Techno-Economic and Environmental Optimization Analysis of the Hybrid System on the Island of Djerba

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***Abstract*— The study aims to provide a techno-economic and environmental analysis to determine the potential for various types of renewable sources of energy. This hybrid system (solar-wind-tidal-hydraulic with batteries) was designed without a grid, using a diesel generator as a backup power source. The system design was studied using Hybrid Multi-Energy Resource Optimization Software, which calculates pollutant gas emissions and simulates, and optimizes energy distribution according to energy consumption, and energy sources used. As part of the economic analysis, the net present cost, and total cost of energy per unit were calculated. This configuration was developed to meet the energy demand of the island of Djerba, located in south-eastern Tunisia. The proposed system is more cost-effective because it takes into account energy production capacity, energy cost, gas emissions, and net present cost.**

Keywords*— Net present cost, Economic analysis, Hybrid Multi-Energy Resource Optimization software, Hybrid system.

I. Introduction

In recent years, the reduction of energy costs, and the mitigation of air pollution have emerged as significant concerns for communities worldwide, as fossil fuel consumption has markedly declined, and the pace of climate change has accelerated in recent times [1]. Smart grids and recent developments in the field of information, and communication are making it possible to reduce greenhouse gas emissions and improve air quality worldwide [2] and at microgrids [3], resulting in significantly lower energy costs and offering more benefits to consumers of commercial and residential properties.

In [4] presented an optimal sizing method for an island based microgrid system for Djerba, Tunisia, comprising a photovoltaic panel, a wind turbine and a tidal turbine. A diesel generator and a battery storage system are employed to compensate.

The proposed center includes photovoltaic systems, biomass, small hydroelectric generators, and local heating systems, as well as local converters, and storage systems. This approach reduces peak energy demand from grid neighbors and lowers energy costs. In [5] have proposed a hybrid energy distribution system based on a different model, optimized to reduce costs and greenhouse effect gas emissions. These centers are interconnected by different distribution lines and have their own specific thermal, and electrical distribution. The energy for each center in the network comes from the production of the main power plants, natural gas, hydrogen, renewable resources, or other energy centers in the network. In the study carried out in this article, multi-objective functions were considered to reduce emissions and optimize costs.

Hybrid systems now play an essential part in rural electricity supply. Numerous studies [6] have investigated the design of hybrid renewable energy systems (HRES) and provided essential information for the creation of stand-alone HRES. In [7], the authors examined the design, and financing of a microgrid on the small island of Djerba in Tunisia. They used the HOMER software application to gain a better understanding of the surrounding technical and economic context.

A review of hybrid renewable energy systems with an impact on the sustainability of energy consumption can be found in [8]. It also examines the major problems and issues related to system configuration and energy management. The authors [9] have focused on reducing costs and CO_2 emissions by solving multi-objective unit commitment problems. However, costs and emissions are not measured on the same scale, making it difficult to combine them effectively.

As part of this work, an economic perspective, and an environmental study were carried out for the design of different types of hybrid systems (photovoltaic/wind turbine/tidal turbine/hydraulic) that integrate other electrical systems such as diesel, and battery. To evaluate the proposed concept, energy consumption on the island of Djerba in south-eastern Tunisia was used as a case study. It should be noted that the innovation of this work is the consideration of the environmental factor in addition to the technical, and economic factors to obtain a solid analysis that enables decisions to be made for the design of energy solutions with hybrid systems.

In the first part of this article, we provide a general description of the proposed regenerative hybrid system. In Section 2, we define the economic analysis of this system. Finally, simulation results are discussed to illustrate the performance of the proposed method, and conclusions are given in the last section.

II. PRESENTATION OF THE SYSTEM AND THE CONTEXT OF OUR STUDY

A. Presentation of the system and the context studied

The area selected for the installation of a PV- wind turbine - tidal turbine - hydraulic generator-diesel hybrid system with a battery is located in a remote region on the island of Djerba in Tunisia. Depending on the geographical conditions, this site has significant water resources and high solar irradiation.

