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OPTIMAL SIZING OF A PV-WT HYBRID SYSTEM FOR AN ELECTRIC VEHICLE RECHARGE STATION APPLICATION BASED ON MIXED INTEGER LINEAR PROGRAMMING

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ABSTRACT

As global efforts advance toward a more environmentally sustainable future, there is a significant surge in the availability of electric vehicles for purchase. A growing number of electric vehicles does, nevertheless, give rise to novel challenges, including the requirement for environmentally sustainable and efficient charging alternatives. At this juncture, the microgrids initiate operation. Decentralized energy systems, such as microgrids, have the capability to function autonomously or in tandem with traditional centralized energy infrastructures. It possesses the ability to operate autonomously or in contrast to the conventional system. There are several benefits associated with microgrids, such as increased productivity, reliability, and resiliency. This article aims to evaluate the feasibility of integrating microgrids into electric vehicle charging stations. Case studies of successful microgrid deployments will be analyzed, the challenges and limitations of using microgrids in charging stations will be assessed, and the benefits of employing microgrids in this context will be discussed. Upon perusing this article's conclusions, you will possess an enhanced comprehension of the potential for microgrids to furnish environmentally sustainable and efficient charging solutions for electric vehicles. In Tangier, the scarcity of electric vehicle charging stations can be attributed to the substantial expenditure required for infrastructure development, such as electrical grids. On one side, the current infrastructure lacks sufficient development, thus impeding the widespread adoption of charging stations. On the other hand, Morocco has made significant progress in the field of renewable energy, particularly through investments in solar and wind power. Consequently, this study holds great potential for yielding valuable insights.

Keywords: *Microgrids, Renewable Energy, Energy Management Plan, Electric Vehicles, Charging Stations*

1. INTRODUCTION

A dependable and efficient charging infrastructure is becoming increasingly crucial as the prevalence of electric vehicles increases. A promising solution for powering electric vehicle charging stations is microgrids, which are decentralized power systems capable of operating autonomously or in conjunction with a larger grid. In light of the growing demand for electric vehicles in Morocco and the potential cost savings, resilience enhancements, and energy efficiency improvements associated with microgrid implementation across residential, commercial, and industrial sectors, in addition to charging stations, are all viable applications. In addition to their potential to revolutionize the way electric vehicle charging stations are powered, this essay will examine the application of microgrids in a the charging station.

A significant number of the sizing studies for hybrid PV-WT systems have been created and based on heuristic optimization approaches such as the Genetic Algorithm in [1], [2], [8], and [16], the Bat Algorithm in [11], and the hill climbing algorithm. In [4, 6], [9], [10], and [15], several surveys about the various ways of sizing were carried out.

In this paper, the optimal scaling problem of a hybrid photovoltaic system used to power a charging station of electrical vehicle installation is investigated. MILP (Mixed Integer Linear Programming) is utilized in the formulation and resolution of such a problem. The problem of sizing has been solved using a variety of techniques, including the cutting plane method, Branch and Bound, Branch and Cut, Branch and Price, and, of course, the heuristics previously mentioned. For additional information, see [18] and [19].

This study examines the charging station for electrical vehicles installation cost estimation based on MILP. Our methodology differs from that of previously published studies [17], [7], and [13] in that it incorporates fewer binary variables. Note that this reduction in the magnitude of binary variables is crucial for the proposed MILP problem's solvability. A simulation test comparing the Genetic Algorithm (GA) and the Branch and Cut Algorithm (BCA) is used to demonstrate the effectiveness of the proposed method. Our simulation demonstrates that BCA is superior to GA.

The structure of the subsequent sections is as follows. A PV-wind turbine hybrid system is described in detail in Section 2. Our constrained sizing puzzle is described in Section 3. Section four of the paper presents the optimized hybrid model. Case studies are discussed in Section 5. Section 6 concludes with concluding remarks.

2. SYSTEM DESCRIPTION

The system under investigation is comprised of Wind Turbines (WT), Photovoltaic cells (PV) and a battery energy storage system (BESS) are both components of a photovoltaic system. Figure 1 illustrates this system's architecture.

The solar energy captured by the PV cells is converted into electricity, which is then used to meet demand and/or charge the batteries. AC/DC converters are installed between the PV panels/BESS and the load because the energy generated by the PV panels is DC energy. This connection is facilitated by the Point of Common Coupling (PCC).

2.1 PV System illustration

The following formula is used to calculate the output power of a multi-crystalline PV system based on previous research published in [20] and [21].

$$P^{pv}(t) = \eta A G_T (t) \quad (1)$$

In which:

- η is the total efficiency derived from η= ηPV ηSYS
- A is the PV panel's surface area.
- GT is the total amount of radiation per square meter per hour.

