EJEEE

Article

Tilos Island's ideal microgrid size for wind, solar, and batteries

Faraqid Q. Mohammed [1] and Yousif Ali Latif Al-Zuhairy [2,*]

[1] National School of Electronics and Telecoms, University of Sfax, Tunisia; faraqid@enis.tn
[2] Dep. of computer and communication engineering, Islamic University of Lebanon, Lebanon; yl76354@net.iul.edu.lb
* Correspondence: Tel.: +961-3866468

Abstract: This article describes a power plant that is versatile regarding its modeling and associated with a Multiple Objectives Particle Swarm optimization in order to determine the optimal size of each component of the power plant. The simulation is appropriate for a variety of power sources, storage devices and loads. The method is utilized on a Wind Turbine/ Photovoltaic Device/ Battery System setup located in Tilos, Greece. The optimization is intended to reduce the expense of the system and the energy derived from alternative sources that are not renewable. The results produce a Pareto front that represents the expense of the equipment and the degree of autonomy of the micro-grid. The most effective solution to a specific expense associated with energy importation is demonstrated as an example.

Keywords: Particle swarm optimization; hybrid power plants; techno-economic research

Citation: To be added by editorial staff during production.

Academic Editor: Firstname Lastname

Received: 10/4/2023
Revised: 15/5/2023
Accepted: 25/5/2023
Published: 1/6/2023

1. Introduction

In certain instances, the error value rose to 59.5 percent (depending on the weather and renovation scenarios combination considered) [1]. The average increase in slope coefficient over the course of a decade was between 3.8 and 8 percent, which is consistent with a drop in the number of heating hours throughout the heating season from 22 to 139 hours (depending on the combination of weather and renovation scenarios considered). Conversely, function intercept rose by 7.8–12.7% every ten years (depending on the coupled scenarios). The proposed values could be used to adjust the function parameters for the scenarios taken into account and raise the heat demand estimator's accuracy.

Such a power plant is costly and may not turn a profit if it is not scaled correctly [2]. Numerous methods, including the Genetic Algorithm[3, 4], and the Particle Swarm Algorithm [5, 6], have been used to study this topic in the literature [7]. All of these references, nevertheless, are concentrated on certain power plant configurations. This paper's methodology employs a 12-variable modeling that may be applied to a variety of micro-grid layouts [8]. The Multi Objective Particle Swarm Optimization (MOPSO) technique is utilized to reduce the dependence on external energy sources and system costs [9]. Following optimization, this external energy cost is utilized to determine the optimal plant configuration for a specific location and consumption profile. On the Greek island of Tilos, the algorithm is used to size a wind and solar power plant connected to a battery bank. The flexible plant modeling, its configuration for the case under study, its power sources, the energy conversion components, the energy management plan, and the economic assumptions are all covered in the following section. The optimization issue and the MOPSO algorithm are briefly presented in Section 3. Lastly, Section 4 presents the optimization outcomes.

2. Materials and Methods

2.1 Flexible plant modeling

https://doi.org/10.xxxx/xxxxx

This work uses a modular approach to modeling. One or more Renewable Energy Systems (RES) and one External Storage System can be combined to create a broad variety of plant designs that it can emulate (ESS). The simulated plants must always supply a load or have a tolerance for a loss of power supply. If the RES power is insufficient, they can be connected to the main grid or a controlled source, such as a diesel generator, and they may or may not export the excess energy generated. Nine Generic Conversion Systems (GCS) provide this flexibility; they can be turned on or off based on the configuration that is depicted. The algorithm configuration for the plant used as an example in this paper is shown in Figure 1. It consists of a bank of sodium nickel chloride batteries, a photovoltaic array, and a wind turbine. The facility has to provide electricity to about 800 people and is situated at Tilos, Greece [10]. If the energy from the RES is insufficient to supply the demand, electricity can be imported from the nearby island of Kos via an underwater cable or generated using a diesel generator.

