Design and Development of Dual Power Generation Solar and Windmill Generator

Firas B. Ismail[1], Nizar F.O. Al-Muhsen[2], and Norul Ilham Noruddin[1]
[1] Power Generation Unit, Institute of Power Engineering (IPE), Universiti Tenaga Nasional (UNITEN), 43000 Kajang, Selangor, Malaysia
[2] Technical Instructors Training Institute, Middle Technical University, Baghdad, Iraq
Email: Firas@uniten.edu.my; nizar.almuhsen@mtu.edu.iq

***Abstract*—The fast depletion of conventional energy resources and the issue of global warming have encouraged researchers worldwide to come up with the best energy solution. Renewable energy resources such as wind and solar energy have been widely adopted as an alternative source of energy. In this work, an integrated solar and wind energy system were implemented aiming to produce the maximum possible output power from the available renewable energy resources such as solar irradiance and wind energy. The proposed system comprised two solar modules and horizontally rotating wind blades. An energy storage system plus a charge controller were also used aiming to improve the overall energy conversion efficiency. The results showed that this system demonstrated superior performance compared with the solar modules and wind system when they had worked individually. The proposed system was generating an average energy of 61.729 Wh daily. Therefore, it was estimated that the system can generate an annual output power of about 207.4 kWh. During the conducted experiments, the solar panels worked as the main source of the generated energy while the wind system acted as a secondary source of energy during the solar absent times. Moreover, the safety factor was calculated to be within the limits of 2 that shows the proposed system can work according to the industrial safety limits of Malaysia.**

***Index Terms*—Dual power generator, renewable power generation, solar energy, sustainability, wind energy**

I. Introduction

The escalated demand on the electrical power has been caused by the dramatic rise of population and city urbanization. This has led to a fast depletion to the conventional energy resources such as fossil fuels. Moreover, this has also risen the event of global warming as an urgent issue to be quickly addressed [1]. Recently, the renewable energy industry of solar and wind in terms of production and demand have grown substantially in the last decade [2]. The current technological advancements have facilitated the optimum utilization of the abundance of renewable energy resources such as solar and wind [3]. Nowadays, the idea of hybrid systems by using solar and wind energy have become common approaches for power generation world widely. Therefore, various studies have been conducted on the dual systems of photovoltaic (PV) integrated with Wind Turbine (WT) aiming to maximize the conversion efficiency and then increase the utilization of renewable energy resources [4]-[13]. It is worth to be mentioned that exploiting the green energy resources is not only for producing a clean and reliable electrical power, but it is also more economical than that comes from the conventional ways [14]. However, since solar and wind are unpredictable sources of energy, the use of the hybrid systems approach could provide a better opportunity for a continuous power generation. Hemeida *et al*. [4] studied the configuration and performance of PV and WT system accompanied by a storage system. Their results were also compared to a hybrid PV/WT system in terms of technical and economic aspects. The authors' results showed that establishing an integrated system of PV-WT and storage system was much more efficient than install these systems individually.

Pinheiro *et al*. [5] reviewed and analyzed the performance of the PV and WT systems in terms of the contemporary techniques that can be used to improve the efficiency of the aforementioned systems. This was comprising a highlighting of several technical and economic views regarding solar and wind power systems. Moreover, the on-site systems' performance was also emphasized and analyzed. The authors concluded that the integrated solar PV and WT systems need to be considered to overcome the intermittency of the solar and wind energies based on daily and seasonal variance. A couple of energy management strategies were evaluated based on real-time recorded data for a hybrid residential PV-WT system which was connected with a battery system [6]. A performance model was developed for the used system considering a range of variable parameters including the actual site conditions, solar irradiance and wind energy in the country of Denmark. Furthermore, the used energy storage system was assessed and quantified. It was found that integrating the PV-WT system with an energy storage system is necessary to address the issue of the energy variability of the solar and wind. A small-scale PV-WT system combined with a fuel cell system was investigated in terms of technical and economic aspects in the countryside region of Egypt [7]. The authors'

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Corresponding author: Firas B. Ismail (email: Firas@uniten.edu.my)

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outcomes showed that the integrated PV-WT-fuel cell system performed much better when the used system was incorporated with a hydrogen production electrolyzes. A levelized energy cost of about 0.47 $/kWh was achieved which was claimed as an economically acceptable.

