OPTIMAL SIZING OF HYBRID DIESEL ENGINE – PHOTOVOLTAIC AND BATTERY SYSTEM FOR A MARINE VESSEL APPLICATION

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Dedicated, in thankful appreciation for support,
encouragement and understandings to:
My supervisor Dr Tan Chee Wei;
My family
Also to all my colleagues and individuals that contributed
to this project.

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ABSTRACT

Environmental concerns have been motivating increased interest in the use of renewable energy sources as a result of diminishing of fossil fuel sources and the negative effect it has on the environment. Photovoltaic (PV) energy system is a renewable energy source with various applications and their implementation in energy production and saving are well documented in various research and applications. Installing these systems onto marine vessels or connecting it to marine vessel power plant through external connections could prove to be an efficient way of minimizing conventional fuel costs and simultaneously protecting the environment by significantly reducing carbon emission. In order to understand the technical and economic viability of using photovoltaic system for an offshore marine vessel, it is vital to determine the optimal sizing of PV system, battery, inverter and diesel generator. This project presents the proposed approach used in order to optimally size the power system components of hybrid system such as photovoltaic panels, inverter, battery and the conventional diesel generator. For this study, MATLAB software is used to develop a program to perform the power production calculation in order to meet the load demand pattern by utilizing power source from PV panel and conventional diesel generators. Probabilistic method is used to analyze the impact of random weather conditions to the sizing of the components. In addition, economic analysis was performed to optimize the sizing of the PV panels and batteries. Optimal sizing can save up to 1 percent of the Net Present Cost (NPC) with engine fuel price taken into consideration when comparison is made between 100 kW and 500 kW sized hybrid configuration. The conclusion of this project is that the developed algorithm is suitable to be used to optimally size hybrid diesel, PV and battery system.

ABSTRAK

Kebimbangan terhadap alam sekitar telah memotivasi minat yang lebih mendalam dalam penggunaan sumber tenaga boleh diperbaharui akibat daripada sumber kekurangan sumber bahan api fosil dan kesan negatifnya terhadap alam sekitar. Sistem tenaga fotovoltan (PV) adalah sumber tenaga boleh diperbaharui dengan pelbagai aplikasi dan implementasinya dalam penghasilan dan penjimatan tenaga telah didokumenkan dengan baik dalam pelbagai kajian dan aplikasi. Pemasangan sistem ini ke atas kapal laut atau menyambungkannya ke kilang janakuasa kapal laut melalui sambungan luaran boleh menjadi cara yang efektif untuk meminimumkan kos bahan api konvensional dan pada masa yang sama melindungi alam sekitar dengan mengurangkan pelepasan karbon dengan ketara. Untuk memahami daya maju teknikal dan ekonomi pengunaan sistem fotovoltan untuk sebuah kapal luar pesisir , adalah penting untuk menentukan saiz yang optimum untuk sistem PV, bateri, inverter dan penjana diesel. Projek ini akan membentangkan pendekatan yang digunakan untuk memberi saiz yang optimum kepada komponen sistem kuasa sistem hibrid seperti panel fotovoltan (PV), inverter, bateri dan penjana diesel konvensional. Untuk kajian ini, perisian Matlab telah digunakan untuk membangunkan program untuk melaksanakan pengiraan pengeluaran kuasa untuk memenuhi corak permintaan beban dengan menggunakan sumber kuasa dari panel PV dan penjana diesel konvensional. Kaedah probabilistik akan digunakan untuk menganalisa impak keadaan cuaca secara rawak ke atas saiz komponen. Tambahan lagi, analisa ekonomi telah dilakukan untuk mengoptimumkan saiz panel PV dan bateri. Saiz yang optimum boleh menjimatkan sehingga 1 peratus kos bersih semasa (NPC) dengan mengambil kira harga bahan api apabila perbandingan dibuat antara sistem yang mengunakan 100 kW panel PV dan system yang mengunakan 500 kW . Kesimpulan projek ini ialah algoritma yang dibangunkan sesuai untuk digunakan untuk mengoptimumkan saiz diesel hibrid, PV dan sistem bateri.