ηSYS is the system efficiency, which depends on the efficiency of the AC/DC converter and cable losses, and P V is the PV module efficiency.

The efficacy of the PV modules is dependent on temperature variations, as represented by the equation below:

$$\eta_{PV} = \eta_r[1 - \beta(T_c - T_r)] \quad (2)$$

Where ηr is the rated efficacy of the module.

- β is the efficiency temperature coefficient.
- Tr is the temperature at which efficacy is rated.

Regarding the cell temperature Tc, it is computed based on the instantaneous ambient temperature Tα

$$Tc(t) = \frac{NOCT - T_{\alpha,NOCT}}{G_{T,NOCT}} G_T(t) \quad (3)$$

With:

- NOCT represents the Normal Operating Cell Temperature.
- $G_{T,NOCT}$ is the solar radiation in NOCT

2.2 Wind Turbin Model

In previous works, the expression of the energy output of a Wind Turbine is regarded to be proportional to the cube of wind velocity (see, for example, [23] and [24] where this power is expressed). can be calculated using the formula below:

$$P_{wt}(t) = \tfrac{1}{2}\, C_p\, \rho A V^3(t) \quad (4)$$

where
- ρ is the air density in kilograms per cubic meter.
- A is the swept area of the rotor in m2.
- Cp is the Wind Turbine's power coefficient, which describes its efficacy
- $V(t)$ represents the wind speed in m/s.

2.3. BESS Model

To control the transfer of energy from and to the BESS modules, it is essential to have information about the level of energy available in the batteries at each time t. This information is represented by the State Of Charge (SOC) parameter.

The expression used to determine the state of charge can be found in a variety of sources, including [3] and [5]. These works demonstrate that the State of Charge variation can be calculated using the following formula:

$$\begin{cases} S\dot{O}C = P^{bess}(t) \\ SOC = N^{bat}\, SOC_0 \end{cases} \quad (5)$$

Where:

- Nbat is the number of storage units.
- SOC_0 is the initial state of charge.

  As the charge and discharging operations are distinct, Pbess(t) can be expressed as follows:

  $P^{bess}(t) = \alpha P^{bc}(t) - \beta P^{bd}(t)$ (6)

where:
• α is the efficacy of charging.
• β represents the discharge efficacy.
• Pbc(t) is the amount of electricity used to charge the batteries.
• Pbd(t) is the power supplied by the batteries to meet the demand for energy.

As charging and discharging cannot occur simultaneously, Pbc(t) and Pbd(t) can be expressed as follows:

$$\begin{cases} P^{bc}(t) = x(t) I_{bc}(t) V_b \\ P^{bd}(t) = (1 - x(t)) I_{bd}(t) V_b \end{cases} \quad (7)$$

Where:

- Ibc(t) is the efficacy of charging.
- Ibd(t) represents the discharge efficacy.
- Pbc(t) is the amount of electricity used to charge the batteries.
- Pbd(t) is the power supplied by the batteries to meet the demand for energy.
- Vb is the batteries' voltage
- x(t) is a binary variable taking the value 0 during charging phase, and the value 1 during discharging phase.

As charging and discharging cannot occur simultaneously, Pbc(t) and Pbd(t) can be expressed as follows:

$$\mathbf{P^{bc}(t)P^{bd}(t) = 0} \quad \mathbf{(8)}$$

This equation can be rewritten using the following equations, which involve the binary variable x(t).

$$\begin{cases} x(t) P^{b}_{max} \geq P^{bc}(t) \geq 0 \\ (1 - x(t)) P^{b}_{max} \geq P^{bc}(t) \geq 0 \end{cases} \quad (9)$$

2.4. System modelling

Renewable energies are often used in our everyday lives to provide electricity for residential, commercial, and transportation purposes, with the aim of fostering the development of environmentally sustainable urban areas.

The present study aims to use photovoltaics and wind energy in order to replicate a charging station for electric cars, as seen in Figure 7. The direct current (DC) is first derived from the solar panels and wind turbines. The electrical energy generated by the solar panel was directed towards the highest Power Point Tracking (MPPT) system, which facilitated the transmission of the highest power output from the solar cells. The voltage and current were measured in order to determine the best value. If the voltage fluctuates, it may be adjusted using a DC-DC converter. The DC Microgrid serves as a means of transmitting energy from its source to electric vehicles (EVs). The DC-AC inverter is used at the receiving end to facilitate the conversion of the current. The LC filter serves the purpose of attenuating undesired noise present in the circuit and enhancing the overallwaveform integrity of the electrical signal.