Hasan and Dincer [8] developed an integrated new renewable energy system for the off-grid areas. The developed system comprised units of solar PV, WT, electrolyzer, and an ammonia synthesis system. This integrated system was thermodynamically evaluated, and it was aimed to be reliable and sustainable at the same time so can be implemented in the remote regions. The authors' results showed that the maximum efficiency was achieved, which was around 75% when the generated power was dominated by the wind energy. On the other hand, the minimum system efficiency was recorded when the main source of energy was from solar irradiance. These results were mainly attributed to the high conversion efficiency of the WT system and low conversion efficiency of the PV modules. Al-Ghussain *et al*. [9] optimized the size of a grid-connected PV-WT system for Lafarge cement factory in Jordan. Their study was aimed to use the available renewable energy resources, which are insolation and wind, to reduce the reliance on the national grid to the minimum and meet the factory power demand with a less price for the kWh than that of the national grid. The authors found that the site location must be carefully selected according to the annual availability of the wind and solar irradiance. The proposed system performance was technically and economically evaluated when it was integrated with energy storage systems. It was also concluded that it was economically feasible to install such systems (a renewable energy system with reliable energy storage systems) for this cement factory. Similar results were also concluded by another study in Germany and Europe that suggested that using a combined PV-WT system could be also technically and economically promising [10], [12]. Furthermore, this could substantially reduce greenhouse gas emissions and the electricity bill as well.

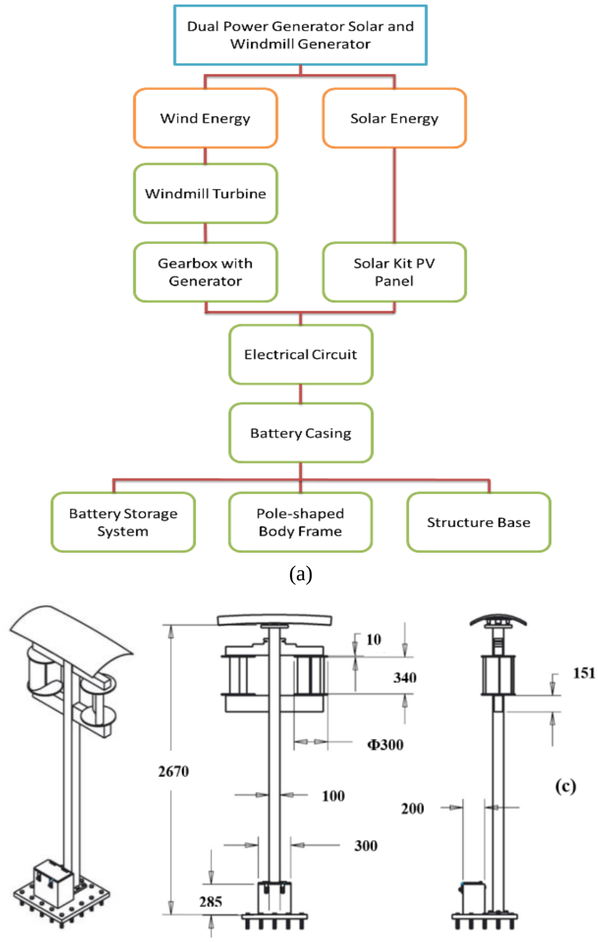
A smart micro-grid of WT-PV-battery with a capacity of 6kW was designed and developed by Liu *et al*. [11]. In addition, a management system, which was working based on the used battery state of charge (SoC), was proposed to smartly control the system. The operation mode of the used WT-PV-battery system was enhanced and fully controlled based on various operating parameters. Likewise, Belmili *et al*. [13] presented a standalone PV-WT system with an optimization method which was implemented based on different control strategies of the DC/DC and AC/DC regulator in the used system. The implemented controllers allowed the output power of the used PV-WT system to be optimized under many possible variations of the supplied wind speed, insolation, and the ambient temperature. Kamal *et al*. [15] conducted a study about the integration and control of an off-grid stand-alone hybrid wind-PV power generation system for rural applications that is combining PV/wind with super-capacitor/battery storage. The power flow was controlled to the load and Maximum Power Point Tracker (MPPT) for maximum power extraction from the photovoltaic/wind systems. Besides, various DC/DC converters were used. In the proposed design, even though the Photovoltaic (PV) had the priority to meet the required load, a wind turbine system is still integrated into the system to support PV during the demand time. In addition, for surplus power and/or backup device during demand, both supercapacitor and battery were used as energy storage systems. The proposed operating system was mainly aimed to maintain the SoC of the battery above 80%, which consequently could increase the life span of the used batteries and improve their performance. The proposed system used a real-time solar, wind data and a load of five rural households available at the University of Nottingham, Malaysia campus. MATLAB simulation that was used in the study showed results that the proposed system could compensate the power fluctuation and meet the required load without grid connections. In this study, a dual renewable power generation system of the solar PV and wind was designed and developed. The proposed system comprises of four main ingredients which are solar PV module, horizontally rotating WT, energy storage system (ESS), and a microcontroller to control the charging power from the PV-WT system to ESS. Furthermore, the microcontroller was also used to control the delivered power directly from PV-WT system and ESS to the electrical load. In this system, the WT was not only used to substitute the insolation absence during the nighttime but also to enhance the power generation during the daytime. The material selection process for the prototype structure and WT blades was also included. The results of the stress and strain analysis were also analyzed and discussed.

