Celal Bayar University Journal of Science

IoT and Cloud Based Remote Monitoring of Wind Turbine

Ersin Akyüz[1]*, Batın Demircan[2]

[1] Balikesir University, Higher Vocational School, Control and Automation Department, Balikesir, Turkey,
[2] İŞBİR Elektrik San. A.Ş., Research and Development Department, Balikesir, Turkey
*Akyuz11@gmail.com

Received: 15 March 2019
Accepted: 12 December 2019
DOI: 10.18466/cbayarfbe.540812

Abstract

With the industry 4.0 revolution, the concept of industrial production will be reshaped with information technologies and will rapidly shift to a new understanding of production. The Internet of things and cloud computing will play a vital role as the most important elements of this transformation. In this study, parameters that are crucial for the performance evaluation of a small power wind turbine are measured. Measurements can be used to evaluate the performance of the system and to avoid errors in the system. In the designed system, basic parameters such as wind speed, air temperature, battery voltage and battery current were measured and recorded through datalogger. These measurements were sent to the Microsoft Azure cloud computing system and recorded there. At the same time, visualization with the aid of the cloud system was performed and viewed in real time on the web via Microsoft Power BI platform.

Keywords: Internet of things; wind turbine; cloud computing; industry 4.0.

1. Introduction

Global warming and climate change caused by greenhouse gas emissions have become one of the most important problems threatening our future. Recently, sustainable energy strategies have been developed to combat this problem and to create more sustainable living spaces. Utilization of renewable energy is believed to be the key to the solution. The European Union (EU) has a target to meet 27% of its energy need from renewable energy sources by 2030. Continuous technological progress and investment are required to meet this target and, in this regard, in the EU, renewable energy consumption level of 10.4% was met by wind power plants in 2016 [1]. As of the end of 2017, the power capacity of installed wind energy reached 177.506 GW [2].

The fact that wind energy technology has a rapidly growing trend requires this technology to continuously find more innovative, efficient and technological solutions. The rapidly evolving cloud-based IoT solutions with Industry 4.0 transformation will provide important solutions in wind energy technology such as increasing life span of devices and reducing operating and maintenance costs in wind turbine technology. This technology will provide real-time data storage and retrieval of wired or wireless information from the sensors [3]. Real time monitoring of wind farms during especially in harsh operating conditions provides pre-detection of faults and better understanding of operating behavior in order to produce more economical solutions [4].

1.1 Background

The Supervisory Control and Data Acquisition (SCADA) structure usually is used for monitoring, collecting, and storing finite amount of data with computers for day-by-day operations of plants without internet network. The new IoT based cloud SCADA concept is considered as a key element of the Industry 4.0 revolution and will play a crucial role in shaping the future of internet [5,6]. Cisco predicts the number of connected objects to be 26.3 billion by 2020 and by Huawei to be 100 billion objects by 2025. It is also envisaged that this sector will reach a 3.9-11.1 trillion-dollar value to the economy in 2025 [7].

Implementation of IoT and cloud-based systems are used in many ways such as wired or wireless sensor networks, intelligent control units, RFID tags, mobile platforms, different communication protocols and security solutions [8-9]. It plays an important role in remote monitoring systems and provide crucial solutions for data transmission, acquisition, storage and data analytics [10,11].

These systems are advantageous for renewable energy power plants such as wind farm environments that have been robust and sparsely located [12]. With IoT-Cloud based SCADA systems, it is easy to increase data storage, accessibility, cost efficiency and scalability [13].

Although there are many studies focusing on a cloud based IoT concept such as smart grids, energy management and smart buildings in the literature, few studies have paid attention to wind energy technology. One of the major research studies focuses on the potential of cyber-physical integration of wind energy systems. The author described the leading-edge technologies that enable internet of energy and discussed the future of SCADA concept for wind farms [14]. Applied studies are largely commercial-oriented and are carried out for off-shore wind turbines. General Electrics (Digital Wind Farm) and Siemens (Wind Service Solutions) have been developing IoT service solutions which optimize wind turbine performance and life span of components to anticipate maintenance requirements [15].

One major example for integration of IoT and Cloud concept is the ROMEO project which provides relatively effective and reliable predictive maintenance and monitoring for the off-shore wind farms. In addition, due to the decision support mechanism, early fault detection of the components may also provide the prevention of failures [17,18].