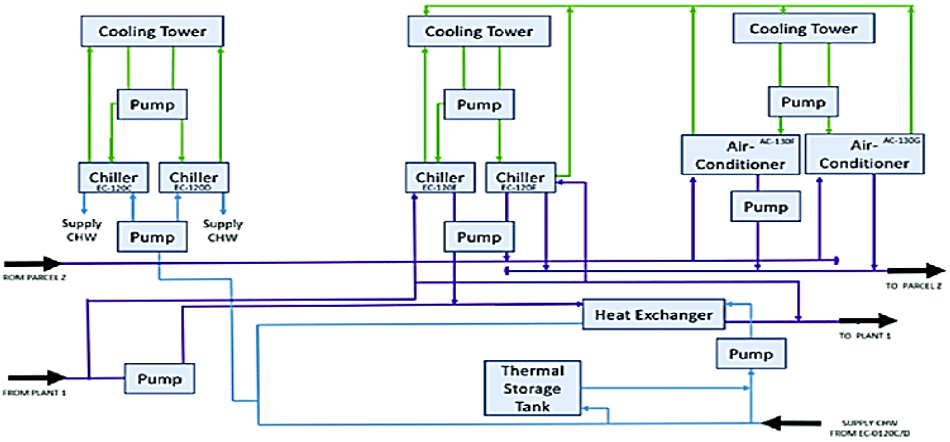


Figure 1. Procedure arrangement for the plant design

2.2 Renewable Energy Systems

The power output of the PV panels and wind turbine is calculated using in-situ meteorological weather data. Prior to optimization, calculations are performed using a unitary installed power, and the result is multiplied by the installed power in reality. The plant can also import power using a diesel generator or an underwater cable in addition to these RES [11].

2.3 Power management

To identify the optimal solution, the optimization algorithm requires values that represent the plant performances. A specific plant's behavior is simulated using weather and consumption data over an extended period of time in order to assess its performance. In order to prevent seasonal phenomena and ensure that the timeframe is reflective of the location, it should be at least one year. It is imperative that the power management method be sufficiently simple to execute rapidly, given that the optimizer will simulate many configurations. In our instance, WT control converts the power generated by the wind turbine to the voltage and frequency of the grid. PV inverters are used in a similar manner to transform the power generated by PV panels [12]. The load is supplied by this electricity. The remaining power is sent to Charge so that it can be converted to DC and kept in the battery bank if the RES power is higher than the consumption. If it is feasible, energy is exported to the main grid when the batteries are full. The batteries are depleted and converted to AC through discharge if the RES are insufficient to power the load. Should that prove insufficient, the residual energy can be obtained by importing it from either the diesel generator or the grid. Ultimately, there is a Loss of Power Supply, and the plant is penalized by the optimizer if the import power limitation prevents it from meeting the load [13].

To prevent the algorithm from returning a costly solution with almost no energy input, an economic requirement must also be lowered [14].

2.4 Economics

A power plant's cost estimation is a challenging task because there are many economic criteria involved, and they can vary greatly. For instance, the price of an installed PV panel dropped by 83% in just seven years [15]. They are also susceptible to sudden changes and rely on the location, labor costs, and supplier. The PV panels and inverters values are taken from [16] and [17], the wind turbine values are from [18], and the battery values are from [19] and [20]. The prices utilized in this paper are merely illustrative, according to the authors, who also emphasize that the paper concentrates on modeling and optimization techniques. The installation cost of each component varies based on its size. The equipment lifespan (Year) and the study duration (Year), which is set at 25 years, are used to determine how many replacements (Year) are needed. After then, the installation cost multiplied by the actualization rate (R), which reflects the yearly cost volatility, equals the purchase cost. An annualized cost is calculated by dividing the purchase price by the length of the study.

$$C_{BA} = \sum_{k=0}^{N_R} \frac{C_1 \left(1-\tau_A\right)^{L_S}}{D_S} \qquad \textbf{(1)}$$

It is estimated that the annual maintenance cost will be a small percentage of the installation cost. Finally, the yearly cost of a certain piece of equipment is:

$$C_A = C_{BA} + C_1 \tau_M \qquad \textbf{(2)}$$

The yearly cost of each piece of equipment is then added up to determine the Annualized Cost of System (ACS). The second optimization target to be minimized is the ACS. The optimization outcomes will give rise to a Pareto front since it clashes with the imported energy.

2.5 Particle Swarm Optimization

The goal of the optimization issue is to reduce the imported energy and the Annualized Cost of System (ACS) while ensuring that the Probability of Loss of Power Supply (Positive). It can be expressed like this:

$$Find\ \mathrm{x}^{*}\ \text{and X}\ such\ as \begin{cases} x^{*}=\mathrm{arg(min)}[ACS(x)] \\ LPSP(x^{*})=0 \end{cases} \qquad \textbf{(3)}$$

Where V is the vector that defines the study domain, XX the wind turbine nominal power, PV array peak power, PV inverter rated power, and battery bank capacity. Multi-Objective Particle Swarm Optimization (MOPSO) is used to address this four-parameter optimization issue [21]. Large-scale issues can be resolved using this stochastic approach that lacks gradients. It functions by shifting the particles in the research domain, which stand in for different plant arrangements. The particle velocity is determined by the plant performances, namely $AAAAA$ and $EEIIAA$, in order for them to approach the best possible solution, if any. A list of nondominated plants in the form of a Pareto front is produced by the method.

