes by capturing real-time data. SCADA links sensors that monitor equipment such as motors, pumps, and valves to a local or remote server. Organizations can use a SCADA system to control processes locally or remotely and perform real-time data acquisition, analysis, and visualization. It can directly interact with industrial equipment such as sensors, valves, pumps, and motors and record and save events for future use or report generation.

4. SYSTEM DESIGN

The wind speed of a wind turbine is a crucial factor in determining its power output. Wind turbines are designed to generate electricity from the kinetic energy of the wind, and the power output of a wind turbine is directly proportional to the wind speed. Typically, wind turbines are designed to start operating at a minimum wind speed of around 3-5 m/s, also known as the cut-in speed. The rated wind speed is the speed at which the turbine produces its maximum power output, typically around 12-14 m/s. As the wind speed increases beyond the rated speed, the turbine's power output increases slightly but eventually reaches a limit called the rated power. The wind turbine is designed to shut down at a high wind speed, typically around 25-30 m/s, to prevent damage to the turbine's components.

Wind direction affects the efficiency of a wind turbine, as it affects its ability to generate power. The turbine needs to be adjusted to create maximum power. Additionally, wind direction can affect the turbulence the turbine experiences, decreasing the turbine’s efficiency and potentially damaging the turbine over time. Blade position affects the efficiency of a wind turbine by dictating the angle of attack relative to the wind direction. The optimal angle of attack is when the blades are perpendicular to the wind, which maximizes the lift created and produces the most power. Nacelle direction affects the wind turbine by steering the blades into the wind. Sensors detect the direction and speed of the wind and adjust the nacelle direction accordingly, allowing the turbine to capture the most energy from the wind and operate at peak efficiency. The capacity factor is an essential factor in the performance of a wind turbine. It is measured in kilowatts (kW) and is the maximum power the turbine can generate. Wind speed and swept area of the blades also influence the amount of power generated. The larger the swept area, the more power the turbine will be able to generate.

The rotor is the part of a wind turbine that collects kinetic energy from the wind and converts it into rotational energy. The wind speed and the shape of the blades determine the speed of the rotor. Longer blades create more torque and power, while wider blades increase the swept area and capture more wind energy. The power generated by a wind turbine directly affects its efficiency. To maximize power output, the turbine must be kept in an optimal position relative to the wind direction, and the blades must be correctly angled.

Additionally, the turbine blades' size can directly impact the amount of power that can be generated. Larger blades can capture more wind and generate more power, while smaller blades may be more efficient. The wind speed and efficiency of the turbine blades determine the active control of a wind turbine. When the active power output is low, the turbine's efficiency is reduced, generating less electricity. When the active power output is high, more electricity is generated.

The theoretical power of a wind turbine is an essential factor in determining its efficiency, as it indicates the maximum amount of power that can be generated. However, the theoretical power is only an estimate of the actual power output, which can be affected by external factors such as wind speed, air density, and other environmental conditions.

Figure 1 illustrates the use of SCADA systems for condition monitoring systems. Many sensors installed at the site are used to collect the data used by the monitoring module. Most wind turbines have SCADA systems installed, which gather data to track the operation of wind turbines. Telegraf is an agent written in Go to collect metrics from the SCADA system and write them into the Influx database. In the Influx database, an aggregation query runs every 5 minutes, storing data in another bucket for computation. The data in the aggregation bucket can be fetched and processed with the help of influx queries. The proposed system has six significant modules:

– Customer onboarding.
– Real-time data management.
– Asset model management.
– Site management.
– Asset management.
– Power curve and alarm management.