II. Experimental Setup and Methodology

In this study, the information is gathered from various sources in order to determine the design principles and elements that will be used for system design.

A. Wind and Solar Energy in Malaysia

Peninsula Malaysia experiences two main weather seasons every year; southwest monsoon starting from May/June to September with an average wind speed of about 7 m/sec, and the northeast monsoon starting from November to March with an average wind speed of about 15 m/sec particularly at the east coast of the country. Another weather event that should be taken into the consideration is the effect of the typhoons seasons that could strike the neighboring countries causing most probably a speedy wind of around 10 m/sec in the regions of Sabah and Sarawak. According to the annual report by Jabatan Meteorologi Malaysia in 2016, the highest daily average wind speed could reach 8.6 m/sec at the region of Kota Bharu, Kelantan on 25th January 2016, and highest average wind speed could reach 28.7 m/sec experienced by Mersing, Johor on 15th Jun 2016 [16]. Moreover, from the analysis by Christopher Teh Boon Sung from university Putra Malaysia in 2013, Malaysia has only experienced a potential wind speed at the early and late time of the calendar year. It was found that Malaysia’s mean annual wind speed is 2 m/sec at a height of 2 m from the ground level. It was also noticed that the wind speed could increase by 10% when the hight level increases by double to 4 meters [17]. On the other side, Malaysia is one of the Equatorial countries that receive a large amount of solar irradiance throughout the calendar year which is increasing the possibility in investing in the power generation industry from the solar PV systems. It was proven that the optimum tilt angle for the PV module is inclined from the horizon by about 5-15 degrees. Al-Obaidi *et al*. reported that Malaysia is exposed to about 10 sun hours daily [18]. The sun position in Malaysia peaks in the orbit from 1:15 pm to 1:30 pm all year round, with the altitude reaching a minimum of 61 °in December and January and the maximum reaching approximately 89 ° toward the end of March and the beginning of April and September. Moreover, it was reported that the average daily solar irradiance in Malaysia is in the range from 4.2 kWh/m^2 to 5.6 kW/m^2 [19].



(a)

(b) (c)

Fig. 1. (a) Simple schematic diagram for the proposed solar PV-WT dual power generation system, (b) isometric view of the complete system structure, and (c) Multiview drawing with complete dimensions for the dual power generation of the solar PV-WT system.

B. *Prototype Design Specification*

The designed prototype comprises of four main systems. Firstly, two small scale commercial solar modules with a maximum output power of 20W. The solar PV modules were installed at the top of the prototype frame with a tilt angle of 30 degrees. This was to avoid any possible shadowing and/or to maximize the insolation penetration. Besides, an electrical circuit was used to connect the PV modules with the WT system and a solar charge controller. Secondly, vertical axis windmill turbine, Savonius shape, that consists of a single blade fixed between two circular plates so that it can utilize the received wind from different directions. This advantageous design needs a small torque to initiate the WT rotation. The generated kinetic energy by the windmill turbine will be converted into electrical energy with the help of a gearbox and an alternator. Thirdly, a sealed lead-acid battery, and a solar charge controller that was used to control the charging power from the PV-WT system to the used battery. In this system, the WT was used to substitute the insolation absence and to enhance the power generation during the daytime. All the PV-WT system apparatuses were attached to a pole-shaped body frame and a base that is made of aluminum alloy. The frame made of an aluminum alloy was chosen due to its lightweight compared with stainless steel. This may also add portability merit to the proposed system. Fig. 1 shows (a) simple schematic diagram for the proposed solar PV-WT dual power generation system, (b) isometric view of the complete system structure, (c) The multiview drawing with complete dimensions for the dual PV-WT system. A CREO Parametric 3.0 software was used to generate the 3D model of the proposed design. The whole structure design of the proposed system was able to be replicated precisely according to proposed system specifications.