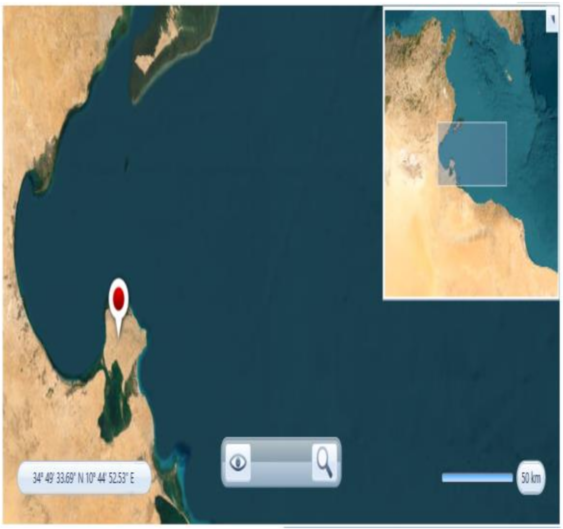


Fig. 1. Geographical location of study area

The study area is located on Djerba, a small island in south-eastern Tunisia. Located in the Gulf of Gabes, Djerba covers an area of 514 km2. The geographical coordinates of its site are 33° 48′ N, 10° 51′ E. Consequently, this site is an appropriate location for designing a hybrid energy system as shown in Fig. 1.

The proposed system represents a renewable solution for the Tunisian island of Djerba, shown in Fig. 2, and consists of a photovoltaic unit, wind turbines, tidal turbines, hydraulic as renewable generation sources, and a diesel generator.

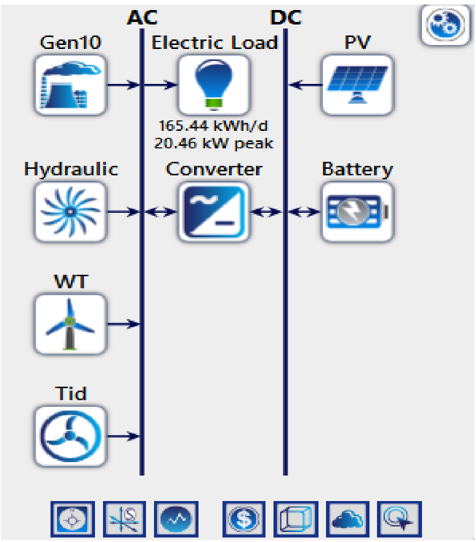


Fig. 2. Hybrid renewable energy system

B. The environmental data

Fig. 3 shows the annual solar irradiance for the island of Djerba, Tunisia, where the lowest irradiance is observed in December at 2.69 kWh/m2/day, while the highest irradiance is recorded in July, at 7.62 kWh/m2/day.

