Dandelion-Optimizer based power sharing in hybrid renewable energy system optimum sizing with EV: grid-connected, wind, solar, battery, electric vehicles

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Abstract

The increasing popularity of electric vehicles highlights the importance of power sharing in hybrid renewable energy systems. This article discusses the integration of electric vehicles into hybrid renewable energy systems using the Dandelion-Optimizer based optimal sizing method. An amalgamated energy mechanism, which encompasses a solar/wind/battery/electric vehicle grid connection, has been suggested to generate electricity for a university positioned at 40°39.2' N latitude and 29°13.2' E longitude. Two loads have been connected to the system, one is the campus load, and the other is the electric vehicle charging load. Renewable energy sources, such as PV and wind, have been utilized in the system. The study shows that four electric vehicles with a capacity of 52.4 kWh from the Turkish automotive manufacturer TOGG can be charged at designated locations on the campus, and the university campus load can be met continuously with a grid-connected hybrid energy system. The comprehensive examination comprises of estimation of yearly expenses, energy expenditures, scheduling of electric vehicles, decrease in the consumption of electricity from the primary power grid, and ecological consequences.The entire simulation study has been carried out using MATLAB 2022b software.

Keywords: Electric vehicles, Charging station, Renewable energy sources, Optimization, Dandelion-Optimizer.

Nomenclature

DC	Direct Current
AC	Alternative Current
EVs	Electric vehicles
EV	Electric vehicle
EVC	Electric vehicle charging
EVCP	Electric vehicle charging platform
V2G	EV to grid
G2V	Grid to EV
LCOE	Levelized cost of energy
HRES	Hybrid renewable energy systems
PV	Photovoltaic
WT	Wind Turbine
BT	Battery
TNPC	Total Net Present Cost
LPSP	Loss of Power Supply
REF	Renewable Energy Fraction
GCF	Grid-Connected Frequency
DO	Dandelion Optimizer

1. Introduction

Worldwide, the integration of Electric vehicles (EVs) into the grid is gaining importance as technology advances. Compared to fossil fuel-powered vehicles, EVs offer a range of benefits, including lower operating costs, greater energy efficiency, and zero exhaust emissions. Due to their ability to function as mobile energy storage devices, they can be seamlessly integrated into the main grid. The number of personal and commercial EVs is also rapidly increasing. Two-way controlled energy flow from EV to grid (V2G) is feasible. The intermittent nature of renewable energy sources has resulted in the need for energy storage facilities, making electric vehicles a potential and efficient energy source. This is why storage facilities are becoming increasingly significant. Electric vehicles (EVs) can be incorporated into the grid in diverse methods, such as through microgrids, contingent on their power capacities, power flow directions, converter topologies, and charging management schemes. EV charging stations can be categorized into three primary levels: Level 1, Level 2, and Level 3. Level 1 charging stations have the lowest power output, which ranges between 1.3 kW and 2.4 kW, making them the slowest. Level 2 charging stations are faster, with a power output of up to 19 kW. Level 3 charging stations are the swiftest and utilize DC power, with an output of up to 350 kW, which can charge an electric vehicle battery up to 80% in around one hour, according to sources [1-3].

EVs are creating a new energy source for hybrid renewable energy systems (HRES) and have significant implications in overcoming various challenges associated with these systems. Several studies in the literature have focused on different aspects of HRES, including two hybrid systems and an EV [4].

Nonetheless, constructing a PV-based charging station independent of the grid is not practical, as the output of the PV system is erratic, affected by atmospheric clarity and weather conditions, and produces no power at night when it generates the most energy during the day. Additionally, the charging station lacks a specified EV limit for charging, enabling energy to be accessible at the periods of maximum production. In a grid-connected system, the excess energy can be sold back to the electrical grid to maximize revenue. Several studies have been presented in recent years to establish this. A study is being conducted to assess the practicality of a hybrid solar and wind-based charging station. Nevertheless, PVs and wind energy have fluctuating outputs, and the absence of a grid connection makes system reliability a persistent concern. Another scholarly article proposes a charging station that merges grid power, solar energy, and diesel generator power. Although the reliability of the system remains intact, worries regarding the environment persist because of the utilization of a diesel generator. The writer talks about the optimal method of combining solar power with a storage solution for batteries. Which makes the suggested system relatively reliable even in the absence of grid connection. However, if the weather remains overcast for an extended period, the reliability of the system will be compromised [5].

