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REVIEW

Efficient monitoring and control of wind energy conversion systems using Internet of things (IoT): a comprehensive review

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Abstract
The necessity of making smart devices, intelligent processing and informative communication has taken the Internet of things (IoT) to a new level. Various industries have been implementing IoT-based services to increase the throughput as well as for information management and analysis. Such IoT-based systems with the use of cloud computing and big data analytics are now approaching toward the field of wind energy, one of the most promising, environment friendly and clean renewable energy sources. In the scenario of the competitive energy market, productivity, efficiency, operating costs and profitability are of prime importance. All these parameters demand a system with the ability to continuously monitor and maintain high performance over the time. That is where Internet of Things (IoT) analytics is seen as a significant technology trend for the sustainable growth of renewable energy sector. This paper discusses the recent trends and use of IoT in energy generation, specifically in relation to wind energy generation. This paper explored various areas of IoT application with respect to WT system such as IoT integration with energy generation system, IoT in wind turbine monitoring and control, maintenance and prediction systems. The prime contribution of this review paper is that it summarizes the current state of the art of IoT-based applications in the wind energy conversion systems.

Keywords Wind power plant · IoT integration · IoT analytics · Wind power prediction · Internet of energy

1 Introduction

1.1 Concepts

Industry 4.0—a Fourth Industrial Revolution, is being extensively empowered by various recent technologies such as communication systems (e.g., 5G, LTE),

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artificial-intelligence-based robots, AR/VR techniques and the Internet of things (IoT). The rapid development of big data and the IoT is positively affecting different areas of technologies and businesses and thereby increasing the paybacks for organizations and individuals. There are enormous opportunities for analyzing and exploiting massive amounts of IoT data in applications such as smart cities, smart grids, smart transport and smart energy meters (Marjani et al. 2017).

The Internet of things is an innovative architype in the present information technology world. The term "Internet of Things" which is well known as IoT is a makeup from the two words, i.e., the "Internet" and the "Things," and becomes a disruptive level of innovation into today's ICT world (Atzori et al. 2010). Due to the recent developments in smart sensors, communication technologies and Internet protocols, it became possible to interconnect billions of heterogeneous devices and objects through IoT. Approximately 25 billion devices will be connected to the Internet by 2020 and the data collected through these connections will help in big data analysis, planning and management of data with autonomous intelligent decision-making (Ray 2018). An IoT is also counted in the list of six prospective "Disruptive Civil Technologies" with impacts on US national power by the US National Intelligence Council.

The smart grid and renewable energy are two prime areas of application of IoT in the recent period. The renewable energy market has seen exponential global growth over the last decades. Cumulative capacity in the wind energy sector has gone up from 24 GW (2001) to 590 GW (2019) (Ministry of New and Renewable Energy 2020). However, this growth imposed a burden to increase their profits and productivity as the industry scales all over the world (Hansen 2019). Such a challenging situation demands the use of new techniques and innovation for solid growth. The next batch of innovation would be driven by data and sensors, thereby IoT. The promising aspect of IoT is that we can analyze IoT data with real-time speed. IoT technology helps us to improve the capability to build deeper and more accurate digital modeling for the real world and achieve more closely interconnection between people, things and services (Nivas 2016). According to Capgemini Digital Transformation Institute (2018), energy and utility sector is the high potential sector to be considered for implementing the IoT and currently its full operational deployment is nearly 35%.

1.2 Motivation

The ever-increasing usage of big data in wind energy sector generates approximately 25 trillion bytes/day data. Connections of machines to machines through networks, data and analytics cause a paradigm shift with the Internet of things (IoT) in wind energy generation. IoT is becoming a significant tool to deal with challenges of wind energy operation and maintenance (O&M). It is likely to cut down the operating cost and deploy sophisticated predictive and proactive O&M solutions through IoT's advanced analytics capabilities (Bouqata 2017). Information management that includes data acquisition, transmission and processing is the most challenging task for consistent operation and control of any system. By introducing more relevant and useful information to data processing systems, it can take more appropriate decisions based on the knowledge base (Shakerighadi et al. 2018). The IoT market is expected to increase to 43% by 2022 according to the International Energy Agency. The Information Technology division of National Institute of Wind Energy (NIWE) is working to build its skills in the area of data analytics, design thinking, machine learning and Internet of things (IoT), which are foreseen as critical areas of expertise that NIWE will need in upcoming era of big data.

The wind control system is indispensable for dependable and safe procedure, monitor devices and variables, so that these variables are in an acceptable range and must achieve fault detection and prediction. IoT technology could solve the issues of full sources and reliable data acquisition and efficient and secure transmission. Big data technology provides the ability to process and analyze massive data (Yuan 2016). Power generation through wind turbine also depends on various parameters such as wind speed estimation, surface landscape and weather conditions. Innovative sensing techniques and IoT will probably play a key role in obtaining and communicating raw data inputs to wind prediction models (Muhanji 2019). Hossein Shahinzadeh et al. (2019) discussed applications of IoT for smart grid infrastructure. The study also highlights the need for IoT in renewable energy generations such as wind and solar. Real-time monitoring and control of power flow and power quality (PQ) are also important in energy generation systems. Authors in Viciana et al. (2019) proposed an IoT-based system using open hardware design approach which is proposed as a solution for PQ analysis which will help in energy-saving solutions.