C. *Design Validation and Material Selection*

The proposed 3D design was validated by using CREO software, and the simulation results were discussed and analyzed. This process was necessary to ensure the safety and workability of the proposed design. Meanwhile, a simple Computational Fluid Dynamics (CFD) simulation, ANSYS Fluent code, was adopted to numerically study the flow pattern of wind energy over the windmill. The manufacturing materials were selected carefully based on the required specifications for each part of the presented prototype as shown in Table I.

TABLE I: SUMMARY OF MATERIAL SELECTION

Apparatus	Specifications
Windmill turbine Glass fiber: Reinforced plastics (GRP)	- High tensile strength. - Good corrosion resistance. - High temperature tolerance. - Production process is easy.
PV solar panel Mono-crystalline silicon	- High conversion efficiency, 15%-20% - Space efficient. - Has longest life span. - Perform better at low-light conditions.
Battery storage Lead acid	- Longest life cycle. - High reliability and working capability. - It withstands a slow and fast charging - Offers good performance at low and high temperature
Body frame, Battery casing, Structure base Aluminum alloy	- Has high strength as high as 300MPa and strength-to-weight ratio - High flexible strength or resilience under static and dynamic loading - Able to maintain its strength at low temperature - Good heat and corrosion resistance

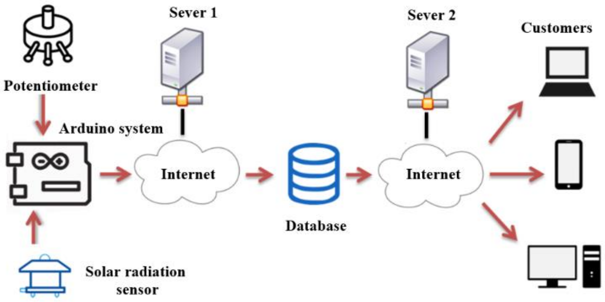


Fig. 2. The visual representation for the dual power generator equipped with the GUI system.

D. Graphical User Interface (GUI)

Graphical user interface (GUI) platform was designed for monitoring purposes to demonstrate the output power of the dual PV-WT system and the battery system SoC. The proposed GUI for this dual system was an online website so the users can access the system from everywhere at any time, as shown in Fig. 2. In addition to monitor the system remotely, the used GUI platform can be also used to calculate the conversion efficiency of the solar PV modules and windmill turbines. A JavaScript software was adopted to create the monitoring interface for this GUI system. This JavaScript is receiving the input data from the server and then calculate the power saved by the dual PV-WT power generator. Each of the generators is tagged with a unique identification so that the input data will not be mixed up.

E. Prototype Fibrication and Testing

The dual power generation system was fabricated and tested at a wide range of operating conditions. In this study, the product design was developed to provide a better visual representation towards the project, as well as to showcase for the functionality of the designed system. After that, the designed product was tested to measure its performance. Fig. 3 shows an actual photo for the proposed system and side from the system testing stages. This also shows illustrations of the system electric circuit.

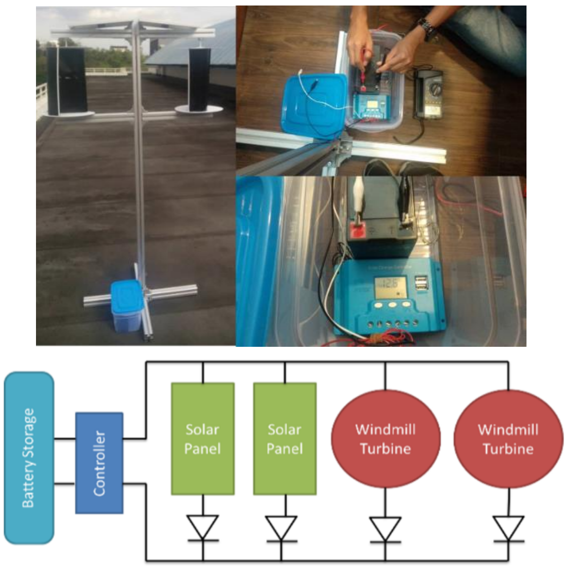


Fig. 3. The prototype fabrication and testing stage, illustration of the system electric circuit.