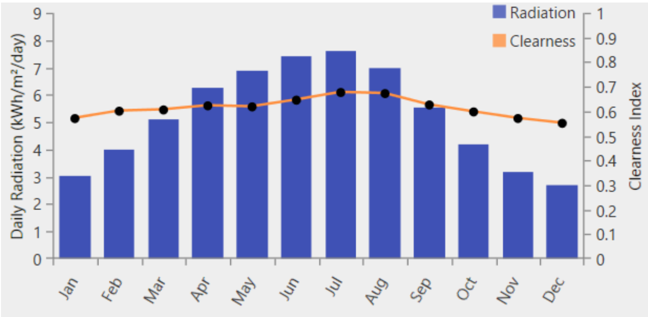


Fig. 3. Solar irradiance profile over a year

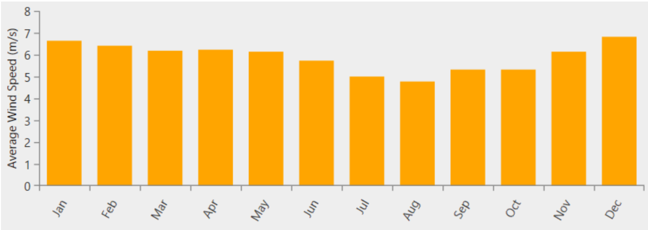


Fig. 4. Mean annual wind speed

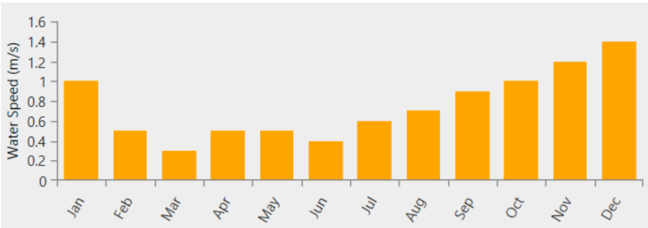


Fig. 5. Mean annual water speed

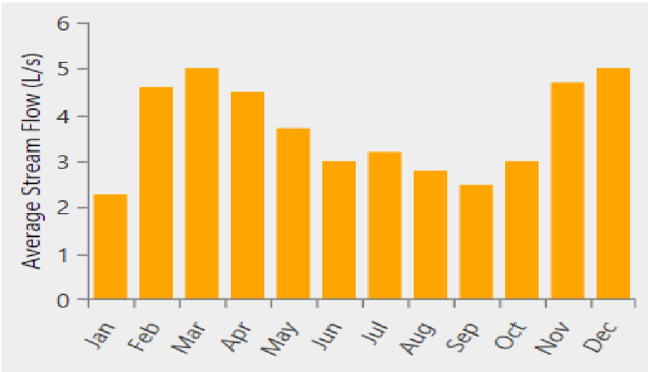


Fig. 6. Mean monthly flow rate

Fig. 4 shows the wind speed distribution, and the average wind speed on the island is 5.89 m/s. Similarly, the average tidal speed is 0.75 m/s, as shown in Fig. 5.

Fig. 6 shows the water flow with an average value of 6.96 l/s.

The proposed hybrid system was developed on the island of Djerba, Tunisia. The hybrid system structure was designed for a consumption of 165.44 kWh/day. The electrical load configuration is illustrated in the Figures below, which show the electrical energy load profile.

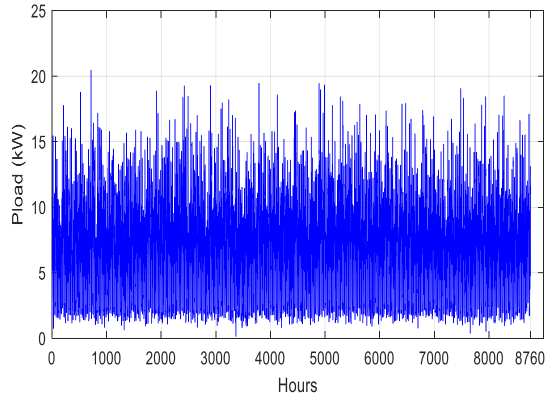


Fig. 7. Annual load demand for the site studied

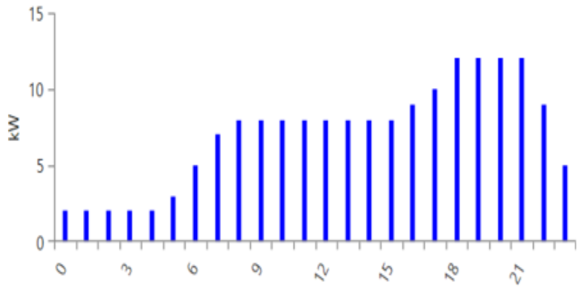


Fig. 8. Electric charge profile

III. ECONOMIC ANALYSIS

Traditional sources have high operating, and maintenance costs but lower initial investment costs, unlike renewable energy generation sources which have high capital but lower operating and maintenance costs. Furthermore, by accounting for various economic and environmental variables, the software provides valuable insights into the sizing of energy-supplying elements and their configurations [5]. In this context, the primary economic factors computed using the software include (NPC), and levelized cost of energy (LCOE).

$$f_1 = \min(\mathrm{NPC}) \quad (1)$$

$$f_2 = \min(\mathrm{LCOE}) \quad (2)$$

The net present cost (NPC) was calculated using the following formula:

$$\mathrm{CNPC} = \frac{C_{annual,total}}{\mathrm{CPF}(j, R_{project})} \quad (3)$$

With

- CNPC: Cumulative Net Present Cost
- $C_{annuel,\ total}$: Total annual cost
- j: Effective annual interest rate
- $R_{project}$: Project life period
- CPF: Capitalization Coefficient

The discounted cost of a given energy depends on equation (4):

$$\mathrm{COE} = \frac{C_{ann.t}}{E_{served}} \quad (4)$$

Where $C_{ann.t}$ signifies the overall annual expenses linked to the project, and E_{served} represents the quantity of energy generated in kilowatt-hours (kWh) during a year.

