# OPTIMIZATION OF PV SIZE FOR OFF-GRID CONNECTED PV SYSTEM CONSIDERING UNCERTAINTIES USING DIFFERENTIAL EVOLUTION ALGORITHM

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A project report submitted in fulfilment of the
requirements for the award of the degree of
Master of Engineering (Electrical Power)

School of Electrical Engineering
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JANUARY 2020

# DEDICATION

This project report is dedicated to my father, who taught me that the best kind of knowledge to have is that which is learned for its own sake. It is also dedicated to my mother, who taught me that even the largest task can be accomplished if it is done one step at a time.

# ACKNOWLEDGEMENT

In preparing this project report, I was in contact with many people, researchers, academicians, and practitioners. They have contributed towards my understanding and thoughts. In particular, I wish to express my sincere appreciation to my main thesis supervisor, Dr. Madihah Binti Md Rasid, for encouragement, guidance, critics and friendship. Without his continued support and interest, this thesis would not have been the same as presented here.

My fellow postgraduate students should also be recognised for their support. My sincere appreciation also extends to all my colleagues and friends who have provided assistance at various occasions. Their views and tips are useful indeed. Unfortunately, it is not possible to list all of them in this limited space. I am grateful to all my family members.

# ABSTRACT

Increase in global energy demand has made renewable energy systems more attractive. In the past decade the utilization of PV systems has tremendously increased due to global warming phenomena and the rapid depletion of fossil fuel reserve. However, the intermittency and inconsistency of energy supply are some of the main drawback associated associate with the PV technologies. The hybridization of PV system with battery storage system improves the reliability and efficiency of the PV supply. In the past decade, standalone PV system become one of the systems that has been widely used. In this dissertation, the optimization of the PV system with battery storage is performed. The objective is to optimize PV system with battery, considering temperature and solar irradiance in order to maximize the output. The proposed system is designed to supply the energy demand of Al-Mamoon University College. This project considers yearly temperature and solar irradiance. The sizing optimization is performed using differential evolution (DE). Two key criteria are considered during the optimization process i.e., reliability and price of electricity. The proposed methodology is implemented using MATLAB software. The proposed approach based on (DE) is compared with particle swarm optimization technique in terms of fast convergence, accuracy.

# ABSTRAK

Peningkatan dalam permintaan tenaga global telah menjadikan sistem tenaga boleh diperbaharui lebih menarik. Dalam dekad yang lalu, penggunaan sistem PV telah meningkat dengan pesat disebabkan fenomena pemanasan global dan kekurangan simpanan bahan api fosil yang cepat. Walau bagaimanapun, bekalan tenaga tidak berterusan dan tidak konsisten adalah beberapa kelemahan utama berkaitan dengan teknologi PV. Penghibridan sistem PV dengan sistem storan bateri memperbaiki jaminanan bekalan berterusan dan kecekapan bekalan PV. Pada dekad yang lalu, sistem PV individu menjadi salah satu sistem yang telah digunakan secara meluas. Dalam disertasi ini, pengoptimuman sistem PV dengan storan bateri dilaksanakan. Objektif adalah untuk mengoptimumkan sistem PV dengan bateri, mengambilkira suhu dan sinar suria untuk memaksimumkan keluaran. Sistem yang dicadangkan ini direka untuk membekalkan permintaan tenaga Kolej Universiti Al-Mamoon. Projek ini mengambilkira suhu dan sinar suria tahunan. Pengoptimuman saiz dilaksanakan dengan menggunakan evolusi pembezaan (DE). Dua kriteria utama yang dipertimbangkan semasa proses pengoptimuman iaitu jaminan bekalan berterusan dan harga elektrik. Metodologi yang dicadangkan dilaksanakan menggunakan perisian MATLAB. Pendekatan yang dicadangkan berdasarkan (DE) dibandingkan dengan teknik pengoptimuman koloni zarah dari segi penumpuan cepat, ketepatan.

