UNIVERSITI PUTRA MALAYSIA

DESIGN OF A HYBRID WIND -SOLAR GENERATOR USING A VERTICAL AXIS WIND TURBINE STRUCTURE WITH ROTATING PHOTOVOLTAIC CELLS

MOHAMMAD SH GH M M ALAJMI

DESIGN OF A HYBRID WIND -SOLAR GENERATOR USING A VERTICAL AXIS WIND TURBINE STRUCTURE WITH ROTATING PHOTOVOLTAIC CELLS

By

MOHAMMAD SH GH M M ALAJMI

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Doctor of Philosophy

March 2022

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Doctor of Philosophy

DESIGN OF A HYBRID WIND -SOLAR GENERATOR USING A VERTICAL AXIS WIND TURBINE STRUCTURE WITH ROTATING PHOTOVOLTAIC CELLS

By

MOHAMMAD SH GH M M ALAJMI

March 2022

Chairman : Associate Professor Izhal bin Abdul Halin, PhD
Faculty : Engineering

Standalone hybrid wind-solar energy generating systems have been around for more than two decades where the early versions consist of a traditional type stand-alone wind turbine generator and several stand-alone PV-panels. Since the early 2000s, two patents have been found for a new type of hybrid wind-solar energy generator where the PV-cells are mounted onto the blades of a wind turbine generator. This allowed for a compact hybrid wind-solar generator to be realized. Very recently, two new prototypes of such a device have been proposed. The first prototype was simulated for PV-cell efficiency and temperature while the second proposed prototype focused on the simulation of rotational speed when magnets are used to levitate the turbine for less friction during rotation. Although these are important perimeters to be studied, there were no mention of the solar output current loss when the PV integrated blades rotate. Near 100% Solar energy extraction from the rotating PV-blades is a special feature/function for this type of hybrid wind-solar generator and needs to be quantified.

Therefore, this thesis focuses to measure this loss by design and prototyping of a hybrid wind-solar generator with rotating PV-cells integrated into the blades of the turbine. Laboratory measurements show that approximately 4.3 % Solar generated current loss is experienced by the prototype when the turbine rotates in wind speeds ranging from 4 to 20 m/s. Since the current loss is less than 5 %, it is concluded that the functionality of the Solar-VAWT prototype is acceptable. The start-up wind speed of the VAWT was measured to be 4 m/s. On-site measurement results were also conducted and shows that the Solar efficiency, η is 2.7 % and the power coefficient, C_p is 0.32 when measured at Location A (3.00,0.1.072). The daily average generated Solar energy is 1 Wh/day and the daily average wind energy is 0.07 Wh/day.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

REKABENTUK PENJANA TENAGA HIBRID ANGIN-SOLAR MENGGUNAKAN STRUKTUR TURBIN ANGIN MENEGAK DENGAN SEL-SEL FOTOVOLTAIK BERPUTAR

Oleh

MOHAMMAD SH GH M M ALAJMI

Mac 2022

Pengerusi : Profesor Madya Izhal bin Abdul Halin, PhD
Fakulti : Kejuruteraan

Penjana tenaga hybrid solar dan angin telah wujud lebih dari dua dekan yang lepas di mana ianya terdiri dari sebuah penjana tenaga angin dan beberapa panel PV yang dipassangkan secara berasingan. Sejak awal tahun 2000, dua patent penjana hybrid angin dan solar telah dijumpai yang mempunyai sel-sel PV yang dipasangkan di atas blah-bilah turbin penjana tenaga angin. Ini membolehkan sebuah penjana hybrid angin dan solar yang lebih kecil direalisasikan. Baru-baru ini, dua lagi prototaip penjana jenis ini telah dicadangkan. Efficiancy sel-sel PV dan suhu telah dikaji melalui simulasi untuk prototaip yang pertama. Halaju kitaran pula telah disimulasi untuk prototaip kedua yang menggunakan magnet untuk mengangkat turbine agar geseran dapat dielakkan sama sekali. Walaupun perimeter-perimeter ini untuk penjana sepeti ini, tiada kajian berkenaan kehilangan kuasa keluaran Solar apabila sel-sel PV turut bergerak Bersama-sama putaran turbin. Pencirian penting untuk turbin jenis ini yang harus dikaji ialah pengeluaran tenaga Solar hampir 100 % apabila turbinnya berputar. Tesis ini memfokus kea rah pembangunan sebuah penjana tenaga angin-solar hybrid yang mempunyai sel-sel PV yang diintegrasi Bersama-sama bilah-bilah turbin sesebuah turbin angin paksi menegak (VAWT). Turbin yang dipilih ialah sebuah VAWT Darrieus yang mempunyai lima bilah. Pengukuran makmal menunjukkan 4.3 % penjanaan arus solar hilang apabila turbin yang direkabentuk berputar dalam kelajuan angin dari 4 hingga 20 m/s. Oleh kerana kehilangan arus itu kurang dari 5 %, ianya disimpulkan fungsi Solar-VAWT tercapai. Ujian makmal juga menunjukkan halaju angin permulaan ialah 4 m/s. Pencerapan data di Lokasi A (3.00, 1.072) menunjukan effciany, η ialah 2.7 % dan the pekali kuasa, C_p ialah 0.32. Purata keluaran tenaga solar harian pula ialah 1 Wh/hari dan angin ialah 0.07 Wh/hari.