A. *Renewable factor*

The project aims to minimize distributed generation (DG) as well as net cost of production (NPC), and cost of energy (COE), thus reducing CO2 emissions and increasing the environmental sustainability of the system. The evaluation is carried out using a measure called Renewable Fraction (RF).

$$f_3 = \max(\mathrm{RF}) \quad (5)$$

The RF is calculated from equation (6) as follows:

$$\mathrm{RF} = \left(1 - \frac{\sum P_{DG}}{\sum P_{gen}}\right) \times 100 \quad (6)$$

With P_{gen} is the power generated of our system, P_{DG} is the generated power by DG.

B. *Emissions of CO2*

The use of distributed generation poses specific challenges, not least environmental pollution. The environmental impact of hybrid systems is assessed by measuring CO2 emissions during the production phase. Life cycle emissions (LCE) include energy consumed during the manufacture, transport, and installation of distributed generation system components, as well as carbon dioxide emissions from fuel combustion in the system. For distributed generation [5], the calculation formula is equation (7).

$$\mathrm{LCE} = \sum_{i=1}^{N} \beta_i E_L \quad (7)$$

Carbon dioxide emissions over the lifetime of the generator and the energy generated or stored in the battery are given in equation (7) indices i (kg CO2-eq/kWh), and per E_L (kWh) respectively.

C. *Restrictions*

The main objective of this study is to reduce carbon dioxide production, COE, and NPC emissions, while ensuring improved RF, and durability of the hybrid system. These decision variables are as follows: photovoltaic capacity (C_{pv}), distributed generation capacity (C_{DG}), hydraulic capacity (C_{hy}), number of wind turbines (N_{wt}), number of tidal turbines (N_t), and number of batteries (N_{bat}).

D. *Decision variables*

The limits of the decision variable are determined according to the specificity of the problem.

$$\begin{cases} 0 \le C_{pv} \le C_{pv}^{max} \\ 0 \le C_{DG} \le C_{DG}^{max} \\ 0 \le C_{hy} \le C_{hy}^{max} \\ 0 \le N_{wt} \le N_{wt}^{max} \\ 0 \le N_t \le N_t^{max} \\ 0 \le N_{bat} \le N_{bat}^{max} \end{cases} \quad (8)$$

E. *Battery storage restrictions*

The energy stored by the battery is controlled according to the following limits:

$$SOC_{min} \le SOC \le SOC_{max} \quad (9)$$

Where SOC is the state of charge, SOC_{min}, and SOC_{max} represent minimum and maximum production capacity respectively.

IV. Hybrid System Results

Fig. 9. Electric production

Fig.9 shows the monthly electricity production of the optimum system. The total distribution of the system's electricity production over the year by source is 64.9% of the community's needs on the site studied. For wind turbines is 65.7%, for solar panels is 23.9%, and 10.1% for tidal power, and finally for diesel generators is 0.293%. The island's hydroelectric and diesel generator installations are useless. Electricity production from renewable sources was observed to be higher in winter than in spring and autumn.

The average monthly electricity generated by each component of the hybrid system is shown in Table. I.

TABLE I. Power Generated By The Various Components

Production	**kWh/yr**	**%**
Trina Solar 330TSM-330PD14	43,829	23.9
Generic 10kW Fixed Capacity Genset	537	0.293
Generic 10kW	120,204	65.7
Generic Hydrokinetic[40kW]	18,471	10.1
Total	183,042	100

As Table.II shows, that after adopting the hybrid system, environmental differences in pollutants such as carbon dioxide, carbon monoxide, and sulfur dioxide are considerably reduced.