The widespread applications of IoT in the energy sector have been reviewed in Motlagh and Mohammadrezaei (2020) and discussed specifically the enabling IoT technologies and the various platforms for data analytics. Moreover, the review presented in Shakerighadi et al. (2018) discussed the challenges and state of the art of the IoT components as well as solutions for the challenges in the energy sector. Most of the literature survey conducted regarding IoT applications and their enabling technologies are more specifically oriented to the smart grid (Saleem et al. 2019), renewable energy (Nivas 2016; Al-Ali 2016) and some specific subsector application areas such as energy-efficient devices and building automation (Alonso-rosa et al. 2018), metering infrastructure (Marinakis and Doukas 2018), etc.

1.3 Methodology

During this survey, our focus is on the latest IoT-based developments and methods used for wind turbine monitoring and control. A preliminary related literature was carried out using search engines such as IEEE Explore Digital Library, Springer, Google Scholar and Research Gate. The articles are selected according to their importance for the wind turbine monitoring and control, and only most significant and indexed articles which belong to journals or magazines or important conferences are selected. Internet of things and IoT-based condition monitoring are some of the key terms searched on the Web. Likewise, all cited research papers were examined well and only the appropriate articles were included in this study.

This paper is intended to provide an overview of recent advances and trends of IoT-based applications for wind energy conversion systems. Initially, the need and uses of IoT-based system are introduced. A brief overview of wind energy is given in Sect. 2. Section 3 gives a brief regarding IoT integration with the wind energy system, and Sect. 4 describes the IoT analytics. The application of IoT for monitoring and maintenance of WECS are reviewed in Sect. 5, whereas Sect. 6 is devoted to the IoT application for data analysis and prediction. Section 7 presents IoT-based reliability analysis. In Sect. 8, we have introduced the future trend of energy research—the Internet of energy (IoE). Section 9 summarizes the conclusion and future scope.

2 Wind energy

The increasing consumption of electrical energy and the continual decline in traditional sources of energy caused a massive demand and supply gap in electrical energy. This has shifted the interest to harness energy from the unconventional energy sources like solar, wind, biomass, geothermal, etc. Wind is considered as a favorable and popular alternative source of power generation. Wind is the extensively distributed and abundantly available clean energy resource. Figure 1 shows that, in December 2018, global wind power installed capacity is approximately 591 GW. In India, approximately 36.68 GW of energy is generated from wind out of 81 GW of renewables as of July 2019 (Karad and Thakur 2019).

Considering increased penetration of large-scale and small-scale wind farms with different turbine technologies and topologies, it becomes imperative to study and use advanced monitoring and control strategies for wind turbine.

A WECS is an arrangement of subsystem components altogether that converts wind energy into electrical energy. A typical WECS comprises a wind turbine, a generator, power electronics devices and control system as shown in Fig. 2. Wind turbines (WTs) are used to harness mechanical power from wind.

3 IoT integration with wind energy generation system

Wind energy is seen as a prospective energy resource that holds the greatest chance of evolution and use of modern communication technologies. Most of the techniques which are already employed are conventional and are too unitary such as the wired method that has many weaknesses. The wireless sensor networks (WSNs) have been becoming more attentive technology in recent years for the wind industry. The wireless sensor network (WSN) (Mendhule et al. 2014) is one of the solutions to overcome communication difficulties in remote communication. The WSN also found its importance in structural health monitoring (Lestari and Arafat 2019; Swartz et al. 2007) of the wind turbines. The remote wireless monitoring system can be used for real-time remote monitoring and management (Bhuiyan and Billah 2013; Chakkor et al. 2014) by using the WSN for various parameters such as the direction of winds, current and voltage.