ACKNOWLEDGEMENTS

Firstly, I would like to express my sincere gratitude to my supervisor, Assoc. Prof. Dr. Izhal Abdul Halin for the continuous support, patience, motivation, and guidance throughout my Ph.D study. His suggestions have helped me to overcome the many obstacles faced during development of the prototype and especially during academic writing. I could not have imagined having a better supervisor and mentor for my Doctorate of Philosophy study.

I would also like to thank the rest of supervisory committee members, Prof. Ir. Dr. Faizal Mustapha and Prof. Ir. Dr. Mohd Khairol Anuar Mohd Ariffin for their insightful comments and encouragement. I thank my fellow colleagues for the stimulating discussions, for the sleepless nights we were working together before deadlines, and for all the fun we have had in the last years in pursuing this study.

Last but not the least, I would like to thank my family, my wife for standing beside me and who encouraged me to complete my studies, from the depth of my heart I thank you, and my loving children for being patient with me, my parents and siblings for supporting me spiritually throughout writing this thesis. Alhamdulillah.

This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Doctor of Philosophy. The members of the Supervisory Committee were as follows:

Izhal bin Abdul Halin, PhD
Associate Professor
Faculty of Engineering
Universiti Putra Malaysia
(Chairman)

Faizal bin Mustapha, PhD
Professor, Ir.
Faculty of Engineering
Universiti Putra Malaysia
(Member)

Mohd Khairol Anuar bin Mohd Ariffin, PhD
Professor, Ir.
Faculty of Engineering
University Putra Malaysia
(Member)

ZALILAH MOHD SHARIFF, PhD
Professor and Dean
School of Graduate Studies
Universiti Putra Malaysia

Date: 8 December 2022

Declaration by Members of Supervisory Committee

This is to confirm that:

- the research conducted and the writing of this thesis was under our supervision;
- supervision responsibilities as stated in the Universiti Putra Malaysia (Graduate Studies) Rules 2003 (Revision 2012-2013) are adhered to.

Signature:	
Name of Chairman of Supervisory Committee:	Associate Professor Dr. Izhal bin Abdul Halin

Signature:	
Name of Member of Supervisory Committee:	Professor Ir. Dr. Faizal bin Mustapha

Signature:	
Name of Member of Supervisory Committee:	Professor Ir. Dr. Mohd Khairol Anuar bin Mohd Ariffin

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

LIST OF ABBREVIATIONS

UN	United Nations
GHG	Green House Gas
PV	Photovoltaic
VAWT	Vertical Axis Wind Turbine
HAWT	Horizontal Axis Wind Turbine
RE	Renewable Energy
LSHREPP	Large-Scale Hybrid Renewable Energy Power Plant
LSPVPP	Large-Scale PV Power Plant
LSWPP	Large-Scale Wind Power Plant
LSHWSPP	Large-Scale Hybrid Wind-Solar Power Plant
PMSG	Permanent Magnet Synchronous Generator
IG	Induction Generator
EMF	Electromotive Force
HVAC	High Voltage Alternating Current
LVRT	Low Voltage Ride-Through
CC	Point of Common Contact
PPF	Power Production Factor
MPPT	Maximum Power Point Tracking
PWM	Pulse Width Modulation
DAWT	Diffused Augmented Wind Turbine
SM	Side Mounted
TM	Top Mounted
SB	Solar Blade

CHAPTER 1

INTRODUCTION

1.1 Research Background

Standalone hybrid wind-solar energy generators have been used in green energy generation where in its basic form consists of an array of PV-cells for solar energy production and a wind turbine that drives an electric generator for wind energy production. Traditionally, the system is constructed from a separate wind turbine generator and fixed PV-panels whose output is terminated at a common charge controller. Therefore, the foot print of the system is large and can be larger than the footprint of the turbine itself.