Fig. 4. Wind turbines photos used for the dual PV-WT system.

For the presented dual power generation system, the specifications of the power bank were 48V, 200Ah with consideration of a DOD (depth of discharged) of 50%. The total energy required to charge the used battery when the DOD is 50%, which is the drained energy, is 4800Wh. For the simplicity of the design, assumption is also made that the sun's energy is available for 10 hours a day. Therefore, a 480W rated solar PV module can produce 4800Wh in 10 hours. However, this is practically not applicable due to the variation of the availability of isolation. Consequently, the solar PV module rating of 175% was selected for this system. This designed rating was only suitable to charge a half-drained battery to 100% SOC. However, the power system became more reliable with the incorporation of the windmill generator to this system as the power was harnessed from two different sources. The recommended batteries for renewable energy systems were deep cycle batteries. The size of the battery was chosen according to the capacity that is required to provide the needed electricity. In addition, the DOD limits and the maximum operating temperature limit was also considered to ensure a safe operation for the used battery.

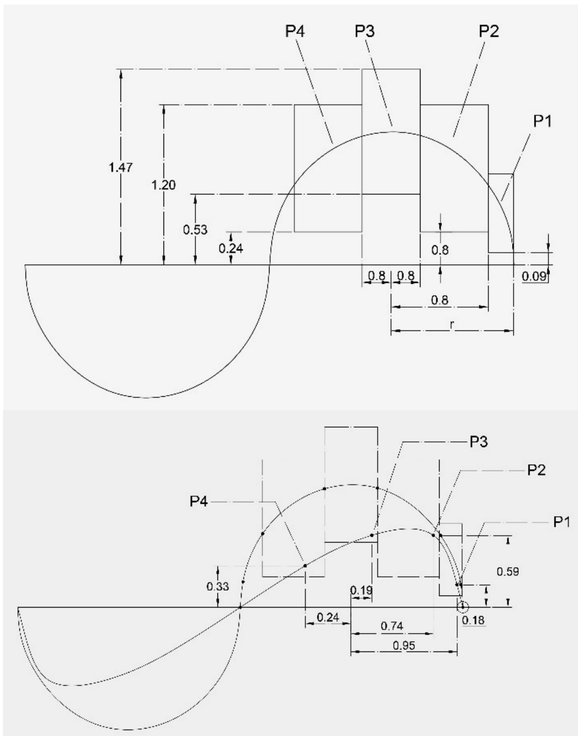


Fig. 5. The optimized blade shape (S-shape).

The used windmills, a drag vertical axis small scale wind turbine, were designed and validated according to the conventional Savonius turbine that was adopted by Ramadan *et al*. [7]. It was reported that this type of wind turbine could have a strong potential for the small-scale power generation applications. The used windmills' blade shape was numerically optimized by using a genetic algorithm. Fig. 4 shows the wind turbines photos used for the dual PV-WT system, and Fig. 5 illustrates that the wind turbine blades are optimized to the S-shape from the semi-circle shape to enhance the conversion efficiency of the WT system.

III. Result Analysis and Discussion

The subsection of the results' discussion and analysis is disciplined into three main sections which are started with the generated power outcomes of the proposed system, strength and strain analysis, and then ends with the CFD analysis for effective airflow characteristics around the windmills of the used system.

TABLE II: RESULTS OF TESTING

Details	Initial Powe Capacity	Final Power Capacity After Charging					
		10 AM	11 AM	12 AM	1.0 PM	2.0 PM	3.0 PM
Voltage (V)	12.51	12.55	12.56	12.57	12.58	12.60	12.64
Current (I)	1.60	1.60	1.60	1.60	1.61	1.61	1.61
Power	20.02	20.08	20.10	20.11	20.25	20.29	20.35
Percentage of power saved		0.32	0.40	0.48	1.19	1.35	1.67