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| | | |
|---|---|---|
| DEA | - | Differential Evolution Algorithm |
| PSO | - | Particle Swarm Optimization |
| SAPV | - | Stand Alone Photovoltaic |
| CSP | - | Concentrated Solar Plants |
| LLP | - | Loss of Load Probability |
| LPSP | - | Loss of Power Supply Probability |
| LOPP | - | Loss of Power Probability |
| TFSC | - | Thin Film Solar Cell |
| CIG | - | Copper Indium Gallium |
| CIGS | - | Copper Indium Gallium Selenide |
| OPC | - | Organic Photovoltaic Cell |
| GCPVS | - | Grid Connected Photovoltaic System |
| BIPV | - | Building Integrated Photovoltaic |
| TPV | - | Terrestrial Photovoltaic |
| T&D | - | Transmission and Distribution |
| DESS | - | Battery Energy Storage System |

# LIST OF SYMBOLS

| | | |
|---|---|---|
| P | - | Power |
| G | - | Solar irradiance |
| T | - | Temperature |
| $\eta$ | - | Efficiency |
| $\sigma$ | - | Rate of self-discharge/hour |
| SOC | - | State of charge |
| $C_B$ | - | Battery capacity |
| AD | - | number of autonomy days |
| DOD | - | Depth of discharge |
| C | - | Cost |
| $i$ | - | Actual interest rate |
| n | - | Service life of the system |
| t | - | Time |
| E | - | Energy |
| $^{o}$C | - | Celsius |
| F | - | Future cost |
| α | - | Cost of PV array |
| % | - | Percentages |

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# CHAPTER 1

# INTRODUCTION

## 1.1 Background of study

The solar photovoltaic renewable energy (RE) development had expanded greatly because of continuous decrease in the rate of solar photovoltaic prices. The change in global energy structure towards a sustainable structure is because of technical innovations and use of renewable energy sources. The present-day power system structure has two main challenges - supplying a continuous secure power and reduction of environmental issues from power production [1]. In recent times, electric energy is the fastest growing form of energy in the world; the reason for this fast growth is the increased industrialization and extensive technical development.

Conventional energy sources such as petroleum, natural gas and coal are used as a major source to produce this enormous energy to meet power demand. About 67% [2] of current total electricity is produced by using fossil fuel sources, and their use leads to increased greenhouse gas emission and other types of environmental changes. This condition enforces energy sector to make a good effort to ensure environmental safety and continuous energy production. Therefore, the main task of power sector is to produce appropriate technical solutions and business models to maintain the energy sector stability.

The RE sources are considered as suitable alternative solutions for future electricity generation. RE Sources are environment friendly resources which gives clean energy and naturally replenished sources of power generation which are quickly getting to be viewed as best alternatives as compared to conventional resources such as fossil fuel power generation plants. In addition Renewable energy sources, mainly solar, wind, hydro and geothermal are the fastest-growing energy sources for electricity generation. The solar energy mainly is considered as a future of energy sector and is the fastest growing of all renewable energy sources. Solar energy is the most abundant resource of power in form of heat and light from the sun. It can produce concrete module output efficiency that can help in making precise estimation of power generation. However, solar irradiation is dependent on weather conditions and have some flexibility to be designed for distributed generation or as grid connected large scale production.

Stand-alone PV system (SAPVS) is considered the future of the energy sector and will play very important role in the future of electricity production. Stand-alone PV system usually includes an energy storage system with it; the idea of SAPVS is well established for both distributed and centralized systems [3]. Malaysian conditions are considered very suitable for the stand-alone PV system as they produce electricity throughout the year. The solar irradiation data of Malaysia shows that its very suitable for solar PV system with high irradiation throughout the year. However, there are technical issues with the SAPV systems because of the size optimization of the system. The optimization of the system is not possible by directly experimenting the installation because of different load and irradiance data. For this purpose, differential evolution algorithm is used in this project in the MATLAB platform to optimize the suitable size of SAPV for a rural area [4].