Recently, a new topology hybrid wind-solar that integrates the solar power generating PV-cells into the wind turbine's structure, specifically on the turbine blades has been proposed mainly to reduce the hybrid wind-solar generator's footprint. The blades of both the Horizontal Axis Wind Turbine (HAWT) and Vertical Axis Wind Turbine (VAWT) have been proposed to be integrated with PV-cells in order to increase the efficiency of the turbine. From these articles, the maximum solar capacity is estimated to be 50 W. Simulation work were focused on the aerodynamics of the turbine blades when fitted with PV-cells and methods used to decrease the turbine's start-up wind speed because turbines fitted with PV-cells on the blades will experience higher star-up wind speeds due to the weight of the PV-cells.

From an engineering point of view, a function that must be inherent to these types of hybrid wind-solar generators is the ability to transfer solar power generated from the PV-cells to the load ideally with zero loss or within a certain percentage of confidence margin. Typically, in a margin of no less than 5%. However, analysis on the power output and energy generation of the PV-cells in rotation have not been considered. Moreover, the mechanism that allows for the extraction of power from the rotating PV-cells have not been discussed in detail. Thus, this work aims to fabricate a prototype of a VAWT with integrated PV-cells on its blades and measure the power loss because it directly effects the functionality of solar generator portion of a hybrid wind-solar generator.

1.2 Problem Statement

The idea of a hybrid wind-solar generator where the blades of the wind turbine are fabricated with PV-cells have been proposed as a means to reduce the footprint of standalone hybrid wind-solar generating systems (Saurabh, 2022). The integration of a HAWT with PV-cells attached on the blades was first patented in 2006, (Kasyap, 2006). A Savonius VAWT structure with PV-cells on the vertical blades have also been patented attached in 2008. In order to focus lateral coming solar irradiation onto the PV-cells, two reflectors were proposed (Gilbert, 2008). Recently, another Savonius VAWT with PV-cells on the blades was proposed where it was simulated to verify the amount of turbulence the VAWT would experience when PV-cells are attached on its blade. The simulation results suggests that the aerodynamic performance reduction is minimal (Ackshaya, 2021). In another recent study, a Savonius like VAWT with PV-cells mounted on top of the rotating blades was proposed. In order to reduce turbine friction during rotation, the VAWT is magnetically levitated using Neodymium magnets. Simulations shows that the VAWT can achieve a start-up wind speed of 1 m/s with a rotation speed of 17 RPM. However, there is a lack of study on the functionality of the Solar output when the PV-cells are rotating.

The difference in functionality between the traditional type of hybrid wind-solar generator with the newer proposed variants that features rotating PV-cell blades must produce output when the PV-cells are either stationary or rotating. In the newer designs, a brushed contact is used to extract generated solar power from the Solar-blades as they rotate. Ideally, the Solar power generated during stationary and rotating conditions must be the same, however, due to the rotating mechanical contact that all of the proposed prototypes must use, power loss is expected due to the dynamic resistance of the rotating contact. However, the percentage of power loss has never been quantified. In this work, the percentage of solar power loss during rotation is studied because it is an important function of generating power from rotating Solar-blades. In engineering practice, if the percentage of power loss falls under a confidence interval of 5% or less, then it is concluded that Solar-bladed hybrid wind-solar generators are also a suitable solution for generating green energy.

1.3 Research Aims and Objectives

The aim of this study is to determine through experimental measurements the percentage of current loss from PV-cells for a new type of hybrid wind-solar generator where the PV-cells are mounted on the blades of a Darrius type Vertical Axis Wind Turbine when the turbine is rotating. Therefore, the objectives for the thesis are:

1. To design and fabricate a new type of hybrid wind-solar generator with rotating PV-cells integrated on the wind turbine's blade and to analyse and verify its functionality. The special feature or functionality of this device is defined as the ability to produce and extract solar energy at an optimum magnitude for when the blades are stationary and rotating.
2. To measure and analyse the effects of self-shadowing of the PV-cells mounted on the turbine's blades.
3. To estimate the daily solar and wind energy generation of the prototype in real working environmental conditions.