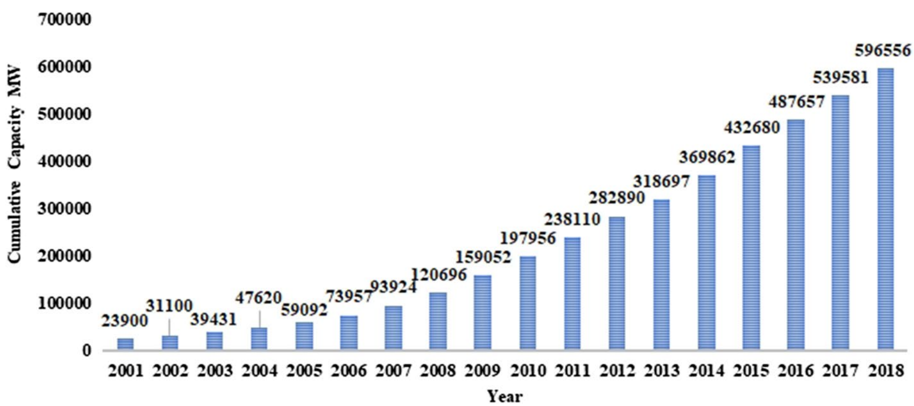

Fig. 1 Worldwide wind energy installation

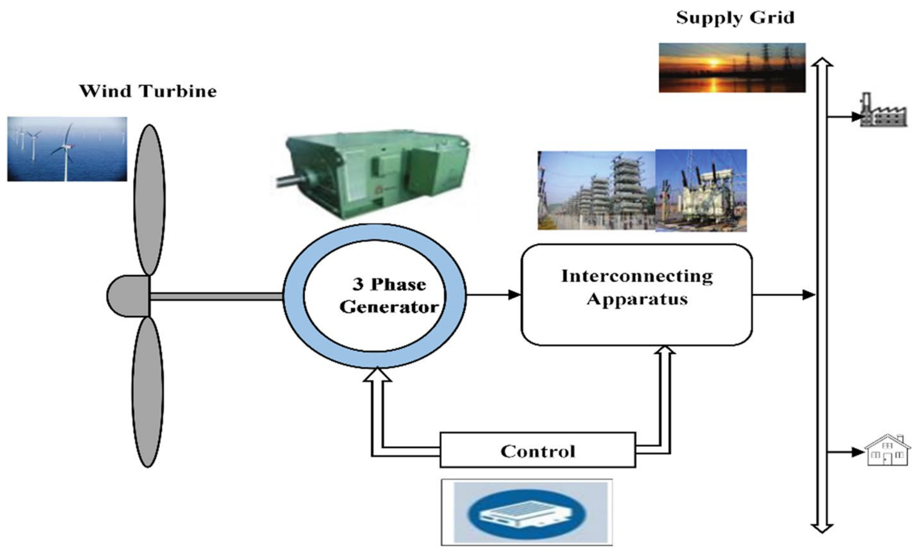

Fig. 2 Schematic of WECS

The wireless communication using WSN and IoT is used to monitor the WTs with modifications in traditional SCADA (supervisory control and data acquisition)-based systems. IoT consists of embedded entities, network layer and control functions, thereby improving the scalability and reducing the network overhead (Ambarish and Bharathi 2016). An integration of WSN and IoT is applied for parameter monitoring in windmill (Vijayaragavan et al. 2019).

In Al-Ali (2016), an IoT/IIoT conceptual model has been proposed to integrate the renewable energy systems in a smart grid. In this study, each renewable energy resource is assigned a unique IP address. Each object is monitored via its unique IP address by using a bidirectional communication protocol which eliminates the need for many communication protocols in the same grid. This concept can also be extended to the distribution and generation field.

Authors in Srbinovski et al. (2017) presented a unique use of IoT in the area of renewable energy monitoring and wireless data collection. An 8×8 (64) IoT wind farm platform was developed using miniaturized WTs with wireless connectivity. The work highlights the possible use of low-cost, wireless, battery-powered, IoT node for remote data collection with a data logger that has limited storage that cannot be remotely accessed. Also, power measurements of the IoT node were carried out and an energy analysis was performed.

In a network, devices and nodes need to communicate in the common language and to follow a set of rules to exchange information with each other called as protocols. Protocols specify how signals are directed from one device to another, or multiple devices, in order to trigger a desired behavior. A survey article (Samaila et al. 2018) briefly explained the various communication protocols such as IEC 62,056, IEEE 802.15.4, DTLS, Zigbee, Ethernet, CoAP and HAN used for smart grid as well as power system applications.

The wind industry started to follow Industry 4.0 with the integration of IoT, big data analytics, cloud computing and machine learning with machine-to-machine communication. There are many commercial platforms which are used for monitoring, managing and optimizing the resources in wind farms. Few of the related product platforms from leading companies in the market are as follows. (Table 1)

3.1 IoT sensors in WECS

Any smart system and IoT-based systems are driven by the combination of sensors/actuators with connected devices to the people/processes. It is expected that approximately 30 billion devices will be added by 2020 into the overall IoT-based systems. Wind turbines need a variety of different sensors in various subsystems for efficient monitoring, control and data collection. Perhaps, without sensors, WTs would be less secure, more costly to operate, unable to accurately anticipate and solve impending failures. Most importantly, wind farms need accurate information about every turbine that can be offered only by sensors linked together and tied to a control center. Figure 3 shows the schematic of a wind turbine with different parameters for which sensors are required in WECS monitoring.

4 IoT analytics in wind energy system

IoT analytics is the use of data analysis tools and techniques to apprehend significant data from the huge amount of data generated by connecting IoT devices. The prospective of IoT analytics is mostly related to the Industrial IoT. The IoT analytics is helpful for companies to understand and devise the strategies for reducing maintenance costs, avoiding equipment failures and improving business operations. IoT analytics also aid real-time edge analytics by providing only meaningful data from the big pool of data for more broad-based, strategic analysis (Schmarzo 2017). A three-tier architecture of IoT analytics for a wind turbine farm is shown in Fig. 4. The data generated through IoT sensors have distinct life stages and time span. In the initial stage (on the edge), data last for 1 s to 5 min, in the medium stage for 5 to 30 min, long term with 30 min to 1 day, and historical data last for more than 1 day. An IoT analytical environment requires a three-tier architecture to support data analytics across these different data life stages.

The advanced monitoring strategies and tools have been developed to analyze the performance of the wind farm turbines in real time. A cloud-based IoT analytics ecosystem platform will include models for identifying and diagnosing wind turbine faults.