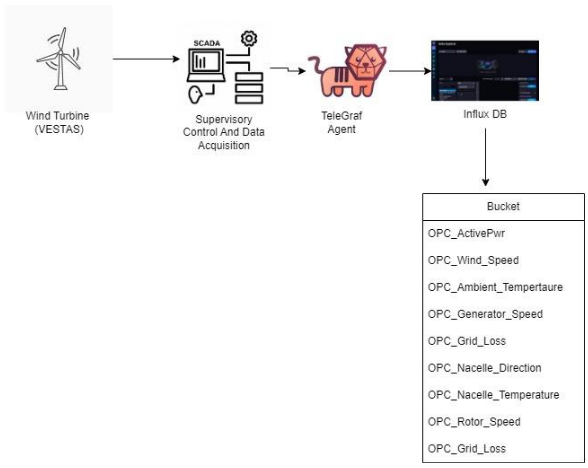

Fig. 1 – SCADA-influx DB interface.

4.1. CUSTOMER ONBOARDING

The customer onboarding process is essential in deploying a new renewable energy monitoring system, ensuring that the system is configured correctly and ready to start collecting and analyzing data from renewable energy sources. The first step in customer onboarding is registering a new customer in the system.

Once the site is configured, the next step is to configure the monitoring devices that will collect data from the renewable energy sources at the site. This typically involves specifying the make and model of the monitoring devices, configuring their settings, and connecting them to the system. Once the devices are configured, the next step is to start collecting data from the renewable energy sources at the site. This typically involves setting up data collection schedules and configuring data collection rules to ensure the system collects the correct data at the right time. Using the collected data, the final step in the customer onboarding process is to start analyzing the data to identify trends, patterns, and anomalies in the renewable energy system. This typically involves setting up data analysis tools and algorithms and configuring alerts and notifications to notify system administrators of any detected issues or anomalies.

4.2. REAL-TIME DATA MANAGEMENT

Real-time data is information ready for use as soon as it is generated. In an ideal world, data is transmitted instantly from the source to the consuming application.

User details in a renewable energy monitoring system in a multitenant web application using Golang typically include information about the users accessing the system and their associated roles and permissions. The most important details are the user's email address, password, image, time zone, and preferred language, which control access and ensure security.

4.3. ASSET MODEL MANAGEMENT

The Asset Model Management Module describes the model used for the wind turbines. Many companies manufacture wind turbines and have several models. Vestas Wind Systems AS, Siemens Gamesa Renewable Energy SA, GE Renewable Energy, Enercon GmbH, and Nordex SE are the popular companies that manufacture wind turbines. Each wind turbine has a different name, maximum power, cut-in wind speed, and cut-off wind speed.

The wind turbine data are stored in the asset model table for future use. The wind turbine is an asset. A wind turbine has only one model. A certain number of the same wind turbine models belonging to a customer may be present in the same and/or different sites. The relation between the asset and asset model is a one-to-many association.

4.4. SITE MANAGEMENT

Site management features are critical for ensuring renewable energy sites' efficient and effective operation. Operators can maximize energy production while minimizing downtime and maintenance costs by providing real-time information about site performance, scheduling and performing maintenance tasks, and tracking equipment assets. The reporting and analytics tools also help operators identify areas for improvement and make data-driven decisions to optimize the site's overall performance, generating renewable energy.

Each wind turbine on the site is an asset. A customer can have many sites in different areas. In each site, there are several wind turbines. The site page displays all the site information, such as site map view, assets present in it, average active power, wind speed, wind turbine status, and graphs to determine the capacity, active power, and wind speed. Site management allows operators to schedule and perform maintenance tasks for each site, including routine maintenance such as oil changes, blade inspections, and more complex repairs.

The gauge chart displays the average current active power, wind speed, and capacity for a site. The graphs monitor the overall site-produced power, wind speed, capacity factor, and theoretical power. The asset page displays the asset details such as site name, wind speed, power generated, and turbine details. The Site Management module allows for continuous monitoring of the wind turbines. This includes data collection from the turbines, such as wind speed, temperature, and vibration. The collected data can be used to monitor the performance of the turbines and identify any potential issues. The data can also be used to optimize the turbines' operation and ensure they run at their optimal performance.

4.5. ASSET MANAGEMENT

The wind turbines and the internal grid of the farm, which includes cables and transformers, are the main assets in wind farm management. An asset system could be used to describe the turbine farm itself. Wind turbines are made up of various parts that require different management, operation, and maintenance techniques because of their vastly different compositions, structures, and functions.