The following are the advantages of PV systems [5]:

i. They are stable electricity generators as they can directly generate electricity from sunlight. They normally come pre-packaged, wired and ready for mounting. There are no moving components in the modules, hence, there is no need for services and maintenance.

ii. The sizes and outputs of PV systems vary depending on their applications. Their lightweight allows for safe and easy transportation of the components.

iii. PV systems can be expanded easily by introducing more modules either in series to increase the voltage capacity of the system or in parallel to increase the current generation.

iv. PV systems are configured to withstand harsh conditions. Modules can withstand high temperatures and can operate at any elevation or wind condition. PV systems can be fabricated with storage capabilities that ensures stable quality power generation even when the weather is dull.

v. PV systems are not associated with any form of noise pollution or carbon emissions.

## 1.2 Problem Statement

The uncertainty associated with solar irradiance and temperature affects the power output of stand-alone PV system. Similarly, the inconsistency of load demand over a period of time is also a challenge. On the other hand, the high cost associated with renewable system components is a major challenge and limits their broad usage in the off-grid application and for the individual homeowner. To overcome the aforementioned problems, the system must be properly size via sizing optimization techniques to fully harness the benefit of the renewable energy resources based energy system.

## 1.3 Objectives

The specific objectives of the study are as follows:

a) To mathematically model PV and battery system.

b) To optimize the PV system using Differential Evolution algorithm (DEA) considering PV, solar irradiance and temperature uncertainties and load variation in order to minimize the cost of energy (COE) at minimum loss of load probability (LLP).

## 1.4 Scope of Study

In this study, the temperature and solar irradiance data was taken from rural areas of Iraq and the case of the study Al-Mamoon University college located in an Off-grid community is considered. This project focuses on the use of differential evolution theorem to optimize the SAPV system for optimal electricity generation in the rural areas. This project involves the designing of the MATLAB programming of the differential evolution theorem and recording of the solar irradiance data and temperature of the rural area to simulate and analyze the SAPV system.

## 1.5 Significance of Study

This study helps in choosing the appropriate PV system size under changing irradiance and temperature. The use of differential evolution algorithm (DEA) helps in appropriate sizing of the PV system and in reducing the computational time, making it easy to implement. This project will help in choosing the optimized PV system size which will be helpful economically and technically for the PV system installer.

## 1.6 Thesis Organization

This project report is organized in the following manner:

Chapter 1 describes the SAPV system and provides general information about the study objectives, the problem statement, as well as the scope of the research.

Chapter 2 reviewed the past works done on the optimization of the PV system using different optimization techniques. This chapter includes the literature review about different optimization techniques, as well as the modeling of different components of the PV system in MATLAB software.

Chapter 3 discusses the methods used in this project for PV system optimization using MATLAB; it also explains the optimization process.

Chapter 4 analysed the result obtained from MATLAB software. The analysis of loss of load probability (LLP) and the cost of energy (COE) will be discussed in this chapter.

Chapter 5 concludes the results and the SAPV system also the suggestion for the future works.