Reliability analysis has been the main agenda for wind energy generation nowadays, where IoT is a vital and have lot of research prospect for improvement and challenging work. Data collected through IoT are converted into meaningful information to improve WT performance with reduced risk and cost-effective energy production. The IoT provides a promising solution for online monitoring and control of the sensors and actuators of the WT for real-time reliability analysis. In Alhmoud and Al-zoubi (2019), IoT-based wind resource assessment and lifetime estimation of wind power modules have been investigated. A PMSG with variable speed control with its various sub-models of an aerodynamic rotor, pitch angle control and grid connected full-scale power converter has been built to study performance assessment. Also, a large number of IoT sensors for measurement of wind parameters are integrated. The integration of IoT in the proposed system is utilized to fulfil the various needs of the system as shown in Fig. 5.

The proposed IoT-based wind farm assessment system has scalability and significant benefits such as data collection for performance optimization with wind farm sensors, identifying predictive and preventive maintenance and integrating system level and component

Table 1 Commercial wind turbine monitoring platforms

Platform	Company	Uses
Windmill Manager (Manager 2020)	WebNMS	Condition-based wind turbine performance monitoring and maintenance
Cloud-Based IoT Solution (IIoT 2020)	Qburst	To monitor turbine parameters CMMS plug-in module supports alerts and calendar-based maintenance management
Digital WindFarm (Wind and Farm 2020)	GE	To improve maintenance strategies, reliability and availability, and increase annual energy production
EnOS™ Wind (EnOS 2020)	Envision	An intelligent IoT operating system which transfers the traditional wind farms into the smart wind farms with remote supervision and regional maintenance

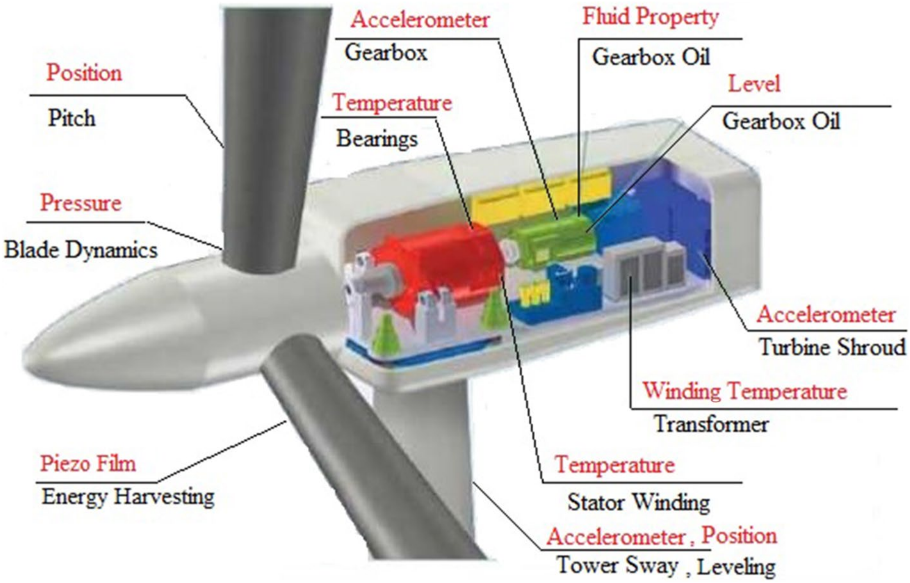

Fig. 3 Wind turbine monitoring sensors

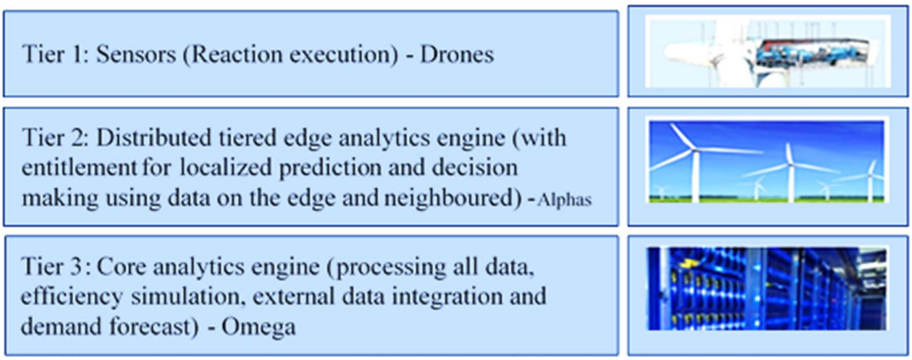

Fig. 4 Three-tier IoT analytics architecture

level through an IoT system. It requires to address issues such as communication protocol, device access through Internet and cost assessment.

5 IoT in monitoring and maintenance of wind power generation system

Monitoring and control systems help to continuously track the real-time performance of system anytime, anywhere by collecting device performance data, energy uses and environmental conditions. Advanced smart grid and smart metering infrastructure revealed

Fig. 5 IoT features used in wind farm

their importance for optimizing operations and in predicting future outcomes leading to cost reduction and increased productivity (Lee and Lee 2020). As on now, IoT-based monitoring in wind power generation is in the primary stage, but a future technological trend has bright scope. Few research studies proposed the IoT-based monitoring systems for wind generation system.