The wind turbine is linked to DC-DC converters, whereby the electric current is monitored using Maximum Power Point Tracking (MPPT) technology in conjunction with a charge controller. Simultaneously, the battery bank underwent charging and discharging processes inside the DC microgrid via the use of a bidirectional DC-DC converter. This article mostly examines solar panels.

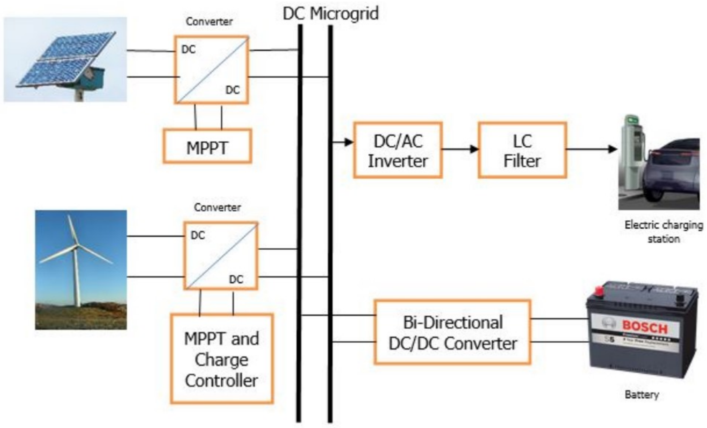

Figure 1: Diagram for charging station using renewable energy

2.5. Load Profile

The electrical load consists to charge the full batteries of 2 cars per day is 121 kWh per day:

3. PROBLEM FORMULATION

Based on the functional constraints, we present the formulation of the constrained sizing problem in this section. The following section describes the objective function and the various constraints.

3.1. Objectif function

The objective function represents the overall cost of installing the system, denoted as Ct.

$$C_t = \sum_{k=1}^{3}((N^k)(I_k + R_k + OM_k)) \quad (10)$$

Where

- k refers to the system's components, such as: Component 1 is the PV panel, Component 2 is the Wind micro turbine and Component 3 are the batteries
- Ik is the Initial cost of component k.
- Rk is the annual replacement cost of component k.
- OMk represents the yearly expenses for operating and maintaining component k, amounting to 1.5% - 2% of the initial investment.

3.2. Constraints in continuous form

The optimization problem is constrained by the subsequent factors:

1. Demand constraint refers to the requirement that the energy generated from the power system components must be sufficient to satisfy the current demand.

$$D(t)= P^{pv}(t)+ P^{wt}(t)- P^{bc}(t)+ P^{bd}(t) \quad (11)$$

Where:

- D(t) is the demand in function of time.
- P^{sf} (t) is the forecasted PV panel power production in function of time.
- P^{wf} (t) is the forecasted wind power production in function of time.
- N_{pv} is the number of PV modules
- N_{wt} is the number of wind turbines

2. State Of Charge Bounds: To safeguard the batteries against excessive and insufficient charging, adherence to the subsequent restriction regarding the highest and lowest possible values (SOCmax and SOCmin) is required.

Table 1 : Net energy needed and loading time for both EV models

Electric Vehicle Model	Net energy Needed (kWh)	Daily Loading Time (hour)	Daily Net Energy Needed (kWh)
Renault Zoe	22	3	66
Hyundai Kona	11	5	55
	Total EVCS power: 33 kWh	Average loading time: 4h	Total Daily net energy needed: 121 kWh

$$N^{bat}\,SOC^{min} \leq SOC(t) \leq N^{bat}SOC^{max} \quad (12)$$

With:

- SOC^{max} is the maximal the Maximum Recommended Operating Current (SO for the storage unit.
- SOC^{min} is the minimum amount of energy that ought to be retained in the storage unit.

3. Ramp constraint: Rapid battery charging and discharging can have detrimental effects on the system's performance and shorten the batteries' lifespan. As a result, the charge and discharging capabilities are constrained by the subsequent inequalities:

$$r \geq \left|\frac{dP^{bd}}{dt}\right| \quad \textbf{and} \quad r \geq \left|\frac{dP^{bc}}{dt}\right| \quad \textbf{(13)}$$

r is the maximal ramp rate.

4. Complementary constraint: The expression for the complementarity between the charging and discharging operations is

$$\begin{cases} x(t)\, P^{b}{}_{max} \geq P^{bc}(t) \geq 0 \\ (1 - x(t))P^{b}{}_{max} \geq P^{bd}(t) \geq 0 \end{cases} \quad (14)$$

Where:

- $P^{b}{}_{max}$ is the maximal exchanged power by the storage system
- x(t) is a binary function such as x(t)=1 during charging process, and x(t)=0 during discharging process.