1.4 Scope of Research Work

The scope of work involves interdisciplinary research in the Electrical and Mechanical Engineering field. The scope of work includes the redesign of a five bladed VAWT to allow integration of PV-cells on the blades while allowing solar generated electrical to be extracted safely even when the blades are rotating. Laboratory measurements to measure the power coefficient of the modified wind turbine and measurements of solar power loss when the blades rotate is done to achieve the first objective of proving the functionality of the rotating solar power extract method designed in this work. To meet objective 2, on-site short and open circuit measurements for the solar generator is done not only to characterize the solar generator, but also used to quantify the effects of self-shadowing that is inherent to the new prototype. Objective 3 is achieved upon the completion of on-site long term data acquisition to obtain the average daily solar and wind energy generation of the prototype.

1.5 Thesis Outline

The work presented in this thesis is separated into five chapters where the contents are arranged to build an understanding on why this thesis was written.

Chapter 1 gives an introduction and brief overview on the objective and scope of work of this thesis. Chapter 2 is an extensive literature review that includes studies on large scale renewable generation and its pros and cons. Topics on standalone wind, solar and hybrid wind-solar generators are included. The important topic on new types of hybrid wind-solar generators with PV-cells integrated on the blades are also discussed.

Chapter 3 explains the detailed methodology used to produce the prototype and methods used to validate the new prototype’s functionality. Both mechanical and electrical design are discussed in this chapter. Discussion on laboratory and on-site measurements for this work is also discussed. Chapter 4 focuses on explaining the results and analysis of the results. Chapter 5 gives a detailed conclusion on this work and proposals for the future development for this work.

REFERENCES

Ahsan, S. M., Khan, H. A., Hussain, A., Tariq, S., & Zaffar, N. A. (2021). Harmonic analysis of grid-connected solar PV systems with nonlinear household loads in low-voltage distribution networks. *Sustainability*, *13*(7), 3709..

Al-Jumaili, M. H., Abdalkafor, A. S., & Taha, M. Q. (2019). Analysis of the hard andsoft shading impact on photovoltaic module performance using solar module tester. *Int J Pow Elec & Dri Syst ISSN*, *2088*(8694), 1015.

Al-Shetwi, A. Q., Hannan, M. A., Jern, K. P., Alkahtani, A. A., & PG Abas, A. E. (2020). Power quality assessment of grid-connected PV system in compliance with the recent integration requirements. *Electronics*, *9*(2), 366.

Amusat, O. O. (2017). *Design and optimization of hybrid renewable energy systems for off-grid continuous operations* [(Doctoral dissertation, UCL (University College London)].

Apostolaki-Iosifidou, E., Mccormack, R., Kempton, W., Mccoy, P., & Ozkan, D. (2019). Transmission design and analysis for large-scale offshore wind energy development. *IEEE Power and Energy Technology Systems Journal*, *6*(1), 22-31.

Atri, P. K., Modi, P. S., & Gujar, N. S. (2020, February). Comparison of different MPPT control strategies for solar charge controller. In *2020 International Conference on Power Electronics & IoT Applications in Renewable Energy and its Control (PARC)* (pp. 65-69). Institute of Electrical and Electronics Engineers (IEEE), Mathura, India, 2020.

Atri, P. K., Modi, P. S., & Gujar, N. S. (2021, February). Design and Development of Solar Charge Controller by Implementing two different MPPT Algorithm. In *2021 International Conference on Advances in Electrical, Computing, Communication and Sustainable Technologies (ICAECT)* (pp. 1-5). Institute of Electrical and Electronics Engineers (IEEE), Bhilai, India, 2021.

Barakat, S., Ibrahim, H., & Elbaset, A. A. (2020). Multi-objective optimization of grid-connected PV-wind hybrid system considering reliability, cost, and environmental aspects. *Sustainable Cities and Society*, *60*, 102178.

Bhattacharjee, S., & Acharya, S. (2015). PV–wind hybrid power option for a low wind topography. *Energy Conversion and Management, 89,* 942-954.