Long Zhao et al. (2019) presented a study of field-programmable gate array (FPGA)-CPU-based holistic condition monitoring system for wind turbines. This proposed system provides condition and SSCI monitoring as well as records past data in real time for the analysis purpose. This approach serves to cut the needless complications and redundant synchronization between two autonomous monitoring systems for the same WT. The FPGA-CPU hybrid controller enhances system performance. Figure 6 shows the schematics of the proposed holistic IoT-based WT health monitoring system.

Due to the integration of IoT in wind energy, the WT and wind farm data are collected in real time and immediately analyzed. This overcomes the hurdles of communication delay for offshore wind farms and inadequate bandwidth to transfer information to remote locations. It also helps in the decision-making situations like turning off a turbine for maintenance or any other purposes. The use of IoT systems in the wind power demands more inclusive approaches for economical, safe and sound frameworks for the design and operation of wind farms (Moness and Moustafa 2016).

The maintenance of the offshore wind system is a challenging and costly task due to its location that is hard to reach. IoT-based maintenance is becoming a competitive trend in predictive maintenance of offshore wind energy systems. Tuyet (2016) evaluated the benefits of using IoT technology in the maintenance of offshore wind system, and it is compared with the conventional maintenance method. In the future, IoT-based maintenance technology will prove to be very promising in offshore wind systems. Sensor technology and information networks are the two prime aspects of IoT-based system for predictive maintenance as well as for the scheduling and analysis. The concept is shown in Fig. 7.

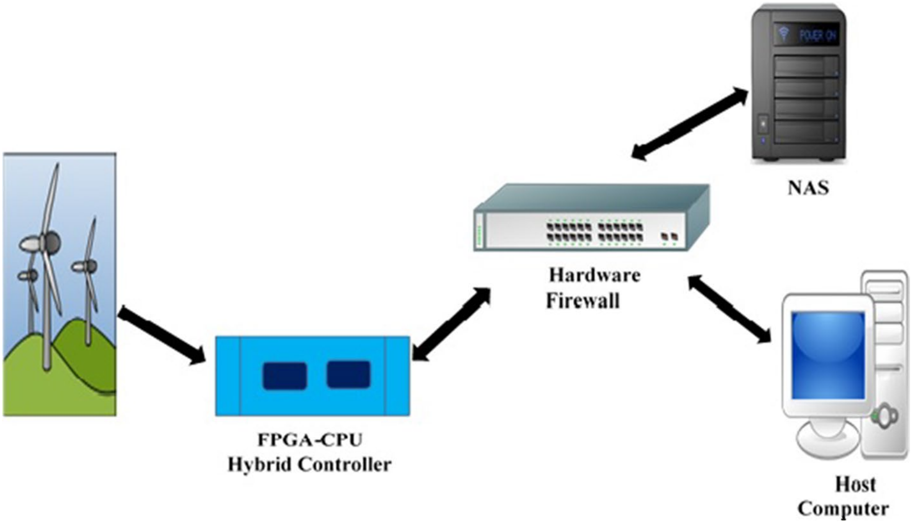

Fig. 6 Structure of holistic IoT-based turbine health monitoring system (Long Zhao 2019)

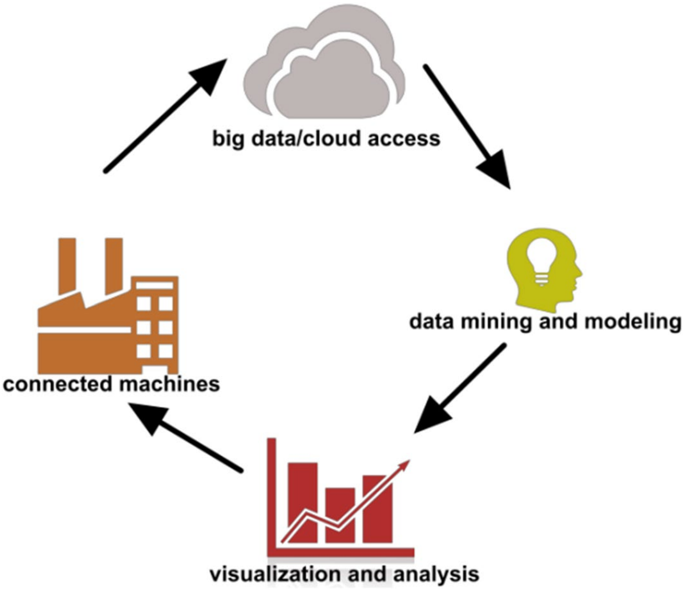

Fig. 7 IoT-based predictive maintenance system (Tuyet 2016)

An optimal condition monitoring of WTs using intelligent image processing and IoT is proposed in Sujatha et al. (2018). The FLC-based intelligent image processing system investigated with IoT offers better online performance monitoring for a WT. Authors in (Edison and Sanoofar 2018) proposed and implemented a real-time monitoring and fault diagnosis system for WT using IoT-enabled techniques. The prosed system gives live status monitoring, early fault identification and analysis of historical status. A low-cost IoT-based monitoring and control system was proposed in Kalyanraj et al. (2016) for a WT with data logging facility. The various turbine parameters such as voltage, current, output power, vibration, speed and humidity are monitored anywhere at any instant.