IoT technology was implemented in stand-alone wind turbine with Raspberry pi and an Arduino microcontroller was used to read analog signals. However, the software used to monitor data has limited features and does not have a user interface. No cloud services are available in the study [18]. In literature, application of IoT-based cloud structure has not been found for stand-alone wind turbines.

In this study, we investigated utilizing of IoT and cloud computing technologies for stand-alone wind turbine. The aim of the study is to investigate real time performance of IoT and cloud computing technologies on monitoring small-scale wind turbine. For this purpose, a program developed to obtain the data from data logger and raspberry pi gateway are used to send the data to cloud service via the internet. In this way, real-time data monitoring as well as performance evaluation could be carried out in different platforms.

2. Materials and Methods

2.1 Cloud-based IoT Architecture of System

The control, monitoring and optimization of the wind energy applications have gained importance. It has been obvious that the SCADA systems continuously have been improved to fulfill the novel requirements of the wind energy technology. The future conceptual framework of IoT and cloud structure is composed of four main parts which are given in Figure 1.

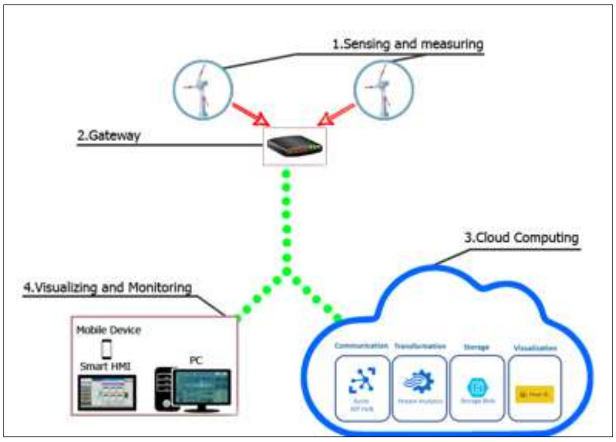

Figure 1. Conceptual framework of wind energy.

- First part consists of wired/wireless many sensors and devices network which are responsible for sensing and measuring the data of wind turbine and environment.
- Second part is an IoT gateway device which provides the communication between IoT devices, sensors and cloud.
- Third part is the cloud which provides a quick and convenient way to store the large amount of data that obtained from different sensors and devices.
- Fourth part is data visualization for real time-monitoring. It provides precious insight that helps maintain the reliability, availability, and performance of a measured system. This helps users react fast changing and emerging situations.

2.2 Configuration of System

The developed system collects data from a stand-alone small-scale wind turbine installed in Balikesir in the northwest region of Turkey. The system consists of a horizontal-axis wind turbine (0.6 m diameter), a permanent magnet alternator, a 3-phase diode rectifier, a battery bank, a charge controller and a system that measures loads, current, voltage, etc. The wind energy set is used for the experimental system (Figure 2).

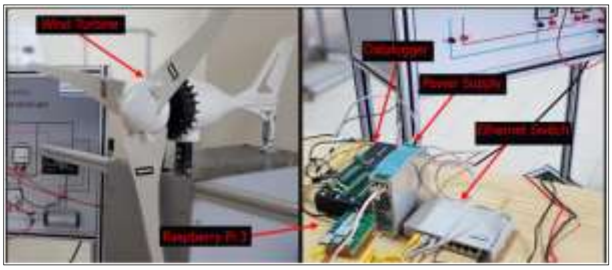

Figure 2. Schema of the experimental system.

A schematic diagram of a cloud based IoT application for real-time monitoring and remote control of a stand-alone wind turbine is shown in Figure 3. The whole system consists of four parts. The first part is the sensing and measurement part which is comprised of sensors for current, temperature, voltage, power, wind speed, etc., and it also includes a data logger (CR1000) for data processing and local storing of data.

The CR1000 datalogger has 16 analog single-ended inputs (8 differentials), and the measurements are recorded at desired intervals with the help of connected sensors. Data are measured by 1 and 10-minute intervals and stored in datalogger memory.

The second part handles data transfer. Raspberry Pi is used to act as the gateway that sends the sensors data to the cloud. The data logger collects and records the data collected from sensors and Raspberry Pi gateway transmits these data to the Azure cloud system simultaneously.