Brinkel, N. B. G., Gerritsma, M. K., AlSkaif, T. A., Lampropoulos, I., van Voorden, A. M., Fidder, H. A., & van Sark, W. G. J. H. M. (2020). Impact of rapid PV fluctuations on power quality in the low-voltage grid and mitigation strategies using electric vehicles. *International Journal of Electrical Power & Energy Systems*, *118*, 105741.

Castellani, F., Astolfi, D., Peppoloni, M., Natili, F., Buttà, D., & Hirschl, A. (2019). Experimental vibration analysis of a small scale vertical wind energy system for residential use. *Machines*, *7*(2), 35.

Chae, S. H., Kang, C. U., & Kim, E. H. (2020). Field Test of Wind Power Output Fluctuation Control Using an Energy Storage System on Jeju Island. *Energies*, *13*(21), 5760.

Chin, V. J., Salam, Z., & Ishaque, K. (2015). Cell modelling and model parameters estimation techniques for photovoltaic simulator application: A review. *Applied Energy*, *154*, 500-519.

Chock, R. Y., Clucas, B., Peterson, E. K., Blackwell, B. F., Blumstein, D. T., Church, K., ... & Toni, P. (2021). Evaluating potential effects of solar power facilities on wildlife from an animal behavior perspective. *Conservation Science and Practice*, *3*(2), e319.

Christoffer, F. (2017). *Simulations of vertical axis wind turbines with PMSG and diode rectification to a mutual DC-bus* [Master dissertation, Uppsala University]. Dalarna University's Academic Repository and Publications Database (DiVA).

Dabiri, J. O. (2011). Potential order-of-magnitude enhancement of wind farm power density via counter-rotating vertical-axis wind turbine arrays. *Journal of renewable and sustainable energy*, *3*(4), 043104.

De Jong, P., Kiperstok, A., Sánchez, A. S., Dargaville, R., & Torres, E. A. (2016). Integrating large scale wind power into the electricity grid in the Northeast of Brazil. *Energy*, *100*, 401-415.

De la Parra, I., Marcos, J., García, M., & Marroyo, L. (2015). Control strategies to use the minimum energy storage requirement for PV power ramp-rate control. *Solar Energy*, *111*, 332–343.

Feng, F., Li, S., Li, Y., & Xu, D. (2012). Torque characteristics simulation on small scale combined type vertical axis wind turbine. *Physics Procedia*, *24*, 781-786.

Gharibi, M., & Askarzadeh, A. (2019). Size and power exchange optimization of a grid-connected diesel generator-photovoltaic-fuel cell hybrid energy system considering reliability, cost and renewability. *International Journal of Hydrogen Energy*, *44*(47), 25428-25441.

Gielen, D., Boshell, F., Saygin, D., Bazilian, M. D., Wagner, N., & Gorini, R. (2019). The role of renewable energy in the global energy transformation. *Energy Strategy Reviews*, *24*, 38-50.

González-Hernández, J. G., & Salas-Cabrera, R. (2021). Maximum Power Coefficient Analysis in Wind Energy Conversion Systems: Questioning, Findings, and New Perspective. *Mathematical Problems in Engineering*, *2021* https://doi.org/10.1155/2021/9932841.

Gupta, N. (2016). A review on the inclusion of wind generation in power system studies. *Renewable and Sustainable Energy Reviews*, *59*, 530-543.

Iracheta-Cortez, R., Durante-Gomez, W., & Dorrego-Portela, J. R. (2017, November). Designing a Radial-Type Multi-Pole Permanent Magnet Synchronous Generator (PMSG) for horizontal axis wind turbines. In *2017 IEEE 37th Central America and Panama Convention (CONCAPAN XXXVII)* (pp. 1-9). Institute of Electrical and Electronics Engineers (IEEE), Managua, Nicaragua, 2017.

Irwan, Y. M., Daut, I., Safwati, I., Irwanto, M., Gomesh, N., & Fitra, M. (2013). A new technique of photovoltaic/wind hybrid system in Perlis. *Energy Procedia*, *36*, 492-501.

Jäger-Waldau, A., Kougias, I., Taylor, N., & Thiel, C. (2020). How photovoltaics can contribute to GHG emission reductions of 55% in the EU by 2030. *Renewable and Sustainable Energy Reviews*, *126*, 109836.