Merely, an electrical or mechanical engineer cannot perform the maintenance of wind turbine systems and increased power generation, but it will be achieved with the innovation of active measures by the sensor data and analysis including the IoT. Chitra (2019) designed an IoT-based oil conditioning monitoring system with smart MEMS sensors for a wind turbine gearbox (Fig. 8). The MEMS-based smart humidity, viscosity and pressure sensors have been developed to be integrated with the IoT-based remote monitoring system. This automatic monitoring system is used to access the real-time data from anywhere with a mobile app through cloud-based IoT system. The proposed system helps in improved energy efficiency and also proper early repairing schedule on account of fast and real-time fault detection and diagnosis.

A combination of WT and an IoT network can be used for real-time performance monitoring and fault detection so that necessary action can be taken on time. It requires a trustworthy wireless communication link between WTs and Internet. An IoT-based wireless communication scheme (Noor-A-Rahim et al. 2019) is proposed to monitor the states of the wind turbine. Besides, a novel fusion algorithm is proposed to combine and process the multiple data acquired from different sensors. The results obtained are used to predict the state of a wind turbine. It is needed to test the proposed state estimation technique on a testbed to study its performance in real use conditions.

The IoT-based services are nowadays influencing all the fields of renewable energy generation, and wind energy is not the exception to it. The work presented in Feij et al. (2020) proposes an intelligent incipient faults detection system to be used in wind turbine electric generators to improve maintenance routines. The proposed system applies the higher-order statistics (HOS), the Fourier transform and structural co-occurrence matrix (SCM) feature extraction methods to vibration signals, and different classifiers such as KNN, MLP, OPF and SVM were used to predict the successive position of the WT. The researchers were able to identify normal conditions of the wind turbine with 98.93% of accuracy and reduce the false positive rate to 0.4.

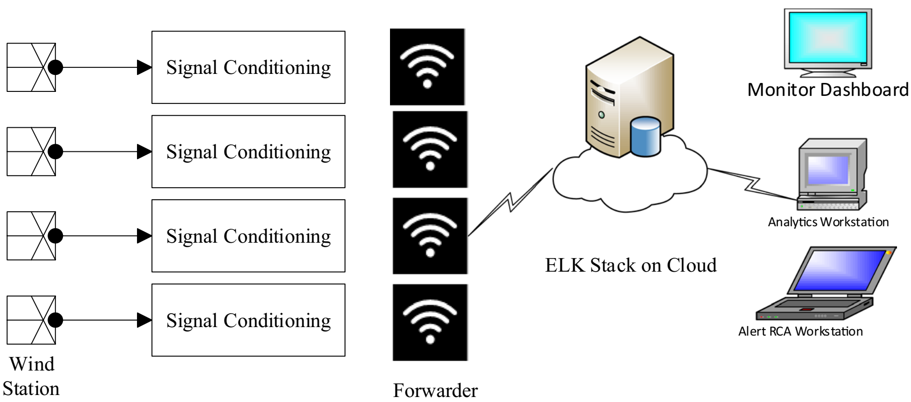

Fig. 8 IoT-based monitoring system (Chitra 2019)

The IoT-based cloud computing technology is becoming a promising alternative for big data processing and therefore can be applied in the condition monitoring of the wind turbine. The novel cloud computing-based conditioning monitoring system for WT is presented in Qian et al. (2019). The paper uses SCADA data obtained from a wind farm to validate the usefulness of the method proposed. Gearbox oil temperature- and bearing temperature-dependent prediction model for gearbox condition monitoring has been carried out. It is shown that the hierarchical extreme learning machine (H-ELM) provides higher prediction accuracy than conventional ELM algorithm. The proposed method needs to be implement in real-time online mode for WT conditioning monitoring.

6 IoT for wind power analysis and prediction

The uncertainty, instability and uncontrollability of wind will affect the security and stability of the power grid as well as impose the gridlock load of the complete power network. That's why precise prediction of wind power is prime importance in the wind farm operation and power grid dispatching (Zhang et al. 2019).

In Rebouças et al. (2019), IoT-based estimation of the electricity generation from a WT has been discussed, so that it can be utilized effectively and substantially. This work proposed two approaches: (1) WT power curve regression, and (2) time series data-based wind speed forecast (Fig. 9). The analysis of the proposed approaches indicates that the wind speed forecast and the power curve modeling might be used separately, for optimized maintenance planning, according to periods of low wind speed, and serve as a WT controller tuner.

One of the key challenges in operating a WT is to take care of the structural health of the WT by detecting structural damages correctly and timely. A wireless sensor and actuator network-based damage prediction system has been proposed (Melo et al. 2017) for WTs. In the proposed system, all decision-making process is accomplished collectively through the nodes. It is a decentralized system, called as Delphos based on a time series forecasting model, called ARIMA (autoregressive integrated moving average). The Delphos accurately predicts the damage state of the turbine and allows timely action to prevent accidents as well as it reduces maintenance cost and power generation delay. Figure 10 represents the schematic of the proposed system.