Because wind speed measurements from one year may not be representative, the MCP (measure, correlate, predict) technique is typically used with long-term historical measurement data – typically from the previous 30 years. Different wind characteristics, primarily wind speed and turbulence intensity, are optimized by wind turbines. The hub height is influenced by the wind profile and wind shear, which depend on the surface roughness, including the presence of obstacles and their height.

4.6. POWER CURVE & ALARM MANAGEMENT

The power curve is an essential tool for monitoring and analyzing the performance of wind turbines. It provides a visual representation of the relationship between wind speed and power output, allowing operators to identify any inefficiency in the system and take corrective action. The power curve can also predict power output for a given wind speed, which helps plan and optimize energy production.

A wind turbine power curve is a graph that shows how much power a turbine can generate at various wind speeds. To plot a power curve, one would typically use an anemometer placed close to the turbine to measure the wind speed multiple times while also measuring the electrical power output of the wind turbine. In the case of the SCADA alarm system, an alarm is triggered when an incident occurs or to keep track of any operational status changes. Various types of alarms can generally be found in SCADA alarm logs.

WT performance may suffer slightly during grid events. As a result, grid-related alarms are generated when specific parameters, such as voltage dips or frequency fluctuations, exceed threshold limits.

Modern WTs include sophisticated condition monitoring systems. Either way, an alarm is triggered when any signal (temperature, vibration, etc.) from the CMS or the SCADA exceeds the threshold corresponding to normal operating conditions. The alarm system can thus inform about the component's health status while avoiding complex signal processing.

Wind speed plays a crucial role in the operation of wind turbines, as it determines how much energy the turbine can capture and convert into electricity. Generally, wind turbines require a minimum wind speed of about 6–9 miles per hour (mph) to start rotating and generating power, and they typically reach their maximum power output at wind speeds between 25–35 mph.

Wind speed sensors are often installed at the top of the turbine tower or in the rotor blades to measure the wind speed and direction to optimize the performance of wind turbines. This information is used by the turbine's control system to adjust the blade pitch and yaw, ensuring that the turbine operates at the most efficient angle and direction to capture the maximum amount of energy from the wind.

Wind turbines generate electrical power from the kinetic energy of the wind. The wind turns the blades of the turbine, which are connected to a rotor that spins a shaft. The shaft is connected to a generator, which converts the rotational energy of the shaft into electrical energy. The amount of electrical power a wind turbine can generate depends on several factors, including the wind speed, the size and shape of the blades, and the efficiency of the generator and power electronics.

5. **RESULTS AND DISCUSSION**

This section presents some sample outputs and visualizations that enhance the monitoring of renewable energy systems using a user-friendly dashboard. Some sample output reports and charts given by the system to help the users monitor renewable energy sources are presented in this section.

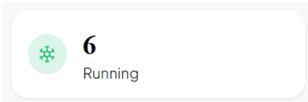

Fig. 2 – Running status of turbines.

Figure 2 presents the number of wind turbines in running status at the site. This display illustrates that six wind turbines are running on the site at the instant.

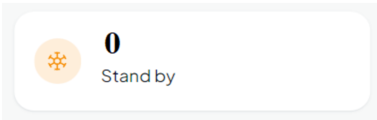

Fig. 3 – Standby status of turbines.

Figure 3 presents the number of standby wind turbines at the site. The zero-wind turbine is on standby at the site. The standby denotes the wind turbine simply standing.

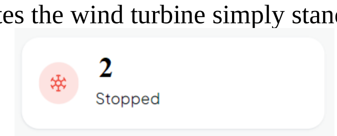

Fig. 4 – Stopped status of turbines.

Figure 4 presents the number of wind turbines stopped at the site. The two wind turbines are stopped at the site. The stopped status may indicate that the wind speed might have damaged the turbines.

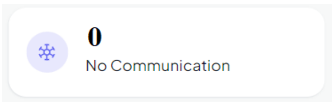

Fig. 5 – No communication status of turbines

Figure 5 presents the number of wind turbines with no communication status at the site. The zero wind turbine operation has no communication on the site. The lack of communication indicates that the wind turbine is being repaired.