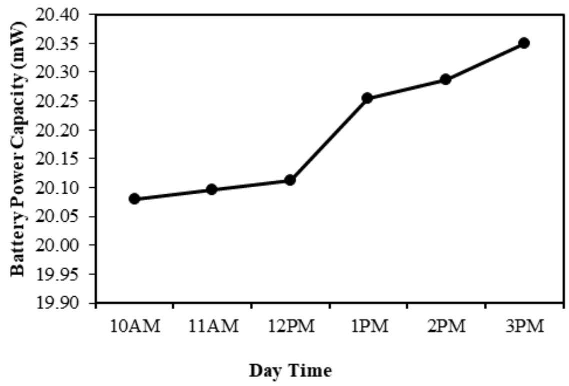


Fig. 6. Battery power capacity versus time.

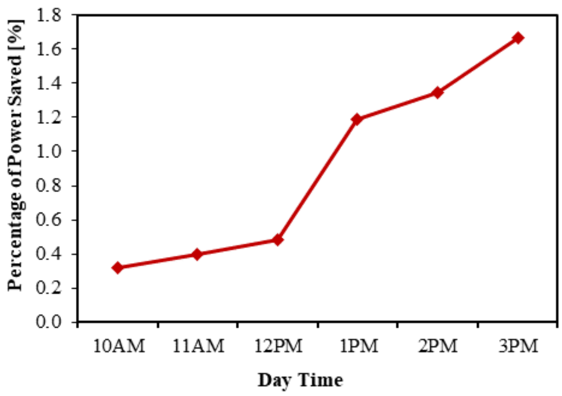
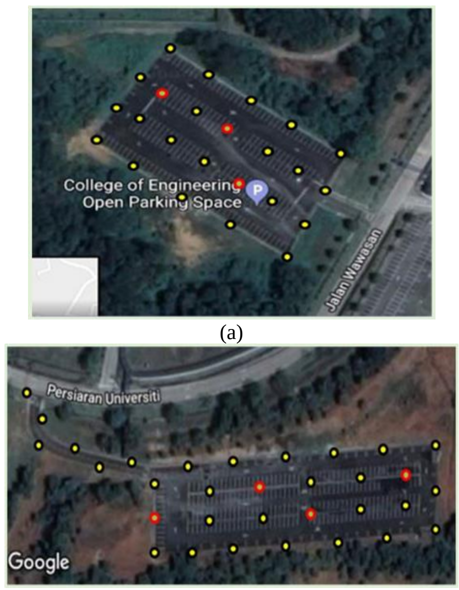


Fig. 7. Percentage of power saved versus time.

A. Generated Power Outcomes

In this study, the experiments were designed to be conducted for mainly 5 hours daily starting from 10.0AM to 3.0PM as shown in Table II. This was due to the hardware limits of the used battery storage and battery charging control system. Three main parameters were measured including output voltage, output current, and the system output power. The trend of the recorded data shown in Table II are demonstrated in Fig. 6 and Fig. 7.

Fig. 6 and Fig. 7 show that the generated power slightly increases with the testing daytime starting from 2.08 mW at 10.0 AM to 20.35 mW at 3.0 PM. This was mainly attributed to the increased solar irradiance with the daytime. Accordingly, the percentage of the saved battery power increases from 0.32% to 1.67% at 3.0 PM. It worth to be mentioned that the amount of the saved power can be varied from time to time due to the unpredicted testing conditions such as the weather situation. The proposed system mainly designed for the streetlight purpose that it is expected to work for a period of 5 hours per day. Meanwhile, the consumed power for each LED light unit is 10 W, so it is expected to consume around 50 Wh per day. Furthermore, it is estimated that the proposed dual PV-WT generation system could produce energy by about 600 Wh per day. Consequently, it is expected that the proposed system could feed 12 LED light bulb units a day. The implementation of this proposed system is discussed according to the attained results of the system. Two sites are chosen as possible candidates for implementing the presented dual PV-WT power generator, as shown in Fig. 8. These sites are the new students' parking area in the UNITEN at the College of Engineering and College of Science and Information Technology. The LED light bulbs supposed to be connected to the dual PV-WT system according to the generated power and capacity of the energy storage system.



(a)

(b)

Fig. 8. Google map photos for the arrangement of light streets for the new students' parking area in UNITEN: (a) College of Engineering and (b) College of Science and Information Technology.