Data storage is the third part of the system. As datalogger have limited storage (2MB) area, Azure platform was used for unlimited data storing. The Microsoft Azure platform, which is widely used and has many different services, has been used as a cloud service provider. This platform has many advantages such as high scaling, server support in different geographic regions, solutions for mobile devices and machine learning support.

The fourth part provides data monitoring for instant access via different platforms such as computers and/or mobile devices using an end-user software (Node-Red and Microsoft Power BI suite).

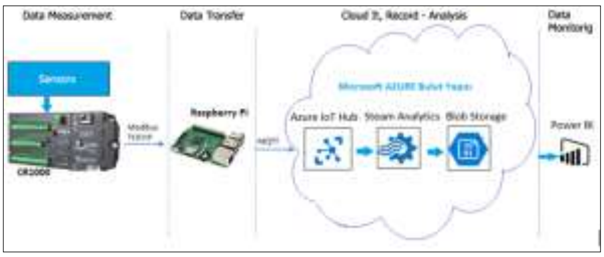

Figure 3. The structure of the system.

2.3 Cloud Services and Software Design

As it is seen in Figure 3, Azure Cloud platform has different services;
IoT Hub: A service that allows mutual secure communication between IoT devices and the cloud. Iot devices communicate via MQTT, HTTPS and AMQP as communication protocols.

Notification Hubs: Messages from any platform for mobile devices and tablets as well as cloud-to-mobile or mobile-to-device applications are also used for informational purposes.

The Stream Analytics: A service allows high-throughput data to be processed directly within a short period of time. Messages constantly received from the other side generate data traffic and the data needs to be processed instantaneously [19].

Node-Red, which was built by IBM, is a free visual software tool that in this study was used to transmit data to cloud and to prepare user interface page. It is a browser-based flow editor which is built on Node.js and therefore can run on a cloud-based server. As it is seen in Figure 4, in order to read data from Modbus holding register address of the datalogger and to send data to the cloud platform, both modules "Modbus TCP / IP" and "Cloud Azure IoT Hub" modules were used. Dashboard nodes which are used in flow diagram are responsible for visualization of the data in GUI page.

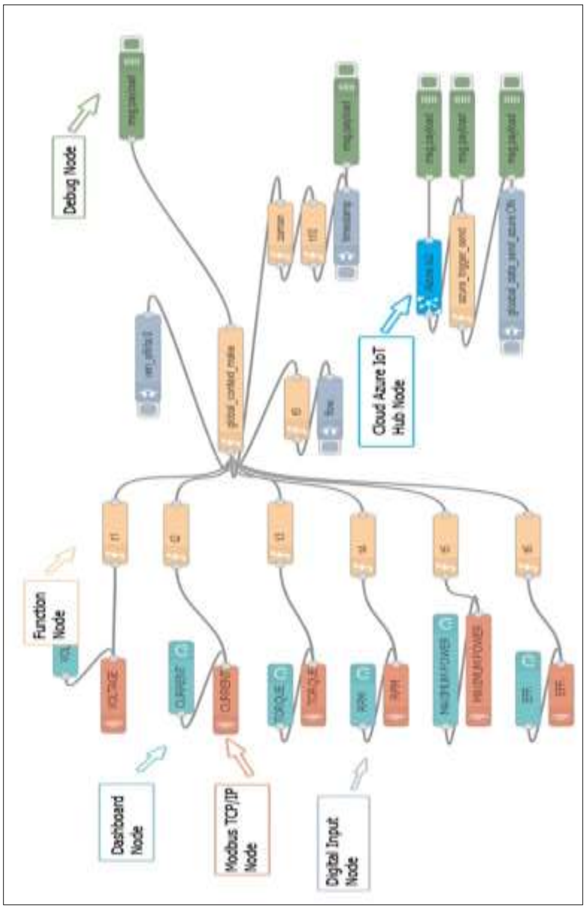

Figure 4. Program flow diagram on Node-Red.

2.4 Wind Energy Calculations

According to the Betz criteria, the maximum benefit that can be obtained from wind is 59.2 %, whereas the wind energy ratio reaches 40-45% on average with modern types of wind turbines. The power output of the wind turbine (Pwt) is expressed as the multiplication of the power coefficient Cp and the power obtained from the wind (Pw) [20].

$$P_{wt} = C_p \cdot P_w \tag{2.1}$$

In this formula, Pw is a variable related with the wind speed V, the air density ρ, and the sweep area A perpendicular to the ground plane and it is calculated as;

$$P_w = \frac{1}{2} \cdot \rho \cdot A \cdot V^3 \tag{2.2}$$

The blade length used in the experimental system is 0.6 m and the sweep area is calculated as 1.13 m^2. The data recorded in the cloud for the performance evaluation of the wind turbine were used in the analysis process.