Mikel Canizo et al. (2017) presented an evolutionary predictive maintenance solution based on a big data framework. The proposed system predicts failures on WTs by a data-driven approach deployed in the cloud. It consists of three main modules: (1) a predictive model generator that uses the random forest algorithm to predict the model of each WT, (2) a monitoring system that forecasts about failures in WT at every 10 min interval, and (3) a console for real-time visualization of the predictions.

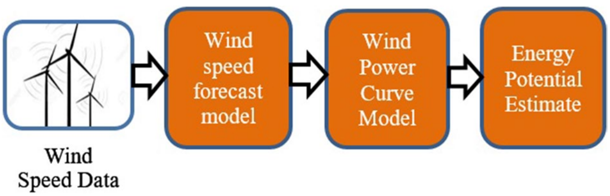

Fig. 9 Estimation of wind potential

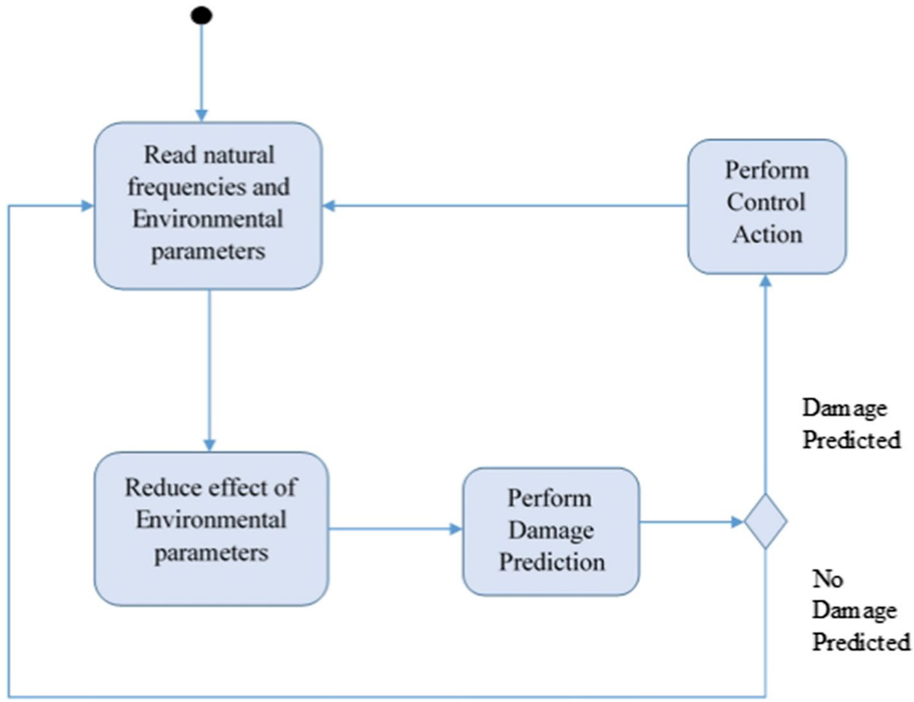

Fig. 10 Delphos prediction process (Melo et al. 2017)

7 IoT-based reliability analytics

Reliability refers and aims to the effective working and increases the success rate of the IoT system based on its specification. Reliability guarantees the availability of information and services over time (Al-fuqaha et al. 2015). The reliability of the IoT devices and system cannot be evaluated individually, but it can only be measured for each service and node separately.

Unlike conventional power plants, wind turbines (WTs) are unmanned and remote power plants are exposed to highly capricious and tough weather conditions such as severe winds, tropical heat and lightning. These external variations impose constantly changing loads on WTs and result in highly flexible operational conditions that lead to extreme mechanical stress on wind turbines. Therefore, WT requires a continuous monitoring and maintenance to provide a safe, reliable and cost-effective power with increased equipment lifetime (Tchakoua et al. 2014).

An IoT-based wind resource assessment and lifetime estimation system was developed for wind power modules in Alhmoud and Al-zoubi (2019) to perform the reliability assessment for a PMSG-based WT system. A MathWorks ThingSpeak-based reliability estimation model was developed for the reliability assessment.

An analytics platform was developed in Takeda et al. (2016) that collects operational data of mechanical systems using the IoT and uses the analytical results in reliability design, operation and maintenance. The data so collected were also used for failure analysis using this platform. The use of the IoT has made it possible to gather a relatively huge amount of data and made it easier to perform quantitative reliability assessment and failure probability calculation. Reliability is expected to improve continuously through the developed analytics platform.

8 The future–Internet of energy

The Internet of energy (IoE) characterizes the combination of IoT and smart grids. The IoE is the strength for connecting, supervising and control of the future energy sources and consumers (Moness and Moustafa 2016). The IoT elements such as sensors are deployed around the microgrids to monitor the microgrid. The Internet of energy (IoE) infrastructure for sensing and estimating the system state is illustrated in Fig. 11 (Rana 2017).

Jaradat et al. (2015) discussed various recommendations and practices used concerning the smart grid and IoT. The authors explored various applications of smart sensor networks in the area of the smart power grid. The control and management task is more challenging in a distributed energy generation system than a solo energy conversion device. In such a scenario, study of an IoT-based techniques becomes more important. The distributed energy control is becoming one of the strategic interests for next-generation decentralized energy infrastructure; sometimes, it is being referred to as “energy internet” or “Internet of Energy (IoE)” (Huang et al. 2010).