# REFERENCES


1. Tan, R.H. and T. Chow, *A Comparative Study of Feed in Tariff and Net Metering for UCSI University North Wing Campus with 100 kW Solar Photovoltaic System.* Energy Procedia, 2016. **100**: p. 86-91.
2. Reitze Jr, A.W., *Electric power in a carbon constrained world.* Wm. & Mary Envtl. L. & Pol'y Rev., 2009. **34**: p. 821.
3. Khatib, T., I.A. Ibrahim, and A. Mohamed, *A review on sizing methodologies of photovoltaic array and storage battery in a standalone photovoltaic system.* Energy Conversion and Management, 2016. **120**: p. 430-448.
4. Mandelli, S., et al., *Effect of load profile uncertainty on the optimum sizing of off-grid PV systems for rural electrification.* Sustainable Energy Technologies and Assessments, 2016. **18**: p. 34-47.
5. Abu-Rub, H., M. Malinowski, and K. Al-Haddad, *Power electronics for renewable energy systems, transportation and industrial applications*. 2014: John Wiley & Sons.
6. Arun, P., R. Banerjee, and S. Bandyopadhyay, *Optimum sizing of photovoltaic battery systems incorporating uncertainty through design space approach.* Solar Energy, 2009. **83**(7): p. 1013-1025.
7. Sangster, A.J., *Solar photovoltaics*, in *Electromagnetic Foundations of Solar Radiation Collection*. 2014, Springer. p. 145-172.
8. Bacha, S., et al., *Photovoltaics in microgrids: An overview of grid integration and energy management aspects.* IEEE Industrial Electronics Magazine, 2015. **9**(1): p. 33-46.
9. Chu, Y. and P. Meisen, *Review and comparison of different solar energy technologies.* Global Energy Network Institute (GENI), San Diego, CA, 2011.
10. BENNAR, M., et al., *Comparative study of three photovoltaic technologies (Monocrystalline–Polycrystalline–Amorphous).* REVUE DE L'ENTREPRENEURIAT ET DE L'INNOVATION. **1**(3).

11. Nesmachnow, S., *An overview of metaheuristics: accurate and efficient methods for optimisation.* International Journal of Metaheuristics, 2014. **3**(4): p. 320-347.
12. Mekhilef, S., et al., *Solar energy in Malaysia: Current state and prospects.* Renewable and Sustainable Energy Reviews, 2012. **16**(1): p. 386-396.
13. Mahela, O.P. and A.G. Shaik, *Comprehensive overview of grid interfaced solar photovoltaic systems.* Renewable and Sustainable Energy Reviews, 2017. **68**: p. 316-332.
14. Eltawil, M.A. and Z. Zhao, *Grid-connected photovoltaic power systems: Technical and potential problems—A review.* Renewable and sustainable energy reviews, 2010. **14**(1): p. 112-129.
15. Obi, M. and R. Bass, *Trends and challenges of grid-connected photovoltaic systems–A review.* Renewable and Sustainable Energy Reviews, 2016. **58**: p. 1082-1094.
16. Omran, W., *Performance analysis of grid-connected photovoltaic systems.* 2010.
17. Fara, L. and D. Craciunescu, *Output analysis of stand-alone PV systems: modeling, simulation and control.* Energy Procedia, 2017. **112**: p. 595-605.
18. Irwan, Y., et al., *Stand-alone photovoltaic (SAPV) system assessment using PVSYST software.* Energy Procedia, 2015. **79**: p. 596-603.
19. Roy, T.D., *Simulation and Analysis of Photovoltaic Stand-Alone Systems*. 2013.
20. Linden, D., *Handbook of batteries and fuel cells.* New York, McGraw-Hill Book Co., 1984, 1075 p. No individual items are abstracted in this volume., 1984.
21. Pavlović, T.M., D.D. Milosavljević, and D.S. Pirsl, *SIMULATION OF PHOTOVOLTAIC SYSTEMS ELECTRICITY GENERATION USING HOMER SOFTWARE IN SPECIFIC LOCATIONS IN SERBIA.* Thermal Science, 2013. **17**(2).
22. Yuan, X. and Y. Zhang. *Status and opportunities of photovoltaic inverters in grid-tied and micro-grid systems*. in *2006 CES/IEEE 5th International Power Electronics and Motion Control Conference*. 2006. IEEE.
23. Markvart, T., A. Fragaki, and J. Ross, *PV system sizing using observed time series of solar radiation.* Solar energy, 2006. **80**(1): p. 46-50.