3. Results

In this study, GUI was prepared with both Node-Red and PowerBI. Node-Red is a free software that is advantageous in terms of monitoring, while Power BI is a paid software that provides very easy design possibilities in terms of visualizing and evaluating real-time data at the same time.

The developed graphical user interface in Node-Red, which shows measured data such as current, voltage, wind turbine power output, rotor speed and efficiency of wind alternator torque is given in Figure 5. Each data was measured at 1 second measurement intervals. The GUI is accessible via Raspberry Pi's IP address and the data is accessed and monitored via internet.

Figure 5. Developed graphical user interface in Node-Red.

Generally, stand-alone wind turbines are constructed at distant points and operate under harsh operating conditions, with frequent failures. Besides, they operate without being controlled by specialists and cannot be continuously monitored by authorized person for maintenance monitoring. Real-time monitoring GUI is used for maintenance and fault analysis. In Figure 6, some critical working condition and set points could be monitored in developed fault GUI screen by authorized persons. The critical situations are monitored in cases where the winding temperature of the generator and the battery voltage exceeds the critical value, or the dump load is active.

During the measurements, the wind turbine started to produce electrical energy when the wind speed was over 3.2 m/s. When wind speed changed between 3-8 m/s and the alternator efficiency of the wind turbine was calculated in the range of 75 - 85%. It is obvious that the rotor angular speed varies linearly with wind speed. In terms of the behavior of the rotor rotational speed with respect to the wind speeds. Alternator rotational speed changed between 80-235 rev/min and current and voltage increased linearly. While current varied between 0.75-2.6 A and alternator voltage was measured between 14-39 V.

In this study, data transmission to the cloud was provided by using the MQTT communication protocol which is based on the logic of publishing messages and subscribing to broadcast messages. Many different application layer protocols such as HTTP, MQTT, AMQP, CoAP, XMPP can be used for IoT applications.

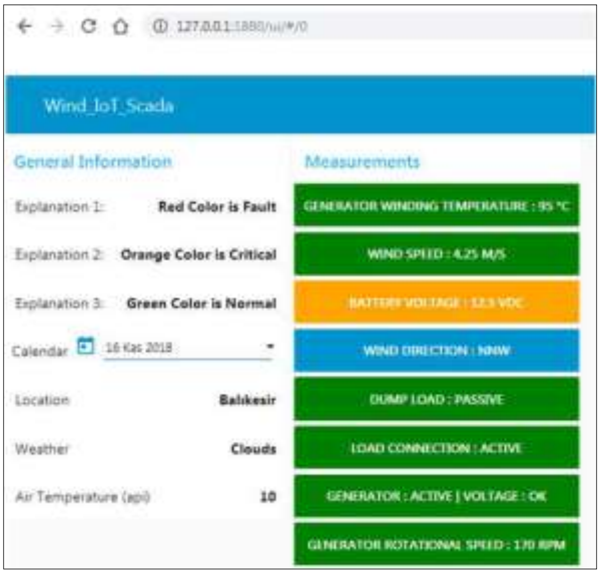

Figure 6. Developed graphical user interface in Node-Red.

The most important advantage of Node Red software is free of charge, but external database is needed to store Iot data in database. Access to the system at different user levels has disadvantages in terms of security. In addition to the mentioned disadvantages, Microsoft

Power BI software has many advantages such as data analysis and it has been preferred to visualize and analyze the IoT data in real time. The user graphical interface prepared in the software is given in Figure 7. The data in user graphical interface such as wind speed, current, voltage, rotational speed of turbine and input torque was measured. In regarding to these data, efficiency of alternator, power coefficient and power output of wind turbine was calculated. The whole information was shown together in same GUI page.