Jordaan, S. M., Xu, Q., & Hobbs, B. F. (2020). Grid-Scale Life Cycle Greenhouse Gas Implications of Renewable, Storage, and Carbon Pricing Options. *Environmental Science & Technology*, *54*(17), 10435-10445.

Jurasz, J., Ceran, B., & Orłowska, A. (2020). Component degradation in small-scale off-grid PV-battery systems operation in terms of reliability, environmental impact and economic performance. *Sustainable Energy Technologies and Assessments*, *38*, 100647.

Kale, G. L., & Shinde, N. N. (2011). Implementation of Prototype Device–Off Grid-Charge Controller–Suitable for Wind Solar Hybrid. *Int. J. Res. Mech. Eng. Technol*, *5762*(1), 89-92.

Kamble, S. J., & Tale, V. T. Design of Solar Panel as Wind Turbine Blade. *International Journal of Engineering Research & Technology (IJERT*), Vol.11 (2), February 2022.

Kashem, S. B. A., Chowdhury, M. E., Ahmed, J., Ashraf, A., & Shabrin, N. (2020). Wind power integration with smart grid and storage system: Prospects and limitations. *International Journal of Advanced Computer Science and Applications*, *11*(5), 552-569.

Klonari, V., Fraile, D., Rossi, R., & Schmela, M. (2019, May). Exploring the Viability of hybrid wind-solar power plants. In *Proceedings of the 4th International Hybrid Power Systems Workshop, Crete, Greece* (pp. 22-23).

Kou, W., Wei, D., Zhang, P., & Xiao, W. (2015). A direct phase-coordinates approach to fault ride through of unbalanced faults in large-scale photovoltaic power systems. *Electric Power Components and Systems*, *43*(8-10), 902-913.

Kumar, B. S., & Sudhakar, K. (2015). Performance evaluation of 10 MW grid connected solar photovoltaic power plant in India. *Energy reports*, 1, 184-192.

Kumar, R., & Singh, S. K. (2018). Solar photovoltaic modeling and simulation: As a renewable energy solution. *Energy Reports*, *4*, 701-712.

Kunjumuhammed, L. P., Pal, B. C., Oates, C., & Dyke, K. J. (2015). Electrical oscillations in wind farm systems: Analysis and insight based on detailed modeling. *IEEE Transactions on Sustainable Energy*, *7*(1), 51-62.

Latif, S. N. A., Chiong, M. S., Rajoo, S., Takada, A., Chun, Y. Y., Tahara, K., & Ikegami, Y. (2021). The trend and status of energy resources and greenhouse gas emissions in the Malaysia power generation mix. *Energies*, *14*(8), 1-26.

Lawan, S. M., & Abidin, W. A. W. Z. (2020). A Review of Hybrid Renewable Energy Systems Based on Wind and Solar Energy: Modeling, Design and Optimization. *Wind Solar Hybrid Renewable Energy System*, https://doi.org/10.5772/intechopen.85838.

Li, J., Liu, C., Zhang, P., Wang, Y., & Rong, J. (2020). Difference between grid connections of large-scale wind power and conventional synchronous generation. Global Energy Interconnection, 3(5), 486-493.

Liu, Y., Hu, C., Miao, M., & Peng, F. (2017, January). Different Terms Fluctuations of Solar Power System. In *2016 4th International Conference on Machinery, Materials and Information Technology Applications*. Atlantis Press, Amsterdam, Netherlands.

Logesh, R. (2017). Resources, configurations, and soft computing techniques for power management and control of PV/wind hybrid system. *Renewable and Sustainable Energy Reviews*, *69*, 129-143.

Lovich, J. E., & Ennen, J. R. (2011). Wildlife conservation and solar energy development in the desert southwest, United States. *BioScience*, *61*(12), 982-992.

Mahajan, V., Agarwal, P., & Gupta, H. O. (2021). Power quality problems with renewable energy integration. In *Power Quality in Modern Power Systems* (pp. 105-131). Academic Press.

Maiwada, N. A., Abdulkarim, H. E. L., Usman, A., & and Abdullahi, S. (2014). The role of renewable energy in mitigating deforestation and climate change in Nigeria. *Journal of Natural Science Research*, *4*, 2225-0921.