Stress Analysis (Von Mises) Min=1.4×10^{-7} MPa Max=9.6×10^{-2} MPa

Displacement Analysis (Magnitude) Min=0.0 mm Max=1.9×10^{-5} mm

Strain Analysis (Max Principal) Min= -1.01×10^{-7} Max = 3.82×10^{-6}

Stress Analysis (Von Mises) Min=1.6×10^{-7} MPa Max=1.6×10^{-2} MPa

Displacement Analysis (Magnitude) Min=0.0 mm Max=1.03×10^{-2} mm

Strain Analysis (Max Principal) Min= -4.9×10^{-7} Max = 3.1×10^{-4}

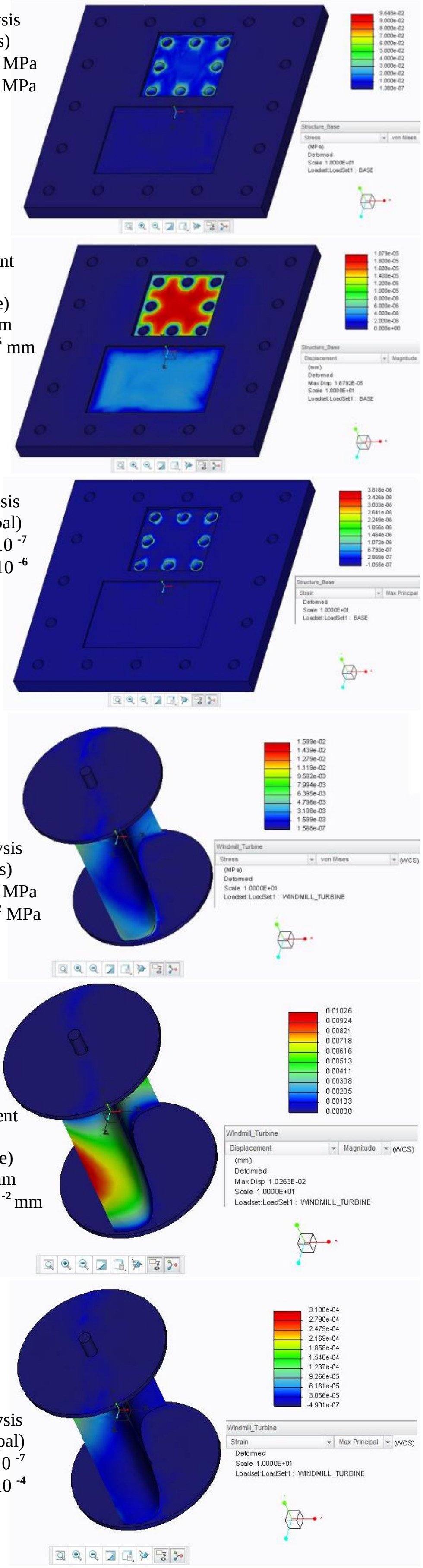


Fig. 9. Design analysis for structure base and windmill turbine.

B. Stress and Strain Analysis of the Apparatus Structure

The design analysis was performed by CREO Simulate software aiming to investigate the relationship between the supplied loads or the most possible effecting external forces applied on the structure of the system. This analysis of the systems' structure would include a brief discussion on the results of stress, displacement and strain analyses that conducted on the windmill blades and system's structure base. The factor of safety of the targeted parts is the main concern in this subsection. In other words, if there is any structural failure could occur in any parts of the components, an amendment on the design would be performed immediately. As shown in Fig. 9, it can be noticed that the design analyses of the used parts are within the acceptable range of the safety factor, which is greater than 2.0. On the other hand, the structure of the system still needs to be observed and examined from time to time to ensure that the proposed design is meeting the safety standard of Malaysia.

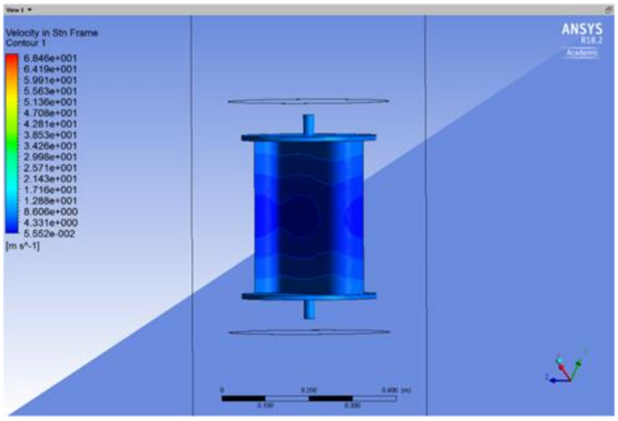


Fig. 10. Flow analysis – velocity results.