3. Results

In Figure 2, the dark blue line represents the algorithm's solutions. With its $AAAAAA$ and the percentage of imported energy, each point in the graph represents an ideal plant: $E\mathbf{D}IIII\ EELL\mathbf{O}C/$. The installed arrangement is indicated by the blue circle, while the battery bank capacity, PV array peak power (yellow), and wind turbine nominal power (green) are represented by the thinner lines (light blue). These findings suggest that wind power should be the main energy source. The plant depends entirely on wind and imports for energy over twenty-five percent; neither solar power nor energy storage is used. It becomes profitable to increase the size of the PV array below this point. Nevertheless, this electricity should be connected to a larger storage unit because it is unavailable at night. This results in a sharp rise in price and pricey autonomous gains.

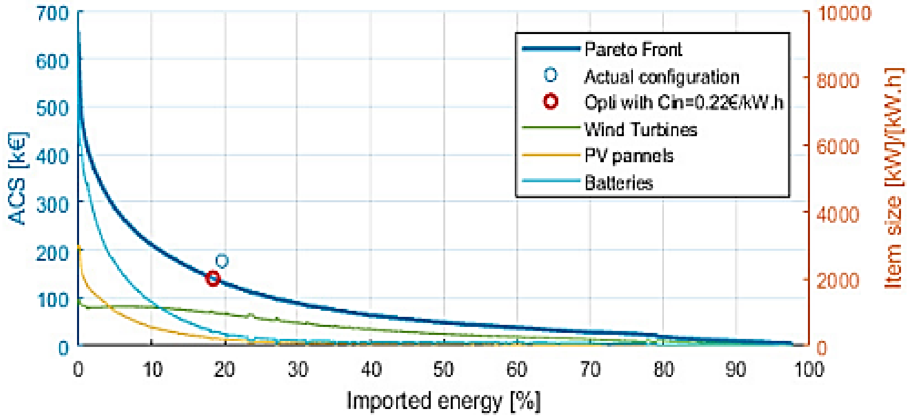


Figure 2. Procedure optimization outcome for a Tilos

The cost of importing energy and the cost of producing energy with the diesel generator now determine the best course of action. These expenses ought to be handled independently and might change every hour. They are assumed to be constant and equal for the sake of example so that the data can be presented in a three-dimensional graph. Let C be the cost of purchasing energy (i.e. the importation and the diesel cost). The ratio of annual expenditures to energy consumption for each plant is known as the production cost $CCpp$.

$$C_p = \frac{ACS + C_B E_{1A}}{E_{CA}} \qquad \textbf{(4)}$$

The plant in the Pareto front that minimizes $CCpp$ is plotted in red in Figure 3a for a given $CCBB$. Ultimately, assuming $CCBB$ specifies the ACS, the imported energy, and the production cost and helps determine the ideal plant component size. These findings are summarized on the same figure in Figure 3b. With instance, the ideal plant for VL = 220 €/MW.h consists of a 1 MW wind turbine, a 200 kWp PV array with connected inverters that provide 350kW of nominal electricity, and a 400 kW.h power bank. This plant has a production cost of 87 €/MW.h. and an energy autonomy of 80%. In Figure 2, this setup is indicated by a red circle. For somewhat better performances than its real equivalent, it needs less storage and more wind power.

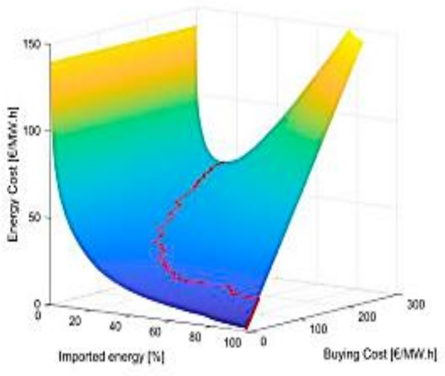
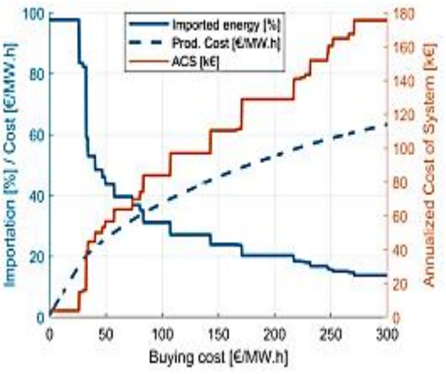


Figure 3a production cost depending on the optimal solution Figure



3bAnnualized Cost of System

4. Conclusions

This work presents an algorithm that can optimize the component sizes of a hybrid renewable power plant that is connected to a storage system. The plant model is flexible enough to accommodate different setups and accounts for the equipment's nonlinear cost as well as power-dependent efficiency. Utilizing a Multi Objective Particle Swarm technique, the optimization issue is resolved.