24. Markvart, T., A. McEvoy, and L. Castaner, *Practical handbook of photovoltaics: fundamentals and applications*. 2003: Elsevier.
25. Bilal, B.O., et al. *Multi-objective design of PV-wind-batteries hybrid systems by minimizing the annualized cost system and the loss of power supply probability (LPSP)*. in *2013 IEEE International Conference on Industrial Technology (ICIT)*. 2013. IEEE.
26. Borowy, B.S. and Z.M. Salameh, *Methodology for optimally sizing the combination of a battery bank and PV array in a wind/PV hybrid system.* IEEE Transactions on energy conversion, 1996. **11**(2): p. 367-375.
27. Yang, H., et al., *Optimal sizing method for stand-alone hybrid solar–wind system with LPSP technology by using genetic algorithm.* Solar energy, 2008. **82**(4): p. 354-367.
28. Zhou, W., et al., *Current status of research on optimum sizing of stand-alone hybrid solar–wind power generation systems.* Applied energy, 2010. **87**(2): p. 380-389.
29. Zagrouba, M., et al., *Identification of PV solar cells and modules parameters using the genetic algorithms: Application to maximum power extraction.* Solar energy, 2010. **84**(5): p. 860-866.
30. Rajasekar, N., N.K. Kumar, and R. Venugopalan, *Bacterial foraging algorithm based solar PV parameter estimation.* Solar Energy, 2013. **97**: p. 255-265.
31. Askarzadeh, A. and A. Rezazadeh, *Artificial bee swarm optimization algorithm for parameters identification of solar cell models.* Applied Energy, 2013. **102**: p. 943-949.
32. Oliva, D., E. Cuevas, and G. Pajares, *Parameter identification of solar cells using artificial bee colony optimization.* Energy, 2014. **72**: p. 93-102.
33. Hamid, N.F.A., N.A. Rahim, and J. Selvaraj, *Solar cell parameters identification using hybrid Nelder-Mead and modified particle swarm optimization.* Journal of Renewable and Sustainable Energy, 2016. **8**(1): p. 015502.
34. Louzazni, M., et al. *Identification of Solar Cell Parameters with Firefly Algorithm*. in *2015 Second International Conference on Mathematics and Computers in Sciences and in Industry (MCSI)*. 2015. IEEE.

35. Wang, Y., et al., *Modeling method research of flexible amorphous silicon solar cell.* Applied Solar Energy, 2015. **51**(1): p. 41-46.
36. AlHajri, M., et al., *Optimal extraction of solar cell parameters using pattern search.* Renewable Energy, 2012. **44**: p. 238-245.
37. Jervase, J.A., H. Bourdoucen, and A. Al-Lawati, *Solar cell parameter extraction using genetic algorithms.* Measurement science and technology, 2001. **12**(11): p. 1922.
38. El-Naggar, K., et al., *Simulated annealing algorithm for photovoltaic parameters identification.* Solar Energy, 2012. **86**(1): p. 266-274.
39. Gong, W. and Z. Cai, *Parameter extraction of solar cell models using repaired adaptive differential evolution.* Solar Energy, 2013. **94**: p. 209-220.
40. Ye, M., X. Wang, and Y. Xu, *Parameter extraction of solar cells using particle swarm optimization.* Journal of Applied Physics, 2009. **105**(9): p. 094502.
41. Askarzadeh, A. and L. dos Santos Coelho, *Determination of photovoltaic modules parameters at different operating conditions using a novel bird mating optimizer approach.* Energy Conversion and Management, 2015. **89**: p. 608-614.
42. Van Den Bergh, F., *An analysis of particle swarm optimizers*. 2007, University of Pretoria.
43. Wang, D., D. Tan, and L. Liu, *Particle swarm optimization algorithm: an overview.* Soft Computing, 2018. **22**(2): p. 387-408.
44. Kalogirou, S.A., *Artificial intelligence for the modeling and control of combustion processes: a review.* Progress in energy and combustion science, 2003. **29**(6): p. 515-566.
45. Holland, J.H., *Adaptation in natural and artificial systems: an introductory analysis with applications to biology, control, and artificial intelligence*. 1992: MIT press.
46. Jain, L.C. and N. Martin, *Fusion of neural networks, fuzzy systems and genetic algorithms: industrial applications*. Vol. 4. 1998: CRC press.
47. Storn, R. and K. Price, *Differential evolution–a simple and efficient heuristic for global optimization over continuous spaces.* Journal of global optimization, 1997. **11**(4): p. 341-359.