5. Space constraint: Given the following inequalities, the space allocated for the system's components is constrained.

$$\begin{cases} N^{pv}{}_{max} \geq N_1 \geq 0 \\ N^{wt}{}_{max} \geq N_2 \geq 0 \\ N^{bat}{}_{max} \geq N_3 \geq 0 \end{cases} \quad (15)$$

Where:

- $N^{pv}{}_{max}$ is the maximum quantity of permitted PV panels.
- $N^{wt}{}_{max}$ is the maximum quantity of wind turbines permitted.
- $N^{bat}{}_{max}$ represents the maximum quantity of permitted batteries.

A. Functional constraints expressed as discrete variables

To implement simulation of our model, it is imperative to employ a discrete form that handles a restricted set of values. These values correspond to a finite number of iterations, referred to as sampling times t_i, which are defined as follows:

$$t_i := t_0 + i\,\frac{tf\_t_0}{N},\ i=0\ldots N \quad (16)$$

- t_0 is the initial time
- t_f is the final time
- N is the horizon of the study.

The sampling interval is defined by:

$$\delta t := t_{i+1} - t_i = \frac{tf\_t_0}{N} \quad (17)$$

The process of discretizing the equations [10-15] produce the subsequent expressions:

$$N^{pv}{}_{max} \geq N_1 \geq 0$$
$$N^{wt}{}_{max} \geq N_2 \geq 0$$
$$N^{bat}{}_{max} \geq N_3 \geq 0$$

$$N^{pv}\,P_i^{sf}\ \ (+\,N^{wt}\,P_i{}^{wf} - P_i{}^{bc} + P_i{}^{bd} \geq D_i$$

$$N^{bat}(S_0 - S_{min}) \geq \sum_{i=1}^{k}(\alpha\, c\, P_i{}^{bc} - \alpha d\, P_i{}^{bd})\,\delta t \geq N^{bat}(S_0 - S_{max});\ k = 1\ldots N$$

$$x_i P^b{}_{max} \geq P_i{}^{bc} \geq 0$$
$$(1 - x_i)P^b{}_{max} \geq P_i{}^{bd} \geq 0$$
$$r\delta t \geq P_i{}^{bd} - P_{i\_1}{}^{bd} \geq -r\delta t$$
$$r\delta t \geq P_i{}^{bc} - P_{i\_1}{}^{bc} \geq -r\delta t$$

(18)

4. OPTIMIZED MODELLING

The optimization problem formulation generates a MILP problem, which is an NP-hard problem that cannot be solved by a polynomial-time algorithm. The resolution time of such problems is predominantly determined by the number of binary variables included in the formulation, the geometry of the problem, and the number of variables.

In order to mitigate potential challenges related to resolution times and accuracy arising from the expanding scale of the MILP problem, a multitude of resolution algorithms have been devised. These include the Branch and Bound, Genetic Algorithm, Ant Colony Algorithm, and Particle Swarm Optimization. A summary of a few of these techniques is presented in [18].

The two algorithms utilized in this paper are the Branch and Cut Algorithm and the Genetic Algorithm. The following software applications may be utilized to implement these algorithms: Matlab, Cplex, Tomlab, Gurobi, and Knitro. Certain software applications may even integrate multiple algorithms during the resolution procedure.

We propose a solution to this issue utilizing the Genetic Algorithm and the Branch and Cut Algorithm in the following section.

5. CASE STUDY

To evaluate the efficacy of the algorithms in addressing the sizing issue and determine the most optimal solution, we conducted comprehensive numerical simulations, which will be elaborated upon in the following sections. The simulations were executed via the Tomlab user interface.

According to the climatic data gathered in the city of Tangier in 2022, December experiences the most severe climatic conditions. As a result, we incorporated December's meteorological data, including solar radiation, ambient temperature, and wind speed, into our simulations. Furthermore, the electrical power consumption values of the street lighting luminaires that were documented during the identical time were incorporated.

Each of the datasets comprises four values per day: 7:00 am, 01:00 pm, 7:00 pm, and 01:00 am. The first time is at 1:00 pm on December 1, 2022, and the last time is at 1:00 pm on January 1, 2023. $\frac{t_f\_t_0}{N}$ is the sampling interval, and N = 124 is the horizon.

The values utilized in Table I were incorporated into the simulations; on the other hand, Table II details the production and storage units implemented in the simulations. (II).