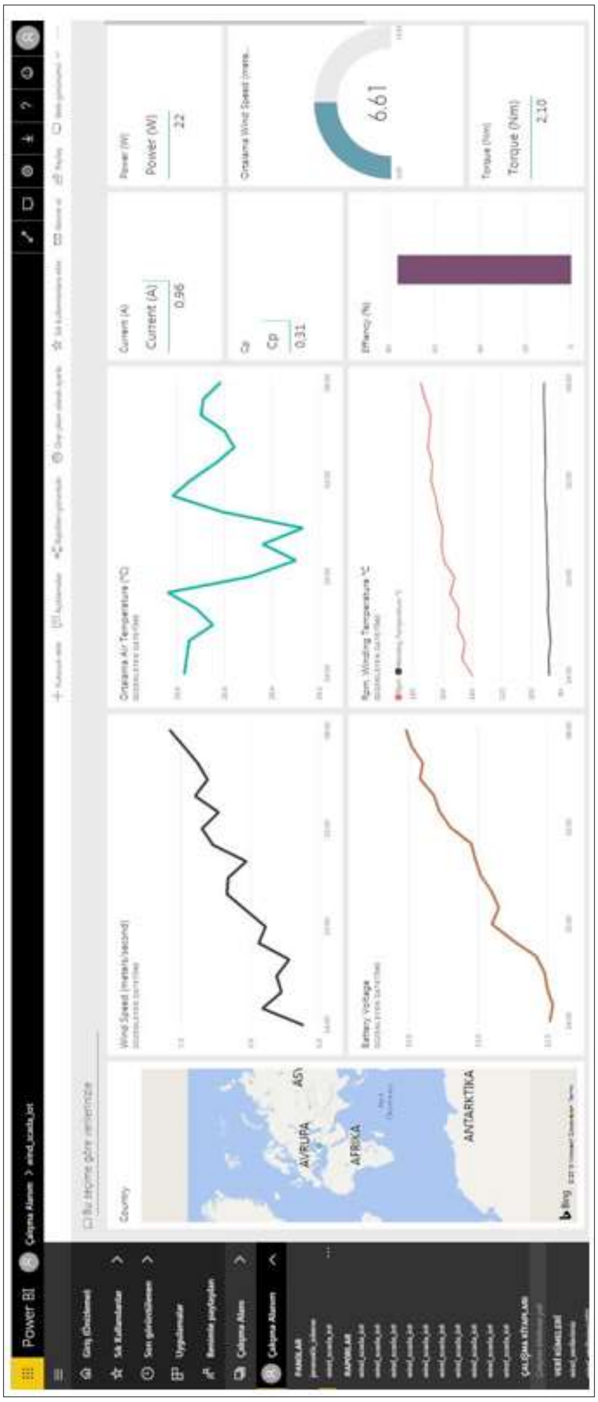

Figure 7. New design of GUI screen in Power BI.

The Power BI tool is a very useful set of services which is used for real time data visualization. Different users can easily make instantaneous data interpretation and visualization via platforms such as mobile device and can analyze historical data from the SQL database. The Data of wind turbine monitoring could also be carried out via smartphone is given Figure 8. Monitoring of data would save the extra travel cost to monitor the system performance especially in rural areas.

Figure 8. Power BI screen in smartphone.

4. Conclusions

Wind energy technology requires implementation of novel strategies that originate from technology improvement in computation, control and communication. Next-generation wind energy systems will be more intelligent thanks to M2M communications and the monitoring of wind turbine that works together with other energy sources for a smart energy concept. In this study, a cloud based IoT remote monitoring system is proposed and implemented for a small-scale stand-alone wind energy system. The designed system is flexible and inexpensive for real-time data monitoring and cloud data storage.

Analysis of real-time sensor data provides faster decision making that avoids damage to the system and can boost total energy output. Reliable operation and real time performance monitoring by using an IoT based concept can provide easy supervision.

The developed system can not only monitor and measure the required data but can also be remotely analyzed. This monitoring system provides the advantage of flexibility in data collection. In addition, this remote monitoring system can be regarded as a low-cost monitoring system and can be used for other renewable applications.

Ethics

There are no ethical issues after the publication of this manuscript.

References

1. Zabala Innovation Consulting, Plan for Dissemination of Results, https://www.romeoproject.eu/wp-content/uploads/2017/09/D9.1ROMEO_Dissemination_Plan.pdf (accessed August 27, 2018).

2. Annual combined onshore and offshore wind energy statistics, Wind in power 2017 Annual combined onshore and offshore wind energy Statistics. https://windeurope.org/wp-content/uploads/files/about-wind/statistics/WindEurope-Annual-Statistics-2017.pdf (accessed 14.03.2019).