TABLE II. Pollutant Emission Values

Type	**Quantity**	**Unit**
Carbon Dioxide	617	kg/year
Carbon Monoxide	4.67	kg/year
Unburned Hydrocarbons	0.170	kg/year
Particulate Matter	0.283	kg/year
Sulfur Dioxide	1.51	kg/year
Nitrogen Oxides	5.30	kg/year

The capital investment and operating and maintenance costs of the hybrid system are shown in Table.III. The largest capital investment in the system is the battery, and the largest operating and maintenance cost is also the battery. The total cost of the system over the life of the project is estimated at 284,617.65$, confirming this assessment. Fig.10 shows the state of charge and discharge of the battery storage station over one year.

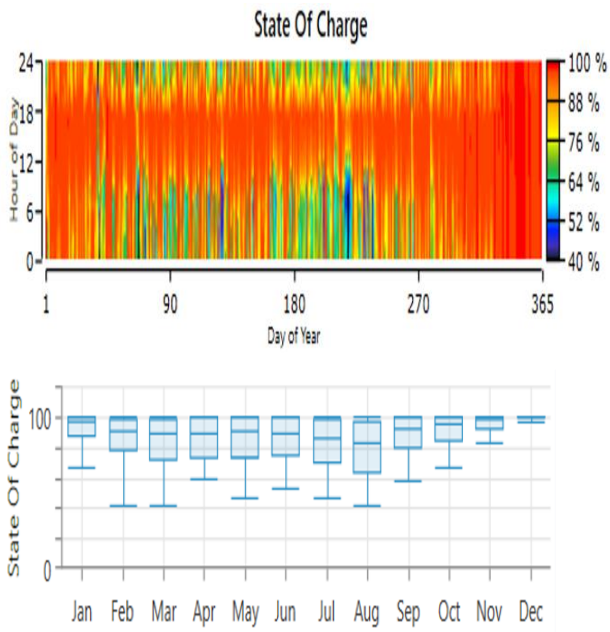
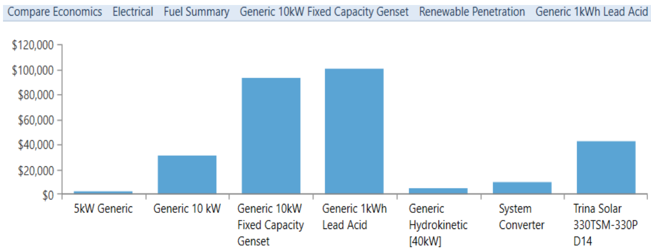


Fig. 10. Battery storage station state of charge

TABLE III. COSTS OF THE SYSTEM.



Component	Capital ($)	Replacement ($)	O&M ($)	Fuel ($)	Salvage ($)	Total ($)
5kW Generic	$1,000.00	$0.00	$1,292.75	$0.00	$0.00	$2,292.75
Generic 10 kW	$5,000.00	$0.00	$25,855.03	$0.00	$0.00	$30,855.03
Generic 10kW Fixed Capacity Genset	$100,000.00	$0.00	$667.06	$14,653.08	($21,873.23)	$93,446.92
Generic 1kWh Lead Acid	$45,600.00	$40,440.72	$19,649.83	$0.00	($5,325.61)	$100,364.94
Generic Hydrokinetic [40kW]	$1,000.00	$1,356.08	$2,585.50	$0.00	($183.86)	$4,757.72
System Converter	$5,731.75	$2,431.83	$2,469.91	$0.00	($457.69)	$10,175.79
Trina Solar 330TSM-330PD14	$39,334.52	$0.00	$3,389.98	$0.00	$0.00	$42,724.51
System	$197,666.27	$44,228.63	$55,910.07	$14,653.08	($27,840.39)	$284,617.65

V. Conclusion

Our article proposes an optimal structural configuration to provide the community of Djerba, Tunisia with an appropriate component capacity, taking into account reduced costs, and lower CO2 emissions. At the end of the simulation, the systems were obtained and compared in terms of cost, energy production, and emissions. The principal conclusion to be taken is that:

- The net reductions in current cost (NPC) and energy cost (COE) were 284.618$ and 0.365$/kWh respectively.
- In terms of emissions, the optimal model shows significant reductions in CO2, sulfur dioxide (SO2), and NOx emissions, with a total reduction of 617 kg/year of CO2, 1.51 kg/year of SO2 and 5.30 kg/year of NOx.

These results indicate the need to predict energy, and load profiles to implement more efficient, cost-effective, and environmentally friendly control strategies.

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