This research proposes a novel bio-inspired optimization algorithm, named the Dandelion Optimizer (DO), for addressing continuous optimization problems. Prior studies focused on dandelion plants have primarily drawn inspiration from their seed dispersion behavior. Specifically, the DO algorithm updates the new generation individuals through the dynamic regulation of the seeding radius and autonomous learning of dandelions [6]. In this context, a modified version of the dandelion algorithm divides the dandelion population into two subgroups: the core dandelion and the auxiliary dandelion, utilizing distinct seeding behaviors for each subgroup [7]. Additionally, the long-distance flight of a dandelion seed is a crucial behavior for biological evolution. Different flight strategies, influenced by wind and air, lead to dandelion seeds landing in different areas. The DO algorithm simulates the lifelong journey of dandelion seeds as they mature and fly through the wind.

In this study, an optimum sizing method based on DO algorithm is used to provide solutions to the concerns mentioned in the literature. The main contribution of the paper is the uninterrupted supply of loads within the campus and the generation of revenue by selling excess energy to the grid for charging 4 TOGG devices. The sizing is carried out using the DO algorithm in the optimization process, and a robust rule-based energy management controls the power flow.

2. Hybrid Energy systems

The proposed hybrid power system integrates a wind turbine and solar power plant, which are connected to the power grid and a battery bank via a converter. An electric vehicle charging station and campus AC load are also included, connected to an AC data bus. The battery bank and EV charging stations operate bidirectionally, and a mathematical model will be provided to estimate EV demand and system performance. A mathematical optimization model has been developed using the predicted demand profile, renewable energy source (RES) availability, and hourly EV visits to optimize the system. The focus of the study is on the operational characteristics of a grid-connected PV/WT/BT/EVCS with a charging demand simulated between 8:00 am and 4:00 pm based on the TOGG model EV. Four EV charging devices with a capacity of 52.4 kW each were installed at the station.

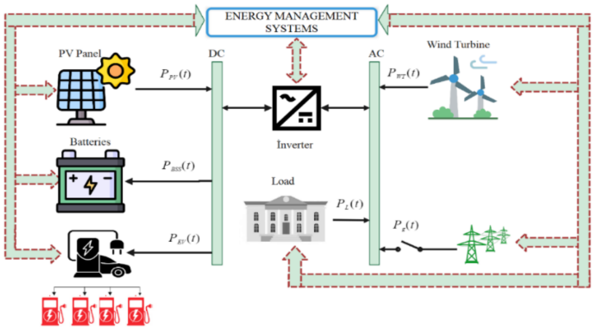

Fig. 1. Renewable energy systems for campus with electric vehicle charging platform

3. Dandelion Optimizer (DO)

DO algorithm is a bio-inspired optimization algorithm developed by taking inspiration from the dandelion plant found in nature. DO is used to solve continuous optimization problems. The DO algorithm simulates the lifelong journey of dandelion seeds under the influence of wind. During this journey, the seeds change their direction and reach different places with the effect of the wind. Based on this natural behavior, the algorithm develops a search strategy to explore possible solution candidates. Unlike other optimization algorithms that use random values to compute starting points, DO uses a balancing process. Additionally, to update the position of each individual in the population, DO dynamically adjusts the pollination radius and learning rate of the dandelion plant, thereby ensuring diversity in the population.

DO is an effective algorithm, especially in solving high-dimensional continuous optimization problems. Furthermore, the algorithm's ease of application and flexibility in parameter settings make it easy to use.

4. Simulation and Results

The graph shown in Figure 2 is the monthly energy graph of HRES obtained after the optimization process. It shows how much energy is generated by each source and what the monthly demand for energy is. For example, it shows how much energy is generated by solar power in kWh in January, as well as how much energy is generated by wind power and how much of the load is met by the battery. The graph also shows how much energy is exchanged between the house and the grid for all months. Similarly, the energy demand shows what the load demand is for the entire month and how much energy is stored in the battery for the entire month. All variables for each month are separated for annual comparison.

The optimization results obtained with DO are presented in Table 1.

Table 1. Optimum sizing results obtained with the DO algorithm

Optimization Results	
Wind Turbine	1200 kW
Solar Units (350 W)	1200
Battery Units	1.77×10^{2}
Grid Cost	1.84×10^{4} \$
Grid Purchased	3.6728×10^{5}kWh
Grid Sale	3.6703×10^{6}kWh

LCOE	0.0640 \$/kWh
NPC	4.5521 x10^6 \$
Total Wind Energy	4.2067 x 10^6 kWh
Total Solar Energy	2.3727 x10^6 kWh
LPSP	0.0874
REF	94.71%
GCF	5.29%

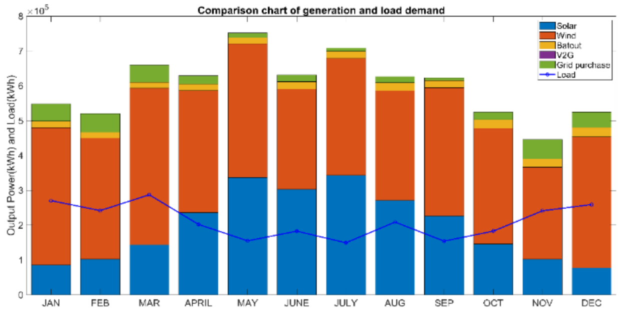

Fig. 2. The average electricity load is provided to determine the optimal configuration and share of HRES components

The energy taken from the grid by the EV and the energy transferred from the EV to the grid are shown on Figure 3.