Figure 6 illustrates wind turbines' active power at a particular site. The site's active power is the sum of the active power produced by the wind turbines on the site. The site's active power is displayed using a gauge chart.

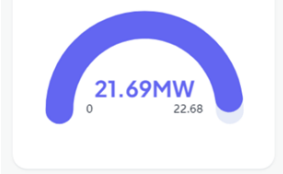

Fig. 6 – Active power generated at the site.

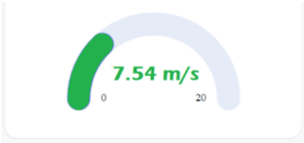

Fig. 7 – Wind speed at the site.

Figure 7 illustrates the speed of the wind at the site. The wind speed is also displayed using a gauge chart.

Fig. 8 – Machine availability at the site.

Figure 8 illustrates the machine availability at the site. The machine availability is the count of wind turbines at the site. The number of machines available is also displayed using a gauge chart.

Fig. 9 – Capacity factor of the site.

Figure 9 illustrates the capacity factor of the site. The capacity factor is the sum of the maximum power the wind turbines generate at the site. The capacity factor is also displayed using a gauge chart.

Figure 10 illustrates the map view, which presents the geographical location of the wind turbines. The color of the wind turbine represents its status. The green color denotes the running status, and the red represents the stopped wind turbines.

Fig. 10 – Map view of assets in the site.

Figure 11 illustrates the active power produced concerning the wind speed. The blue curve represents the active power produced by the site, and the green curve represents the wind speed at the site.

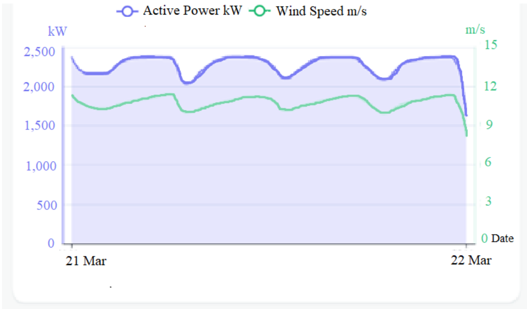

Fig. 11 – Active power vs. wind speed.

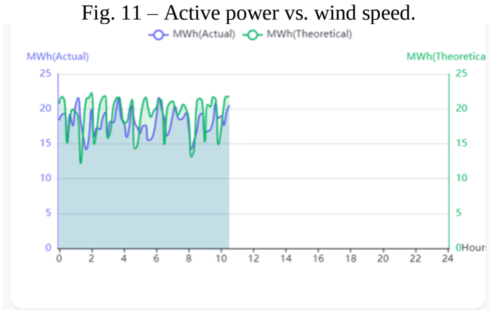

Fig. 12 – Energy produced *vs* theoretical energy.

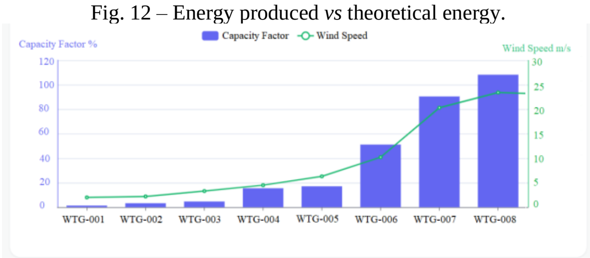

Fig. 13 – Capacity factor *vs* wind speed.

Figure 12 compares the energy produced practically and theoretically by wind turbines. The approximate theoretical energy production is estimated using the measured wind speed. Figure 13 presents the variation in capacity factor with a change in wind speed. Figure 14 presents the power generation status of the various Wind Turbines at a site.