Table 2: Parameters Values For The Simulation

Parameter	Value
N^{pv}_{max}	15 Units
N^{wt}_{max}	6 Units
N^{bat}_{max}	5 Units
P^{bd}_0	0W
P^{bc}_0	1000W
P^{b}_{max}	5000W
S_0	4000W/h
S^{min}	400W/h
S^{max}	4500W/h
r_c, r_d	3000W/h
α_c	1
α_d	1,2

Table 3: Products With Their Corresponding Prices

Product	**Price**
CSUN 255-265-60P 12V 265WP PV panels	158$
Micro wind turbines TEMPSA 12V/24V 400W	285$
Vrla sealed lead acid batteries 12V 230Ah	316$

3.3. Results

The subsequent are the outcomes derived from the simulation that incorporated the Branch and Cut algorithms alongside the Genetic Algorithm:
The results suggest that the Genetic Algorithm requires a considerably longer period of time to converge than the Branch and Cut Algorithm. Moreover, it is evident that the acquired solution lacks optimality and further refinement is required.
The methodology employed, along with the advantages and disadvantages of the present strategy, are detailed in Table 4. Eight scholarly articles were subjected to our examination, each employing unique research methodologies across multiple levels.

Table 4: The Metrics And Drawbacks Of Alternative Methodologies Employed In Prior Investigations

Author/ Methodology	**Advantage**	**Disadvantage**
Petrusic *et al.* / Multicriteria optimization [30]	• Maximized the use of renewable sources. • Flexibility in charging. • Easy to implement.	• Required significant investment in infrastructure, such as solar power plants and energy storage systems.
Noman *et al.* / Interval-based approach [31]	• Cost Effective method. • Reduced greenhouse gas emissions and promote sustainable transportation. • Provided a constant power supply for specific time intervals. • Suitable for urban areas with high demand for EV charging.	• Feasibility depends on several factors. • Required significant investment in wind turbines and other infrastructure.

Sakib *et al.* / Matlab/Simulink [32]	• Reduced the negative impact on the environment and geological aspects. • Meet the demand for the next-generation power system. • Better design and optimization of the system. • Enhancing fuel efficiency.	• Required initial investment and infrastructure development. • Depends on the availability and accessibility of natural gas resources.
Foley *et al.* / PLEXOS [33]	• Minimize the cost of electricity dispatch and to some constraints. • More accurate analysis of the impact of electric vehicle charging under peak and off-peak charging scenarios.	• May not be directly applicable for other electricity markets.
Abas *et al.* / Microbial Fuel Cell [34]	• Developed more efficient and stable water-splitting systems. • A promising technology for generating clean and renewable energy. • Can withstand harsh conditions and resist corrosion.	• Used expensive catalysts. • Need for large areas of land and the requirement for continuous monitoring and maintenance.
Sayed *et al.* / DC microgrid [35]	• Reduced carbon emission • Provide sufficient electricity supply.	• Costly and may require a significant initial investment.
Aboelezz *et al.* / Generic electric vehicle battery charging system and ANN [36]	• Accurate and efficient model. • Achieved the maximum generated power from the wind turbine across the day.	• Required a full prediction of the wind signature. • Required initial investment in wind turbines and charging infrastructure.
Karmaker *et al.* Fuzzy inference system [37]	• Reduced energy costs • Provided lower charging costs • Establish a sustainable charging infrastructure • Effective energy management system.	• Effectiveness may vary with sizes and locations. • Required initial investment costs.

6. CONCLUSION

Population growth, greenhouse gas emissions, and depletion of nonrenewable resources have all contributed to the emergence of novel research directions in renewable resources. This study seeks to comprehend the applications of emergent technologies for extracting renewable energy. In order to reduce greenhouse gas emissions through the efficient utilization of renewable resources, the proposed study is beneficial. The main emergent technologies are comprised of numerous sub-technologies. To purify the planet, it is essential to support these renewable technologies. Furthermore, it is worth noting that renewable energy sources are gradually surpassing the cost-effectiveness and efficiency of non-renewable energy sources, which have historically demanded substantial investments and operated at a relatively high level of efficiency. The current worldwide transition towards renewable and sustainable energy sources, as well as their implementation in electric vehicle charging stations, is motivated by cost reductions, environmental considerations, and the pursuit of enduring sustainability.

As a result of Morocco's substantial energy consumption, electric vehicle (EV) recharge stations may be equipped with these renewable energies.

A methodology is outlined in this paper for determining the optimal dimensions of a self-contained hybrid system that is designed for installation at an electric vehicle recharge station in Tangier. The sizing problem formulation was executed through the utilization of the MILP approach.

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