Mane, M. C., Liang, J., & Jenkins, N. (2014). 49th International Universities Power Engineering Conference (UPEC). In *Permanent magnet synchronous generator for wind turbines: Modelling, control and Inertial Frequency Response*,1-6. Cluj-Napoca, Romania; Piscataway, NJ IEEE 2014.

Marin, E. A. S., & Rodríguez, A. F. (2019). Design, assembly and experimental tests of a Savonius type wind turbine. *Scientia et technica*, *24*(3), 397-407.Sanjari, M. J., Gooi, H. B., & Nair, N. K. C. (2019). Power generation forecast of hybrid PV–wind system. *IEEE Transactions on Sustainable Energy*, *11*(2), 703-712.

Mathew, S., & Philip, G. S. (2012). Wind turbines. *Comprehensive Renewable Energy*, *2*, 93-111.

Micah Gilbert, (2008), US Patent, No. US7,453,167 B2, 18 November 2008.

Mohamed, O. S., Ibrahim, A. A., Etman, A. K., Abdelfatah, A. A., & Elbaz, A. M. (2020). Numerical investigation of Darrieus wind turbine with slotted airfoil blades. *Energy Conversion and Management: X*, *5*, 100026.

Nalley, S. and LaRose, A. (2021), "International Energy Outlook 2021 (IEO2021)", Center for Strategic and International Studies, U.S. Energy Information Administration, 6.

Osborn, J., & Kawann, C. (2002). "Reliability of the US Electricity System: Recent Trends and Current Issues", Energy Analysis Department, Ernest Orlando Lawrence Berkeley National Laboratory, LBNL-47043, Berkeley, CA, 2001.

Patel, S. (2015). Ramagundam Super Thermal Power Station, Karimnagar, Telangana, India. *Power*, *159*(10), 32-33.

Percis, E. S., Manivannan, S., & Nalini, A. (2015). Electric vehicle as an energy storage for grid connected solar power system. *International Journal of Power Electronics and Drive Systems (IJPEDS)*, *6*(3), 567-575.

Racindra Kasyap, (2006), US Patent, No. US7,045, 702 B2, 16 May 2006.

Raj, G. S., Sangeetha, N., & Prince, M. (2018, February). Experimental and Computational Investigations of Vertical Axis Wind Turbine Enclosed with Flanged Diffuser. In *IOP Conference Series: Materials Science and Engineering* (Vol. 310, No. 1, p. 012077). IOP Publishing.

Ray, S. (2021), "Renewables account for most new U.S. electricity generating capacity in 2021", Preliminary Monthly Electric Generator Inventory, October 2020, U.S. Energy Information Administration.

Sawle, Y., Gupta, S. C., & Bohre, A. K. (2016). PV-wind hybrid system: A review with case study. *Cogent Engineering*, *3*(1), 1-311.

Sengupta, M., Xie, Y., Lopez, A., Habte, A., Maclaurin, G., & Shelby, J. (2018). The national solar radiation data base (NSRDB). *Renewable and sustainable energy reviews*, *89*, 51-60.

Sharma, D. K., & Purohit, G. (2014). Analysis of the effect of fill factor on the efficiency of solar PV system for improved design of MPPT. In *6th world conference on photo voltaic energy conversion*.

Slusarewicz, J. H., & Cohan, D. S. (2018). Assessing solar and wind complementarity in Texas. *Renewables: Wind, Water, and Solar*, *5*(1), 1-13.

Turney, D., & Fthenakis, V. (2011). Environmental impacts from the installation and operation of large-scale solar power plants. *Renewable and Sustainable Energy Reviews*, *15*(6), 3261-3270.

Varshini, K. A., Aswin, A. K., Rajan, H., & Charan, K. M. (2021, November). Concept design and numerical analysis of hybrid solar–wind turbine. *In IOP Conference Series: Earth and Environmental Science* (Vol. 850, No. 1, p. 012032). IOP Publishing.

Yan, R., Saha, T. K., Modi, N., Masood, N. A., & Mosadeghy, M. (2015). The combined effects of high penetration of wind and PV on power system frequency response. *Applied Energy*, *145*, 320-330.

Zhu, M. (2019, January). The impact of new energy generation on grid frequency. In *AIP Conference Proceedings* (Vol. 2066, No. 1, p. 020044). AIP Publishing LLC.