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LIST OF ABBREVIATIONS

PV	-	Photovoltaic
FPSO	-	Floating Production Storage Offloading
ASEAN	-	Association of Southeast Asian Nations
LOLP	-	Loss of Load Probability
NPC	-	Net Present Cost

LIST OF SYMBOLS

GW	-	Giga watt
V	-	Voltage
A	-	Ampere
Ω	-	Ohm
W	-	Watt
kHz	-	Kilo Hertz
I_{dc}	-	DC current
$I_{dc\text{-}peak}$	-	DC current correspond to maximum power
V_{dc}	-	DC voltage
$V_{dc\text{-}peak}$	-	DC voltage correspond to maximum power
P_e	-	Electrical power
$C_{p\text{-}max}$	-	Maximum power coefficient
V_{ref}	-	Reference voltage
I_{ref}	-	Reference current
D, d	-	Duty cycle
Ω	-	Ohm
MHz	-	Mega Hertz

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CHAPTER 1

INTRODUCTION

1.1 Background Information

For the past few decades, there have been enormous amount of arguments among scientific researchers and conservationists with regard to global warming phenomenon. It is a known fact that rapid increase in the number of developing countries, improved healthcare services and innovations in technology directly correlates to increase in the energy demand increase. Increase in energy demand has a major knock-on effect in the rise of global temperature and climate change phenomenon for example the melting of glaciers in Antarctic which in return increases the water level in oceans and causes low lying land to be submerged.

In addition, in the wave of modernization process across the globe, large percentage of increase in energy demand is contributed by increase in energy consumption in the form of electricity. Generation of electricity is still vastly dependent on the combustion of fossil fuels such as natural gas, diesel oil, fuel oil and coal which in return results in emission of greenhouse gasses such as carbon dioxide, nitrogen oxide and ozone into the atmosphere. Carbon dioxide emission is the leading factor to global warming across the globe. The growing demand for energy directly increases the rate of pollution of earth, hence it is very vital that energy is harvested using renewable energy that is clean environmentally to mitigate and reduce the pollution caused by conventional fossil fuel combustion.

Considering that ASEAN Region is located near the equator, it receives sunlight all year long and this makes solar energy to be a very viable alternative form of energy to be generated in this region. Solar energy is considered as clean energy because it only uses sunlight as its source of energy and it has zero greenhouse gasses emission. The generation of power using photovoltaic cells is reliable, has a very low cost of operation and maintenance and it involves no moving parts such as those which is used in conventional power generation methods which requires constant maintenance from time to time.

Apart from that, the operation of photovoltaic system is very silent and the installation can be done very quickly. Although solar electricity has a lot of advantages but it has its own drawbacks as well, production of solar energy is intermittent depending on the weather, the capital cost of photovoltaic installations is high and the efficiency of commercially available solar panel is still very low at 27 % [1].

Although solar energy has its disadvantages but it is a very feasible way forward in the field of renewable power generation as sunlight is available all year round at zero cost from the context of energy source. Extensive research is being actively conducted on improvising the efficiency of photovoltaic cells which directly makes sunlight energy a more reliable form of energy.

It was found that a group of researchers from the Fraunhofer Institute for Solar Energy Systems have managed to create a solar cell that can reach 44.7% efficiency, and they are expected to continue the research to increase the efficiency as well as commercializing their product for usage [2].

This project analyzes on the sizing of components in Hybrid PV, Battery Storage and Diesel Engine power system for a marine FPSO vessel.

1.2 Problem Statement

The huge consumption of fossil fuel in order to produce electrical energy has caused visible damage to the environment in various forms. The effect of climate change such as global warming and depletion of natural resources is a major concern that is being faced by the world. These concerns have become the driving factor in encouraging the world towards reduction in conventional energy consumption and exploration of renewable energy such as solar power.

Although solar energy is abundant, the output from PV panel varies and this fluctuation relies upon few factors such as sunlight irradiation and solar cell temperature. Sunlight irradiation and cell temperature depends on the environmental condition and weather which is intermittent. [3] Intermittency of PV panel output causes it hard to be installed without any storage element within a marine vessel power system which already has conventional diesel engine. Due to the concern mentioned earlier, storage elements and the PV panels need to be sized optimally in order to minimize potential of loss of power supply or blackout scenario, in addition to concern on cost.

Besides that, unlike common design for land based application which allows small percentage of loss of load probability to be accepted, marine vessel requires minimal loss of load probability due to the possibility of the vessel being drifted away from the operating position if the vessel is in dynamic positioning mode of operation.[4] Without proper consideration of the sizing of the diesel engine, PV panel and storage element such as battery, it might lead to insufficient power to cater for the load demand during vessel operation.

In this project, optimal sizing of PV array and Battery Storage in Hybrid PV, Battery Storage and Engine system of an FPSO is determined by using loss of load probability algorithm in order to meet the required vessel load demand based on sunlight irradiation and ambient temperature at Kota Kinabalu, Sabah, Malaysia.