More recently, the industrial Internet or industrial Internet of things (IIoT) has been introduced to the energy industry and all the assets in a distributed energy system are treated as a smart industrial device so that a similar industrial distributed control could be applied. The IIoT uses the latest IT tools such as big data or cloud computing methodology to handle the large control signal flow of distributed energy assets. The concept of IIoT-driven software and controls platform developed on the NICE Nano-grid project is introduced in Zhang et al. (2018). Cloud computing is one of the well-accepted platforms and is considered as the basic solution for IoT application. Figure 12 shows the structure of the cloud control platform for distributed generation energy system.

Authors in (Salhaoui and Arioua 2018) provided an IoT- and cloud-based system to monitor various components of the wind turbine system in a real-time environment using Siemens IOT2040 gateway. The use of an IoT gateway helped in transmitting the analyzed data from the cloud to the control system and devices.

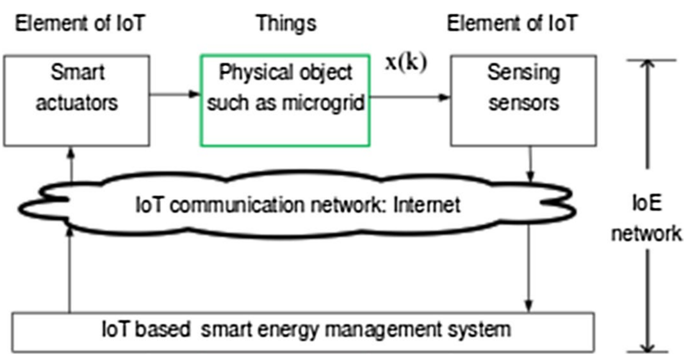

Fig. 11 IoE structure for smart grid

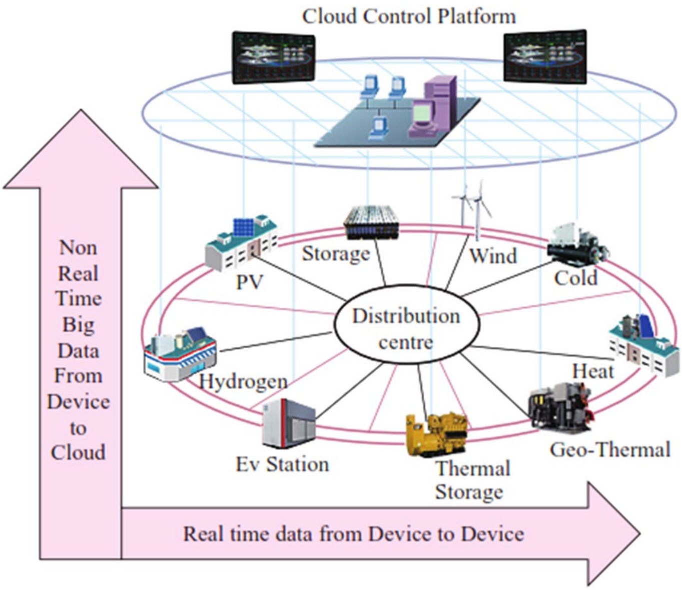

Fig. 12 Structure of cloud control platform (Zhang et al. 2018)

9 Conclusion and future research scope

The use of IoT technology just started to spread its wings under the Industry 4.0 and so has lots of future scope for research and development. Through the cloud-based IoT platform, the data can be easily accessed, transferred, analyzed, stored and presented. In this paper, an overview of IoT integration with WECS is presented. This integration will enable IoT-based WECS to be part of next-generation smart energy grid and IoE. The following important points are concluded from the present literature study:

- The increasing penetration of renewable energy and WECS demands the integration of smart devices, WSN, IoT and big data analytics for increasing productivity and scalability.
- Future IoT-based architecture of WECSs requires the integration of a large number of smart sensors for different applications such as structural health monitoring, wind parameter monitoring and predictions, predictive maintenance, power transmission and integration with the smart grid, control and monitoring of electrical parameter.
- The existing SCADA-based systems in the future may require to integrate with more intelligent M2M communication systems in accordance with Industry 4.0 capabilities.
- So future research trends may consider the more efficient and intelligent communication protocols for this integration.
- Most of the current research focus is on the initial integration of IoT devices for monitoring and maintenance purposes. The use of IoT for overall control needs to be considered as one of the future scopes of research.
- It is also necessary to review and to identify the limitations and advantages of the device connections, such as RFID, Wi-Fi, Bluetooth and Zigbee, and to their integration with other communication technologies such as GSM, 3G and LTE.

- Eventually, we may conclude that IoT, big data analytics and cyber-physical systems (CPS) are the next-generation technology trends for the IoE, and therefore more focused research is demanded to be undertaken regarding the use of these technologies in the area of energy.
- Use of IoT for optimization of operations is in the wind power industry and resulted in (i) reduced wake losses by adjusting pitch and yaw angles of specific WT, (ii) increased turbines production over a rated value, and (iii) individual turbines are optimized to local conditions to increase output. According to Ramamurthy and Jain (2017), there is a 5% to 10% increase in annual energy production with these IoT-based strategies.

Compliance with ethical standards

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

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