48. Holland, J., *Adaptation in Nature and Artificial Systems.., 1975 The University of Michigan Press*. 1992, Reprinted by MIT Press.
49. Gämperle, R., S.D. Müller, and P. Koumoutsakos, *A parameter study for differential evolution.* Advances in intelligent systems, fuzzy systems, evolutionary computation, 2002. **10**(10): p. 293-298.
50. Prakash, P. and D.K. Khatod, *Optimal sizing and siting techniques for distributed generation in distribution systems: A review.* Renewable and Sustainable Energy Reviews, 2016. **57**: p. 111-130.
51. Adefarati, T. and R. Bansal, *Integration of renewable distributed generators into the distribution system: a review.* IET Renewable Power Generation, 2016. **10**(7): p. 873-884.
52. Gözel, T. and M.H. Hocaoglu, *An analytical method for the sizing and siting of distributed generators in radial systems.* Electric power systems research, 2009. **79**(6): p. 912-918.
53. Sheng, S., et al. *A simplified PSO algorithm for sizing and siting distributed generation*. in *2011 International Conference on Materials for Renewable Energy & Environment*. 2011. IEEE.
54. Kaplanis, S., E. Kaplani, and E. Daviskas. *On the maximization of a cost-effective PV sizing; towards an intelligent building*. in *2008 11th International Conference on Optimization of Electrical and Electronic Equipment*. 2008. IEEE.
55. Ayop, R., *Sizing of Energy Storage Based on Loss of Load Probability of Standalone Photovoltaic Systems*. 2015, Universiti Teknologi Malaysia.
56. Suresh, P. and K. Sudhakar. *Life cycle cost assessment of solar-wind-biomass hybrid energy system for energy centre, MANIT, Bhopal*. in *2013 International Conference on Green Computing, Communication and Conservation of Energy (ICGCE)*. 2013. IEEE.
57. Xiaodan, Z. and X. Yuejun. *Research on the LCC Model of Energy-Saving Residential Building*. in *2009 International Conference on Information Management, Innovation Management and Industrial Engineering*. 2009. IEEE.
58. Ma, Z.-j. *The effect of reliability on LCC and management information system design*. in *Proceedings of 2011 International Conference on Computer Science and Network Technology*. 2011. IEEE.

59. Lee, S.H., A.K. Lee, and J.O. Kim. *Determining economic life cycle for power transformer based on life cycle cost analysis*. in *2012 IEEE International Power Modulator and High Voltage Conference (IPMHVC)*. 2012. IEEE.

60. Kalogirou, S., *Economic analysis of solar energy systems using spreadsheets.* Renewable energy, 1996. **9**(1-4): p. 1303-1307.

61. Borhanazad, H., et al., *Optimization of micro-grid system using MOPSO.* Renewable Energy, 2014. **71**: p. 295-306.

62. Bukar, A.L., C.W. Tan, and K.Y. Lau, *Optimal sizing of an autonomous photovoltaic/wind/battery/diesel generator microgrid using grasshopper optimization algorithm.* Solar Energy, 2019. **188**: p. 685-696.

63. Kaelo, P. and M. Ali, *A numerical study of some modified differential evolution algorithms.* European journal of operational research, 2006. **169**(3): p. 1176-1184.

64. Das, S., et al., *Differential evolution using a neighborhood-based mutation operator.* IEEE Transactions on Evolutionary Computation, 2009. **13**(3): p. 526-553.