1.3 Project Objective

By referring to the problem statement stated in subchapter 1.2, this research was performed with several meaningful objectives as stated below:

i. To optimize the size of PV and Battery Storage within the PV-Battery-Diesel Engine power generation system based on the marine vessel power consumption and weather pattern by using loss of load probability algorithm.

ii. To develop and design the proposed loss of load probability algorithm for optimal sizing of PV, Battery and Diesel Engine Power System in MATLAB.

iii. To simulate and analyze the Hybrid PV-Battery-Diesel Engine power generation system simulation result

1.4 Project Scope

Based on the objective mentioned in subchapter 1.3, the scope of work of this project report is clearly elaborated as stated below:

This paper focuses on standalone PV-Battery-Diesel Engine Power system model only. Based on existing offshore vessel design, it is possible to connect vessel power system to shore power supply or offshore power generation plant, however this study covers standalone PV-Battery-Diesel Engine power system.

i. The focus of this study is on optimal sizing of PV Array size and Battery storage based on fixed diesel engine size only using loss of load probability method. It does not cover detail study on

inverter, charge controller or other elements within the vessel power system.

ii. The load pattern used in this study is based on Floating, Production, Storage and offloading Vessel (FSO) Power Demand scenarios. Different marine vessel has different load demand scenario's, for example a drilling rig would have a very dynamic and drastic load demand increase and reduction, in which the gap between peak demand and base load is very huge. Where else, the load demand pattern for FPSO is relatively very stable and the increase in load demand is not very huge even though the operation condition is varied.

1.5 Methodology

Based on the objectives stated earlier, the following work methodologies have been planned:

i. A literature review of optimal sizing of Standalone Hybrid Diesel engine-PV-Battery was carried out. All the information extracted as part of literature review was obtained from conference publication, journal papers, articles from internet and electronic books from internet and UTM digital library. The electrical modelling components were reviewed. Suitable application within each reference was extracted.

ii. A detail and thorough literature review of optimal sizing and standalone power system was performed. In order to propose optimal sizing algorithm, the existing flowchart and formulation have been analyzed. By having in depth literature review, it provides a good theoretical understanding about standalone hybrid

design considerations need to be taken in order to develop the algorithm.

iii. A new optimal sizing of Standalone Hybrid Diesel Engine-PV-Battery algorithm was developed using MATLAB m-file.

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iv. Verification of proposed optimal sizing of Standalone Hybrid Diesel Engine-PV-Battery algorithm was performed by comparing the result output against HOMER software output, which is a sizing and cost optimization software available in the market.

1.6 Project Report Structure

Chapter 1 explains the introduction of Solar Power System. It consists of the problem statement of this study, the key objectives of this report, the scope of this project and the methodology that was applied in completing this project report.

Chapter 2 presents the fundamentals of standalone and grid connected photovoltaic system, in addition to the types of PV Panel, energy storage, diesel engine and inverters.

In Chapter 3, the mathematical modeling of the different component of the overall standalone power system is described in detail. First and foremost, it covers PV Panel, battery and diesel engine modelling. Apart from that, this chapter describes the cost analysis that is utilized to perform the study.

This chapter also covers the data collection method such as load demand data and solar irradiation data.

Chapter 4 starts with simulation result output and detail discussion. The hybrid marine vessel optimal sizing simulation output result was presented and discussed upon.

Chapter 5 draws the conclusions for the work undertaken and few possible suggestion works for future work are highlighted as well.

Lastly, Chapter 6 shows the project management for this project report works the. The details of the task that have been planned and carried out to make this research a success is highlighted too.

REFERENCES

1. Dursun B. Determination of the optimum hybrid renewable power generating systems for Kavakli campus of Kirklareli University, Turkey. Renewable and Sustainable Energy Reviews. 2012;16(8):6183--6190.

2. "Solar Cell." Retrieved 27.02.2014, from http://www.ise.fraunhofer.de/en /press-and-media/press-releases/presseinformationen-2013/worldrecordsolar-cell-with-44.7-efficiency.

3. Ngan M, Tan C. Assessment of economic viability for PV/wind/diesel hybrid energy system in southern Peninsular Malaysia. Renewable and Sustainable Energy Reviews. 2012;16(1):634--647.

4. Eleftherios K. Dedes, Dominic A. Hudson, Stephen R. Turnock, Investigation of Diesel Hybrid systems for fuel oil reduction in slow speed ocean going ships, Energy, Volume 114, 1 November 2016, Pages 444-456, ISSN 0360-5442

5. P.Surendran,N.M.Mohamed,N.S.Husain. Technoeconomic Analysis of an Offgrid Photovoltaic Natural Gas Power for a University. Sustainable Energy and Environment. 2013:3 129-135.

6. Gokcol C, Dursun B. A comprehensive economical and environmentalanalysis of the renewable power generating systems for Kirklareli University, Turkey. Energy and Buildings. 2013;64:249--257.