On the Greek island of Tilos, the algorithm has been deployed to a wind turbine, photovoltaic array, and battery bank power plant. The goals are to decrease the annualized cost of the system and the imported energy in order to avoid assuming an energy importation cost prior to the optimization. The best option for various importation costs can be calculated after the Pareto front is found. The ACS, the imported energy, the cost of producing energy, and the size of each plant component (WT size, PV installed power, inverter nominal power, and storage capacity) make up the solution.

The optimization problem has been effectively resolved by this algorithm. It can be enhanced by putting into practice a more effective energy management plan [22], having the option to deploy numerous storage units, having more accurate power source models, or having storage eventually age. To provide more practical answers, the economic factors for the component purchasing and maintenance expenses also need to be improved.

Conflicts of Interest: Declare conflicts of interest or state “The authors declare no conflict of interest.”

References

1. Bahramian, M. and K. Yetilmezsoy, *Life cycle assessment of the building industry: An overview of two decades of research (1995–2018).* Energy and Buildings, 2020. **219**: p. 109917.
2. Sijm, J., K. Neuhoff, and Y. Chen, *CO2 cost pass-through and windfall profits in the power sector.* Climate policy, 2006. **6**(1): p. 49-72.
3. Sefrioui, M. and J. Périaux. *A hierarchical genetic algorithm using multiple models for optimization*. in *International Conference on Parallel Problem Solving From Nature*. 2000. Springer.
4. Sivanandam, S., et al., *Genetic algorithm optimization problems.* Introduction to genetic algorithms, 2008: p. 165-209.
5. Wang, D., D. Tan, and L. Liu, *Particle swarm optimization algorithm: an overview.* Soft computing, 2018. **22**: p. 387-408.
6. Gad, A.G., *Particle swarm optimization algorithm and its applications: a systematic review.* Archives of computational methods in engineering, 2022. **29**(5): p. 2531-2561.
7. Schutte, J.F., et al., *Parallel global optimization with the particle swarm algorithm.* International journal for numerical methods in engineering, 2004. **61**(13): p. 2296-2315.
8. Abazari, A., et al., *Wind turbine participation in micro-grid frequency control through self-tuning, adaptive fuzzy droop in de-loaded area.* IET Smart Grid, 2019. **2**(2): p. 301-308.
9. Bazmi, A.A. and G. Zahedi, *Sustainable energy systems: Role of optimization modeling techniques in power generation and supply—A review.* Renewable and sustainable energy reviews, 2011. **15**(8): p. 3480-3500.
10. Kaldellis, J.K., *Supporting the clean electrification for remote islands: The case of the greek tilos island.* Energies, 2021. **14**(5): p. 1336.
11. Duchaud, J.-L., et al., *Multi-Objective Particle Swarm optimal sizing of a renewable hybrid power plant with storage.* Renewable Energy, 2019. **131**: p. 1156-1167.
12. Yaramasu, V., et al., *High-power wind energy conversion systems: State-of-the-art and emerging technologies.* Proceedings of the IEEE, 2015. **103**(5): p. 740-788.
13. Geidl, M. and G. Andersson, *Optimal power flow of multiple energy carriers.* IEEE Transactions on power systems, 2007. **22**(1): p. 145-155.
14. Chaudhari, K., et al., *Hybrid optimization for economic deployment of ESS in PV-integrated EV charging stations.* IEEE Transactions on Industrial Informatics, 2017. **14**(1): p. 106-116.
15. Van der Zwaan, B. and A. Rabl, *The learning potential of photovoltaics: implications for energy policy.* Energy policy, 2004. **32**(13): p. 1545-1554.
16. Moser, D., et al., *Identification of technical risks in the photovoltaic value chain and quantification of the economic impact.* Progress in Photovoltaics: Research and Applications, 2017. **25**(7): p. 592-604.
17. Hacke, P., et al., *A status review of photovoltaic power conversion equipment reliability, safety, and quality assurance protocols.* Renewable and Sustainable Energy Reviews, 2018. **82**: p. 1097-1112.
18. Hernández-Callejo, L., S. Gallardo-Saavedra, and V. Alonso-Gómez, *A review of photovoltaic systems: Design, operation and maintenance.* Solar Energy, 2019. **188**: p. 426-440.
19. Jossen, A., *Fundamentals of battery dynamics.* Journal of power sources, 2006. **154**(2): p. 530-538.
20. Campagna, N., et al., *Battery models for battery powered applications: A comparative study.* Energies, 2020. **13**(16): p. 4085.
21. Deb, K. and N. Padhye, *Enhancing performance of particle swarm optimization through an algorithmic link with genetic algorithms.* Computational Optimization and Applications, 2014. **57**: p. 761-794.