3. Horn, G, Eliassen, F, Salvatore, Venticinque, S, Martino, BD, Bücher, M, Wood, L. 2016. An Architecture for Using Commodity Devices and Smart Phones in Health Systems. IEEE Workshop on ICT solutions for eHealth, 255-260.

4. Internet of Things in 2020: Roadmap for the future. Internet of Things 27, https://docbox.etsi.org/erm/Open/CERP%2020080609-10/Internet-of-Things_in_2020_EC-EPoSS_Workshop_Report_2008_v1-1.pdf (accessed 14.03.2019).

5. Fioccola, GB, Sommese R, Tufano, I, Canonico, R, Ventre G. 2016. Polluino: An Efficient Cloud-based Management of IoT Devices for Air Quality Monitoring. Control. Instrumentation, Energy & Communication (CIEC).

6. Manzano, S, Ortiz, RP, Guevara, D, Villacorta, A. 2014. An overview of remote monitoring PV Systems: Acquisition, Storage processing and publication of Real Time Data based on cloud computing. 4th International Workshop on Integration of Solar Power into Power Systems.

7. Zhao, JC, Zhang, JF, Feng, Y, Guo, J. The Study and Application of the IoT Technology in Agriculture. 3rd IEEE International Conference on Computer Science and Information Technology (ICCSIT), Chengdu, China, 2010, pp462-465.

8. Illic, MD, Xie, L, Khan, UA. 2010. Modeling of Future Cyber–Physical Energy Systems for Distributed Sensing and Control. IEEE Transactions on Systems, Man, and Cybernetics - Part A: Systems and Humans, 825-838.

9. Jayavardhana, G, Rajkumar B, Slaven, M, Marimuthu, P. 2013. Internet of Things (IoT): A vision, architectural elements, and future directions. Future Generation Computer Systems, 29, 1645-1660.

10. Jamali, MS, Kumar, P, Khan, UA. Internet of Things: Architecture& Integration with Other Networks. First International Conference on Modern Communication & Computing Technologies (MCCT-14), Nawabshah, Pakistan, 2014, pp 88.

11. Wang, Q, Gao, J. 2012. Research and application of risk and condition-based maintenance task optimization technology in an oil transfer station. Journal of Loss Prevention in the Process Industries, 6, 1018-1027.

12. Rannat, K, Lotus, M, Meriste, M, Preden, J. 2012. On dynamic models for wind farms as systems of systems. 7th International Conference on System of Systems Engineering (SoSE), 113-118.

13. Sajid, A., Abbas, H, Saleem, K. 2016. Cloud-Assisted IoT-Based SCADA Systems Security: A Review of the State of the Art and Future Challenges. IEEE Access, 1375 – 1384.

14. Moness, M, Moustafa, AM. 2016. A Survey of Cyber-Physical Advances and Challenges of Wind Energy Conversion Systems: Prospects for Internet of Energy. IEEE Internet of Thinks Journal, 3, 2.

15. Karnouskos, S, Colombo, AW. Architecting the next generation of service-based SCADA/DCS system of systems. IECON 2011 - 37th Annual Conference of the IEEE Industrial Electronics Society, Melbourne, VIC, Australia, 2011, pp359-364.

16. Community Research and Development Information Service, Reliable OM decision tools and strategies for high LCoE reduction on Offshore wind, https://cordis.europa.eu/project/rcn/210289_en.html (accessed August 09, 2018).

17. Sujatha, K, Deepalakshmi, B, Cao, SQ. 2018. Optimal condition monitoring of wind turbines using intelligent image processing and Internet of Things. International Journal of Renewable Energy Technology, 9, 1-2.

18. Kalyanraj, D, Lenin, S, Sabareswar, S. Wind Turbine Monitoring and Control Systems Using Internet of Things. 21st Century Energy Needs - Materials, Systems and Applications (ICTFCEN), Kharagpur, India, 2016.

19. Microsoft Corporation, What is Azure ?. https://azure.microsoft.com/en-us/ (accessed July 15, 2018).

20. Akyuz, E, Oktay, Z, Dincer, E. 2012. Performance investigation of hydrogen production from a hybrid wind-PV system. International Journal of Hydrogen Energy, 37, 21, 15841-16758.