7. Yang Wang, Jens Kuckelkorn, Fu-Yun Zhao, Hartmut Spliethoff, Werner Lang, A state of art of review on interactions between energy performance and indoor environment quality in Passive House buildings, Renewable and Sustainable Energy Reviews, Volume 72, May 2017, Pages 1303-1319, ISSN 1364-0321

8. Silva S, Severino M, de Oliveira M. A stand-alone hybrid photovoltaic, fuel cell and battery system: A case study of Tocantins, Brazil. Renewable Energy. 2013;57:384-389.

9. *Dimas Firmanda Al Riza and Syed Ihtstam-ul Haq Gilani. Standalone Photovoltaic System Sizing using Peak Sun Hour Method and Evaluation by TRNSYS Simulation. International Journal of Renewable Energy Research. 2014. 4(1): 109-114.*

10. S.M. Shaahid, M.A. Elhadidy, Economic analysis of hybrid photovoltaic–diesel–battery power systems for residential loads in hot regions—A step to clean future, Renewable and Sustainable Energy Reviews, Volume 12, Issue 2, February 2008, Pages 488-503, ISSN 1364-0321

11. Kai-Philipp Kairies, David Haberschusz, Oliver Wessels, Jan Strebel, Jonas van Ouwerkerk, Dirk Magnor, Dirk Uwe Sauer, Real-Life Load Profiles of PV Battery Systems from Field Measurements, Energy Procedia, Volume 99, 2016, Pages 401-410, ISSN 1876-6102

12. Frederick M. Ishengoma and Lars E. Norum. Design and Implementation of a Digitally Controlled Stand-alone Photovoltaic Power Supply. Nordic Workshop on Powerand Industrial Electronics. 12-14 August. Norway: NORPIE. 2012. 1-5.

13. V. M. Pacheco, L. C. Freitas, J. B. Vieira Jr., E. A. A. Coelho and V. J. Farias. Stand-Alone Photovoltaic Energy Storage System with Maximum Power Point Tracking. Applied Power Electronics Conference and Exposition, APEC. Brazil: IEEE. 2003. 97-102.

14. R. Garcia-Valverde, C. Minguel, R. Martinez-Bejar and A. Urbina. Life cycle assessment study of a 4.2 kWp stand-alone photovoltaic system. Solar Energy. 2009. 83(9): 1434-1445.

15. S.E. Hirdaris, W. Bai, D. Dessi, A. Ergin, X. Gu, O.A. Hermundstad, R. Huijsmans, K. Iijima, U.D. Nielsen, J. Parunov, N. Fonseca, A. Papanikolaou, K. Argyriadis, A. Incecik, Loads for use in the design of ships and offshore structures, Ocean Engineering, Volume 78, 1 March 2014, Pages 131-174, ISSN 0029-8018

16. "Solar Data." Retrieved 15.03, 2013, from https://eosweb.larc.nasa.gov/

17. Habbati Bellia, Ramdani Youcef, Moulay Fatima, A detailed modeling of photovoltaic module using MATLAB, NRIAG Journal of Astronomy and Geophysics, Volume 3, Issue 1, June 2014, Pages 53-61, ISSN 2090-9977

18. Khatib T. Modelling of Photovoltaic System using Matlab, John Wiley & Sons.2006.

19. Hai Lan, Shuli Wen, Ying-Yi Hong, David C. Yu, Lijun Zhang, Optimal Sizing of hybrid PV/diesel/battery in ship power system, In Applied Energy, Volume 158, 2015, Pages 26-34, ISSN 0306-2619.

20. Husna.R (2017, Sept 11). Malaysia Interest Rate. Retrieved Sept 25, 2017, from https://tradingeconomics.com/malaysia/interest-rate

21. HOMER ENERGY(2016, Aug.) HOMER® Pro Version 3.7 User Manual August 2016

22. Sufian Ramli, Mohd & Sufiah Abd Wahid, Siti & Kamarudin Hassan, Khairul. (2017). A comparison of renewable energy technologies using two simulation softwares: HOMER and RETScreen. AIP Conference Proceedings.

23. International Electrotechnical Commission.(2013). IEC 61892-6 Mobile and fixed offshore units - Electrical installations - Part 6: Installation. Retrieved from https://webstore.iec.ch/publication/6081

24. Radan, D, et al., *Optimization of Load Dependent Start Tables in Marine Power Management Systems with Blackout Prevention.* ASNE Reconfiguration and Survivability Symposium, 2005. p. 16-18.

25. Ralph E.H. Sims, Hans-Holger Rogner, Ken Gregory, Carbon emission and mitigation cost comparisons between fossil fuel, nuclear and renewable energy resources for electricity generation, In Energy Policy, Volume 31, Issue 13, 2003, Pages 1315-1326,

26. L. El Chaar, L. A. Iamont and N. El Zein. Review of Photovoltaic Technologies. *Renewable and Sustainable Energy Reviews.* 2011. 15(5): 2165-2175.