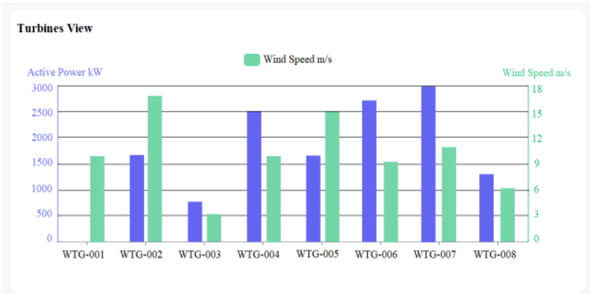

Fig. 14 – Power generation status.

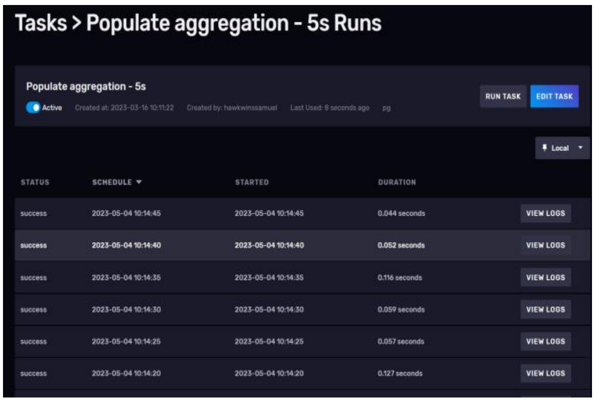

Fig. 15 – Execution of task in influx DB.

Analysis of wind turbine data is required to increase efficiency, save maintenance costs, and forecast remaining usable life when data is inserted into asset models for wind turbines. Based on current wind speed data, turbine generator data is analyzed to anticipate various power values accurately. Essential characteristics, including wind rise, wind profile, and turbulence, are examined by simulating the proposed location of the wind turbine.

Figure 15 shows that the task is executed and passed. The status of the result is SUCCESS after execution of the task. The power generated by a turbine, wind speed at the site, wind direction at the site, nacelle direction of the wind turbine, rotor speed of the turbine, and state of each wind turbine are presented.

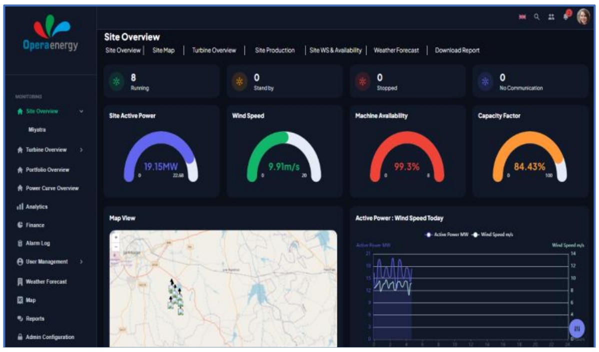

Fig. 16 – Main page of the application.

Fig. 17 – Live status of wind turbine.

Figure 16 presents the main page that displays the dashboard for a site overview of the system. Figure 17 presents the page that shows the live status details of an individual wind turbine. It also includes data analytics using data visualization of average wind speed and renewable energy generation by the particular wind turbine for the past few days.

6. CONCLUSIONS

This paper presents a scalable, efficient, secure web application for monitoring renewable energy systems. It is a long-term and sustainable solution. The website can display real-time energy generation data, wind speed data from the anemometer sensor, etc. Data acquisition is done every minute and sent to the data storage. The asset details are processed, and the analytical data, such as instant power generated, average wind speed, rotor speed, wind direction, nacelle direction, wind speed details, energy production details, power curve, etc., are displayed using various charts.

Additionally, the web-based platform allows for easy access to historical and real-time data. Thus, it facilitates better decision-making and improves the overall management of wind energy systems. Future work will include features to estimate the causes of the failure of wind turbines, air turbulences, *etc*. Monitoring and analysis of sites generating renewable energy using photovoltaic panels will also be included.

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CREDIT AUTHORSHIP CONTRIBUTION

Author_1: Equal contribution to literature survey, system analysis, design, implementation, testing, and documentation.

Author_2: Equal contribution in literature survey, system analysis, design, implementation, testing, and documentation.

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