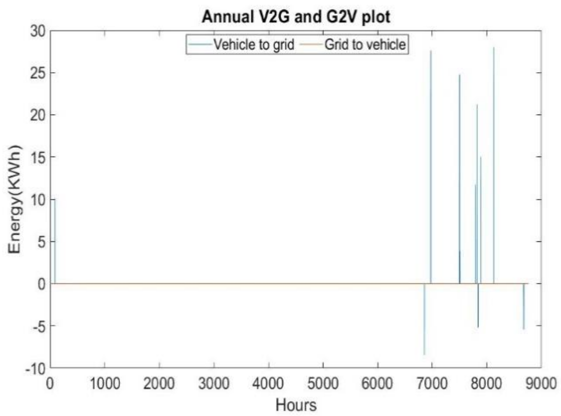

Fig. 3. Annual V2G and G2V

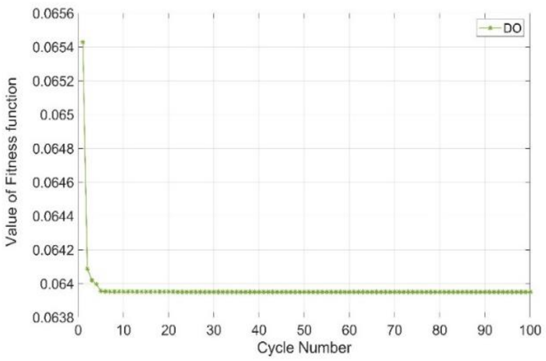

Fig. 4. Convergence analysis of the DO algorithm

In Figure 4, it is clear that the DO algorithm shows a fast convergence towards the objective function. This indicates that the algorithm is effective in minimizing the objective function. The convergence rate indicates how efficient the algorithm is and therefore is an important factor in selecting the algorithm used to optimize the objective function. However, the performance of the algorithm may vary depending on initial conditions, hyperparameters, and other factors.

5. Conclusion

The research aims to optimize hybrid EV charging systems sustainably by considering a techno-economic analysis. The study utilized the Dandelion optimizer algorithm for multi-objective optimization and evaluated the results based on two objectives. The optimum system consists of 1200 PV systems with a capacity of 350 W, a 1200 kW wind turbine, and 1.7748x102 battery systems. The most optimal results were obtained with 4.5521 x106 \$ TNPC, 0.0640 \$/kWh LCOE, and 8.74% LPSP values. The load demand is met by 94.71% renewable energy sources and 5.29% conventional energy sources, generating 3.6703 x106 kWh in energy sales revenue to the grid. To summarize, the study offers a viable and environmentally-friendly solution for hybrid EV charging systems that considers both technical and economic factors. A model is presented for both university power demand and four TOGG vehicles charged at designated intervals in EV charging stations on campus with energy sales revenue to the grid.

References

[1] Mishra S., Verma S., Chowdhury S., Gaur A., Mohapatra S., Dwivedi G., Verma P. A comprehensive review *ondevelopments* in electric vehicle charging station infrastructure and present scenario of India. Sustainability 2021, 13, 2396.

[2] Chavhan S., Zeebaree S.R.M., Alkhayyat A., Kumar S. Design of Space Efficient Electric Vehicle Charging Infrastructure Integration Impact on Power Grid Network. Mathematics 2022, 10, 3450.

[3] Balmelli S., Moresino F. Coordination of Plug-In Electric Vehicle Charging in a Stochastic Framework: A Decentralized Tax/Incentive-Based Mechanism to Reach Global Optimality. Mathematics 2023, 11, 999.

[4] Güven A.F., Samy M.M. Performance analysis of autonomous green energy system based on multi and hybrid metaheuristic optimization approaches, Energy Conversion and Management 269, 116058, 2022.

[5] Shaukat N., Khan B., Ali S.M., Mehmood C.A., Khan J. Farid U., Majid M., Anwar S.M., Jawad M., Ullah Z. A survey on electric vehicle transportation within smart grid system. Renew. Sustain. Energy Rev. 2018, 81, 1329–1349.

[6] Gong C., Han S., Li X., Zhao L., Liu X. A new dandelion algorithm and optimization for extreme learning machine. J. Exp. Theor. Artif. Intell. 30 (1), 39–52, 2018.

[7] Li X., Han S., Zhao L., Gong C., Liu X. New dandelion algorithm optimizes extreme learning machine for biomedical classification problems. Comput. Intel. Neurosci. 2017.