27. Bhubaneswari Parida, S. Iniyan and Ranko Goic. A review of solar photovoltaic technologies. *Renewable and Sustainable Energy Reviews.* 2011. 15(3): 1625- 1636.

28. Khaled Bataineh and Doraid Dalalah. Optimal Configuration for Design of Stand-Alone PV System. *Smart Grid and Renewable Energy.* 2012. (3): 139-147.

29. Dalton G, Lockington D, Baldock T. Feasibility analysis of renewable energy supply options for a grid-connected large hotel. Renewable Energy. 2009;34(4):955--964.

30. Ngan M, Tan C. Assessment of economic viability for PV/wind/diesel hybrid energy system in southern Peninsular Malaysia. Renewable and Sustainable Energy Reviews. 2012;16(1):634-647.

30. Dalton G, Lockington D, Baldock T. Feasibility analysis of stand-alone renewable energy supply options for a large hotel. Renewable energy. 2008;33(7):1475--1490.

31. Lau KY, Yousof MFM, Arshad SNM, Anwari M, Yatim AHM. Performance analysis of hybrid photovoltaic/diesel energy system under Malaysian conditions. Energy 2010;35:3245–55.

32. Isa NM, Das HS, Tan CW, Yatim AHM, Lau KY. A techno-economic assessment of a combined heat and power photovoltaic/fuel cell/battery energy system in Malaysia hospital. Energy 2016;112:75–90.

33. Ma T, Yang H, Lu L, Peng J. Technical feasibility study on a standalone hybrid solar-wind system with pumped hydro storage for a remote island in Hong Kong. Renew Energy 2014;69:7–15.

34. Gamarra C, Guerrero JM. Computational optimization techniques applied to microgrids planning: a review. Renew Sustain Energy Rev 2015;48:413–24.

35. Sinha S, Chandel SS. Review of software tools for hybrid renewable energy systems. Renew Sustain Energy Rev 2014;32:192–205.

36. Tina G, Gagliano S, Raiti S. Hybrid solar/wind power system probabilistic modelling for long-term performance assessment. Sol Energy 2006;80:578–588.

37. Tina GM, Gagliano S. Probabilistic modelling of hybrid solar/wind power system with solar tracking system. Renew Energy 2011;36:1719–27.

38. Koutroulis E, Kolokotsa D, Potirakis A, Kalaitzakis K. Methodology for optimal sizing of stand-alone photovoltaic/wind-generator systems using genetic algorithms.Sol Energy 2006;80:1072–88.

39. Kalantar M, Mousavi G SM. Dynamic behavior of a stand-alone hybrid power generation system of wind turbine, microturbine, solar array and battery storage.Appl Energy 2010;87:3051–64.

40. Borowy BS, Salameh ZM. Methodology for optimally sizing the combination of a battery bank and PV array in a wind/PV hybrid system. IEEE Trans Energy Convers 1996;11:367–75.

41. Markvart T. Sizing of hybrid photovoltaic-wind energy systems. Solar Energy 1996;57:277–81.

42. Acharya N, Mahat P, Mithulananthan N. An analytical approach for DG allocation in primary distribution network. Int J Electr Power Energy Syst 2006;28:669–78.

43. Gözel T, Hocaoglu MH. An analytical method for the sizing and siting of distributed generators in radial systems. Electr Power Syst Res 2009;79:912-8.

44. Rawat SS, Das D. Optimum placement and sizing of DGs using analytical method for different types of loads, in India Conference (INDICON) Annual IEEE; 2015. p.1–5.

45. Shahzad M, Ahmad I, Gawlik W, Palensky P. Voltage profile improvement in radial distribution networks with analytical method of simultaneous optimal DG sizing, in 2016 18th Mediterranean Electrotechnical Conference (MELECON); 2016. p. 1–6.

46. Bernal-Agustín JL, Dufo-López R. Simulation and optimization of stand-alone hybrid renewable energy systems. Renew Sustain Energy Rev 2009;13:2111–8.

47. Mohammed M, Aziz A, Kazem HA, Alwaeli AH. Optimal sizing of photovoltaic systems using HOMER for Sohar, Oman. Int J Renew Energy Res 2013;3:301–7.

48. Maheri A. Multi-objective design optimisation of standalone hybrid wind-PV-diesel systems under uncertainties. Renew Energy 2014;66:650–61.

49. Asano H, Sagai S, Imamura E, Ito K, Yokoyama R. Impacts of time-of-use rates on the optimal sizing and operation of cogeneration systems. IEEE Trans Power Syst1992;7:1444–50.

50. Behzadi MS, Niasati M. Comparative performance analysis of a hybrid PV/FC/battery stand-alone system using different power management strategies and sizing approaches. Int J Hydrog Energy 2015;40:538–48, [1/5/].