C. Flow Analysis

This flow analysis aims to analyze and discuss the behavior of the working fluid (air) that may influence the performance of the windmill turbine as well as the proposed system design in general. The air flow velocity and the surrounding pressure are highlighted in this subsection. The obtained results from the numerical simulations are discussed and analysed.

Based on the weather forecasting of the annual average wind speed in Malaysia, the speed of the airflow was assumed to be 2 m/sec to conduct the CFD simulation of this study. It can be noticed from Fig. 10 that the airflow speed inside the windmill turbine frame is 5.55×10^{-2} m/sec as a minimum value, and 2.14 m/sec as a maximum value. Furthermore, as can be observed from Fig. 10, the airflow speed is well distributed across the windmill blades. The maximum effect takes place at the edge of the blades, and then it gradually reduces reaching its minimum value at the middle of the windmill blades. This could significantly reduce the forces stresses on the windmill and enhance the conversion process (the power generation process) to the optimum level of the proposed design of the wind turbines side. Based on the CFD results, it can be concluded that the windmill turbine could work properly with the assumed flow speed of the supplied air. Fig. 11 shows that the amount of air pressure exerted on the windmill blades is low and evenly distributed across the blades. This could be mainly attributed to the relatively low inflow speed of the working fluid. This could also reduce the cost of the used material for the proposed windmill turbine blades.

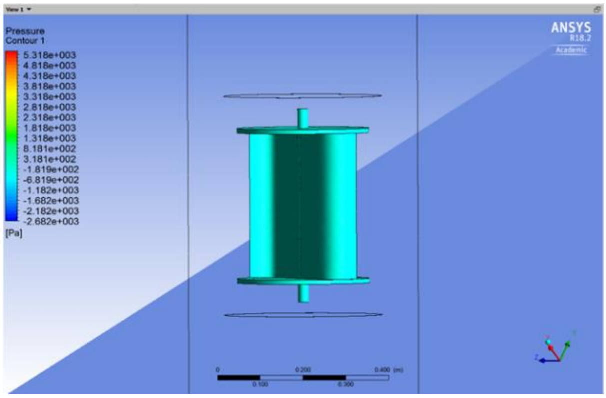


Fig. 11. Flow analysis – pressure result.

IV. Conclusions

This research paper has discussed the performance of the dual power generation solar and windmill generator. This dual renewable power generation system was designed and developed. The proposed system comprises of four main ingredients which are solar PV module, horizontally rotating WT, energy storage system, and a microcontroller to control the charging power from the PV-WT system to ESS system.

The presented system was able to generate an average output power of 61.729W per day. Therefore, the system can generate an annual output power of about 207.4 kWh. Furthermore, these results show that this system demonstrates a superior performance compared with the solar modules and wind system when they work individually. During the conducted experiments, the solar panels worked as the main source of the generated energy while the wind system acted as a secondary source of energy during the solar absent time. Moreover, the safety factor was calculated to be within the limits of two that shows the proposed system can meet the industrial safety limits of Malaysia.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

Firas B. Ismail and Norul Ilham Noruddin conducted the research and analyzed the data while Nizar F. O. Al-Muhsen analyzed the work results and wrote the paper. All authors had approved the final version.

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Dr. Firas B. Ismail Alnaimi is a Head of Power Generation Unit, Institute of Power Engineering (IPE), Universiti Tenaga Nasional, Malaysia. He has 14 years working experience in industry and academic fields. His research focus more on deep learning condition monitoring, big data analysis, renewable-smart power generation, power plants solutions, and flow assurance for oil and gas industries. He has published more than 100 publications in reputable international journals and conference proceedings.

Dr. Nizar F.O. Al-Muhsen was awarded his Ph.D. from the Faculty of Engineering and Information Technology, University of Technology Sydney, Australia. Currently, he is Head of Power Mechanics Department, Middle Technical University, Baghdad, Iraq. He is focusing on research fields of Biofuels, renewable energy developments, and engineering management. So far, he has seven publications, and he has ongoing research projects in the field of renewable energy systems development.