51. Upadhyay S, Sharma MP. A review on configurations, control and sizing methodologies Of hybrid energy systems. Renew Sustain Energy Rev 2014;38:47–63.

52. Chedid R, Akiki H, Rahman S. A decision support technique for the design of hybrid solar-wind power systems. IEEE Trans Energy Convers 1998;13:76–83.

53. Wang C, Nehrir MH. Power management of a stand-alone wind/photovoltaic/fuel cell energy system. IEEE Trans Energy Convers 2008;23:957–67.

54. Babazadeh H, Gao W, Lin J, Cheng L. Sizing of battery and supercapacitor in a hybrid energy storage system for wind turbines, in PES T & D 2012; 2012. p. 1–7.

55. Kellogg WD, Nehrir MH, Venkataramanan G, Gerez V. Generation unit sizing and cost analysis for stand-alone wind, photovoltaic, and hybrid wind/PV systems. IEEE Trans Energy Convers 1998;13:70–5.

56. Kaldellis JK, Kondili E, Filios A. Sizing a hybrid wind-diesel stand-alone system on the basis of minimum long-term electricity production cost. Appl Energy 2006;83:1384–403.

57. Nikhil PG, Subhakar D. Sizing and parametric analysis of a stand-alone photovoltaic power plant. IEEE J Photovolt 2013;3:776–84.

58. Sulaiman SI, Rahman TKA, Musirin I, Shaari S, Sopian K. An intelligent method for sizing optimization in grid-connected photovoltaic system. Sol Energy 2012;86:2067–82.

59. Mukhtaruddin RNSR, Rahman HA, Hassan MY, Jamian JJ. Optimal hybrid renewable energy design in autonomous system using iterative-Pareto-fuzzy technique. Int J Electr Power Energy Syst 2015;64:242–9.

60. Feroldi D, Rullo P, Zumoffen D. Energy management strategy based on receding horizon for a power hybrid system. Renew Energy 2015;75:550–9.

61. Borhanazad H, Mekhilef S, Gounder Ganapathy V, Modiri-Delshad M, Mirtaheri A. Optimization of micro-grid system using MOPSO. Renew Energy 2014;71:295–306.

62. Jamil M, Kirmani S, Rizwan M. Techno-economic feasibility analysis of solar photovoltaic power generation: A review; 2012.

63. Mohammed YS, Mustafa MW, Bashir N. Hybrid renewable energy systems for offgrid electric power: review of substantial issues. Renew Sustain Energy Rev2014;35:527–39.

64. Bhandari B, Poudel SR, Lee K-T, Ahn S-H. Mathematical modeling of hybrid renewable energy system: a review on small hydro-solar-wind power generation. Int J Precis Eng Manuf-Green Technol 2014;1:157–73.

65. Hosseinalizadeh R, Shakouri H, Mohsen G, Amalnick S, Taghipour P. Economic sizing of a hybrid (PV–WT–FC) renewable energy system (HRES) for stand-alone usages by an optimization-simulation model: case study of Iran. Renew Sustain Energy Rev 2016;54:139–50.

66. Paulitschke M, Bocklisch T, Böttiger M. Sizing Algorithm for a PV-battery-H2-hybrid System Employing Particle Swarm Optimization. Energy Proc 2015;73:154–62.

67. Amer M, Namaane A, M'sirdi N. Optimization of hybrid renewable energy systems (HRES) using PSO for cost reduction. Energy Proc 2013;42:318–27.

68. Malhotra R, Singh N, Singh Y. Genetic algorithms: concepts, design for optimization of process controllers. Comput Inf Sci 2011;4:39.

69. Ismail MS, Moghavvemi M, Mahlia TMI. Genetic algorithm based optimization on modeling and design of hybrid renewable energy systems. Energy Convers Manag 2014;85:120–30.

70. Razak JA, Sopian K, Nopiah ZM, Zaharim A, Ali Y. Optimal operational strategy for hybrid renewable energy system using genetic algorithms, in Proceedings of the 12th WSEAS International Conference on Applied Mathematics; 2007. p. 235–240.

71. Nordin ND, Rahman HA. Pre-installation design simulation tool for grid-connected photovoltaic system using iterative methods. Energy Proc 2015;68:68–76.

72. García P, Torreglosa JP, Fernández LM, Jurado F. Optimal energy management system for stand-alone wind turbine/photovoltaic/hydrogen/battery hybrid system with supervisory control based on fuzzy logic. Int J Hydrog Energy 2013;38:14146–58.

73. Kadda FZ, Zouggar S, Hafyani ME, Rabhi A. Contribution to the optimization of the electrical energy production from a Hybrid Renewable Energy system, in2014 5th International Renewable Energy Congress (IREC),; 2014. p. 1–6.

74. Givler T, Lilienthal P. Using HOMER® software, NREL's micropower optimization model, to explore the role of gen-sets in small solar power systems, Case Study: Sri Lanka, National Renewable Energy Laboratory, Golden, Colorado; 2005.

75. Rohani G, Nour M. Techno-economical analysis of stand-alone hybrid renewable power system for Ras Musherib in United Arab Emirates. Energy 2014;64:828–41.

76. Li C, Ge X, Zheng Y, Xu C, Ren Y, Song C, et al. Techno-economic feasibility study of autonomous hybrid wind/PV/battery power system for a household in Urumqi,China. Energy 2013;55:263–72.

77. Abdilahi AM, Mohd Yatim AH, Mustafa MW, Khalaf OT, Shumran AF, Mohamed Nor F. Feasibility study of renewable energy-based microgrid system in Somaliland ′s urban centers. Renew Sustain Energy Rev 2014;40:1048–59.

78. Ramli MAM, Hiendro A, Sedraoui K, Twaha S. Optimal sizing of grid-connected photovoltaic energy system in Saudi Arabia. Renew Energy 2015;75:489–95.

79. P.T. Moseley and D.A.J. Rand, Chapter 1 - The Valve-regulated Battery — A Paradigm Shift in Lead-Acid Technology, In Valve-Regulated Lead-Acid Batteries, Elsevier, Amsterdam, 2004, Pages 1-14.

80. M. Roa, "Marine DC distribution systems — Taking advantage of enabling technologies," 2017 Petroleum and Chemical Industry Technical Conference (PCIC), Calgary, AB, Canada, 2017, pp. 353-362.

81. Battery Specifications, Solar SAGM 12 135 Retrieved October 15,2017, from http://www.trojanbattery.com/product/solar-sagm-12-135/

82. Cotrell J, Pratt W. Modeling the Feasibility of Using Fuel Cells and Hydrogen Internal Combustion Engines in Remote Renewable Energy Systems, National Renewable Energy Laboratory,USA,2003.

83. L. Luckose, H. L. Hess and B. K. Johnson, "Fuel cell propulsion system for marine applications," 2009 IEEE Electric Ship Technologies Symposium, Baltimore, MD, 2009, pp. 574-580.

84. SINAVY PEM Fuel Cell For Submarines and shipbuilding Retrieved October 15,2017, from https://www.industry.siemens.com/verticals/global/de/marine/marineschiffe/energieverteilung/Documents/sinavy-pem-fuel-cell-en.pdf

85. V. Musolino, L. Piegari and E. Tironi, "Technical and economical evaluation of storage systems in naval applications," 2013 International Conference on Clean Electrical Power (ICCEP), Alghero, 2013, pp. 120-127.

86. Flywheel UPS Systems, 50-1000 kVA Retrieved October 13,2017, from http://apps.geindustrial.com/publibrary/checkout/DEA642?TNR=Brochures%7CDEA-642%7CPDF&filename=DEA-642.pdf

87. L. Zhang, J. Y. Song, J. Y. Zou and N. Wang, "High Voltage Super-Capacitors for Energy Storage Devices Applications," 2008 14th Symposium on Electromagnetic Launch Technology, Victoria, BC, 2008, pp. 1-4.

88. BMOD0006 E160 B02, Retrieved October 13,2017, from http://www.maxwell.com/images/documents/160VModule_DS_3000246_6

89. Yan C, Venayagamoorthy GK, Corzine K a. Optimal location and sizing of energy storage modules for a smart electric ship power system. IEEE SSCI 2011 – Symp Ser Comput Intell – CIASG 2011 2011 IEEE Symp Comput IntellAppl Smart Grid 2011. p. 123–30.

90. Zahedi B, Norum LE, Ludvigsen KB. Optimized efficiency of all-electric ships by dc hybrid power systems. J Power Sources 2014;255:341–54.

91. Ovrum E, Bergh TF. Modelling lithium-ion battery hybrid ship crane operation.Appl Energy 2015:1–11.

92. Dedes EK, Hudson Da, Turnock SR. Assessing the potential of hybrid energy technology to reduce exhaust emissions from global shipping. Energy Policy 2012;40:204–18.

93. Wang L, Lee DJ, Lee WJ, Chen Z. Analysis of a novel autonomous marine hybrid power generation/energy storage system with a high-voltage direct current link. J Power Sources 2008;185:1284–92.

94. Bal Besikçi E, Arslan O, Turan O, Ölçer aI. An artificial neural network based decision support system for energy efficient ship operations. Comput Oper Res 2015.

95. Maleki A, Askarzadeh A. Artificial bee swarm optimization for optimum sizing of a stand-alone PV/WT/FC hybrid system considering LPSP concept. Sol Energy 2014;107:227–35.

96. Maleki A, Askarzadeh A. Optimal sizing of a PV/wind/diesel system with battery storage for electrification to an off-grid remote region: a case study of Rafsanjan, Iran. Sustain Energy Technol Assessments 2014;7:147–53.

97. Nelson DB, Nehrir MH, Wang C. Unit sizing and cost analysis of stand-alone hybrid wind/PV/fuel cell power generation systems. Renew Energy 2006;31:1641–56.

98. Rezzouk H, Mellit a. Feasibility study and sensitivity analysis of a stand-alone photovoltaic–diesel–battery hybrid energy system in the north of Algeria. Renew Sustain Energy Rev 2015;43:1134–50.

99. Ramli MaM, Hiendro A, Twaha S. Economic analysis of PV/diesel hybrid system with flywheel energy storage. Renew Energy 2015;78:398–405.

100. Maheri A. Multi-objective design optimisation of standalone hybrid wind-PV diesel systems under uncertainties. Renew Energy 2014;66:650–61.

101. Zhao B, Zhang X, Li P, Wang K, Xue M, Wang C. Optimal sizing, operating strategy and operational experience of a stand-alone microgrid on Dongfushan Island. Appl Energy 2014;113:1656–66.

102. Glykas A, Papaioannou G, Perissakis S. Application and cost-benefit analysis of solar hybrid power installation on merchant marine vessels. Ocean Eng 2010;37:592–602.

103. Lee KJ, Shin DS, Lee JP, Yoo DW, Choi HK, Kim HJ. Hybrid photovoltaic/diesel green ship operating in standalone and grid-connected mode in South Korea – Experimental investigation. 2012 IEEE Veh Power Propuls Conf VPPC, vol. 49, 2012. p. 580–3.

104. Adamo F, Andria G, Cavone G, De Capua C, Lanzolla AML, Morello R, et al. Estimation of ship emissions in the port of Taranto. Meas J Int Meas Confed 2014;47:982–8.

105. Jeyaprabha SB, Selvakumar aI. Optimal sizing of photovoltaic/battery/diesel based hybrid system and optimal tilting of solar array using the artificial intelligence for remote houses in India. Energy Build 2015;96:40–52.

106. Rezaie B, Esmailzadeh E, Dincer I. Renewable energy options for buildings: case studies. Energy Build 2011;43:56–65.

107. Diaf S, Notton G, Belhamel M, Haddadi M, Louche A. Design and techno economical optimization for hybrid PV/wind system under various meteorological conditions. Appl Energy 2008;85:968–87.

108. Sharafi M, ELMekkawy TY. Multi-objective optimal design of hybrid renewable energy systems using PSO-simulation based approach. Renew Energy 2014;68:67–79.

109. Lujano-Rojas JM, Dufo-López R, Bernal-Agustín JL. Probabilistic modelling and analysis of stand-alone hybrid power systems. Energy 2013;63:19–27.

110. Markvart T. Solar electricity. United Kingdom: Wiley; 1994.

111. Yoshida S, Ueno S, Kataoka N, Takakura H, Minemoto T. Estimation of global tilted irradiance and output energy using meteorological data and performance of photovoltaic modules. Sol Energy 2013; 93:90–9.

112. Makbul A.M. Ramli, Ayong Hiendro, Ssennoga Twaha, Economic analysis of PV/diesel hybrid system with flywheel energy storage, In Renewable Energy, Volume 78, 2015, Pages 398-405, ISSN 0960-1481,

113. BMOD0006 E160 B02, March 22,2017, from http://www.marin-etraffic.com/en/ais/details/ships/shipid:370137/mmsi:309499000/imo:8887595/vessel:PETROJARL_FOINAVEN

114. T. McCoy, “Electric Ships Past, Present, and Future [Technology Leaders],” IEEE Electrification Magazine, vol. 3, no. 2, pp. 4–11, June 2015.

115. B. M. Omar, H. Samir, Z. S. Ahmed and D. K. Y. Islam, "A Comparative investigation of maximum power point tracking techniques for grid connected PV system under various weather conditions," 2017 5th International Conference on Electrical Engineering - Boumerdes (ICEE-B), Boumerdes, Algeria, 2017, pp. 1-5.

116. W. Phipps and D. Sivadas, "Economic evaluation of a grid-connected PV system at Otago Polytechnic," 2017 Second International Conference on

Electrical, Computer and Communication Technologies (ICECCT), Coimbatore, 2017, pp. 1-6.

117. R. K. Tarai, M. K. Sahoo, V. Minz and P. Kale, "A study on the PV potential analysis for grid connected PV system in NIT Rourkela," 2016 IEEE 7th Power India International Conference (PIICON), Bikaner, 2016, pp. 1-6.