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Development of an Intelligent Solution for the Optimization of Hybrid Energy Systems

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Abstract: This paper presents a proposal for the development of a new intelligent solution for the optimization of hybrid energy systems. This solution is of great importance for installers of hybrid energy systems, as it helps them obtain the best configuration of the hybrid energy system (efficient and less expensive). In this solution, it is sufficient to enter the name of the location of the hybrid energy system that we want to install; after that, the solution will show the name of the best technology from which the optimal configuration of this system can be obtained. To accomplish this goal, the study relied on the ontology approach for two reasons, one of which is related to the nature of hybrid systems, because it is characterized by a large amount of information that requires good structuring, and the second reason is the interaction of hybrid energy systems with the external environment (climate, site characteristics). Afterward, to develop the knowledge base of the ontology, many steps were followed, the first of which is related to a detailed study of the existing one and the extraction of the basic elements, such as the concepts and the relations between them, followed by the development of the rules of intelligent reasoning, which is an interaction between the elements of the ontology through which all possible cases are treated. The "Protégé" software was used to edit these elements and perform the simulation process to show the results of the developed solution. Finally, the paper includes a case study, and the results show the importance of the developed solution, and it is open to future developments.

Keywords: decision-making tool; intelligent reasoning rules; energy saving; energy domain ontology; hybrid energy system

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1. Introduction

Air pollution, climate change, and limited fossil resources have raised awareness that sustainable development that takes care of the environment in which we live is necessary [1]. With the difficulty of connecting electricity grids to remote areas, RE presents a good alternative to fossil fuels, it does not emit greenhouse gases, and it allows the decentralized production of resources [2]. However, the random specificity of energy sources imposes special rules for the optimization and operation of energy systems. In addition, the hybridization between some of the RE sources forms a complementarity of energy production and an alternative to conventional generators generally used to produce electricity. An HES design is an important step because of its relationship to completion costs and reliability [3]. Therefore, it is necessary to provide new solutions and focus in particular on meeting consumer demands for energy while ensuring the minimum cost [4].

To meet the rapidly increasing demand for energy, all energy sources must be exploited. Renewable energies are unlimited and clean, but the biggest problem with them lies in their intermittent aspect. To overcome this problem, a combination of several energy sources is made to obtain the so-called hybrid renewable energy system [5,6]. Many works have been carried out on HES optimization methodologies. A study by Ammari et al. aimed at presenting and analyzing a literature review of recently published works in the field of hybrid renewable energy [7]. The study focuses on four basic categories of hybrid renewable energy systems, which are scaling (using software or using conventional methods), optimization (classical, synthetic, and hybrid methods), control (centralized, distributed, and hybrid control), and energy management (technical and economic objective). Furthermore, the review compares the different methods used in each category. A research work by Nourollahi et al. presents a hybrid approach to process improvement and addresses uncertainties in a residential energy system consisting of photovoltaics, fuel cells, boilers, and storage units [8]. In this regard, uncertain parameters are divided into two categories, including poorly behaved and well-behaved parameters, and then robust optimization and stochastic programming are used for modeling. Additionally, the conditional value at risk is implemented to assess the risks of well-behaved parameters. According to simulations, it has been shown that uncertainties with bad behavior have greater effects on the operation of the system. Moreover, changing the control parameters for robust optimization and conditional value at risk from 0 to 24 and from 0 to 1 increases the total cost by 5.2% and 0.47%, respectively. Comparative results also show that the proposed hybrid method makes less conservative decisions for cost optimization. The application of hybrid energy storage to distributed energy systems can greatly improve energy efficiency and reduce operating costs. However, insufficient efforts focused on investigating the integration of the two systems, configuration optimization, and systems operation strategy were found. Therefore, a new distributed energy system that combines hybrid energy storage was proposed, and the configuration of the system optimization and the operation strategy of the new system were considered simultaneously [9]. The studied hybrid system contained thermal storage and two forms of energy storage, that is, supercapacitors and a lithium battery. The impact of hybrid energy storage on distributed energy systems was fully considered. Then, a two-layer cooperative optimization method for the new system was introduced, taking into account energy efficiency, economy, and environmental protection. The new system was applied to an almost energy-free society. The results indicate that the energy-saving and equivalent pollutant-equivalent primary emission reduction rates for the new system were evaluated to be 54.8% and 63.6%, respectively, under the low-pass filter operating strategy combined with secondary feedback modulation of the supercapacitor charge state. System configuration and operating strategy can be optimized simultaneously by the two-layer collaborative optimization method. Renewable energy resources often suffer from challenges, such as erratic energy generation, as a consequence of weather and seasonal changes. Hybrid renewable energy systems are a solution for efficient energy densification of renewable resources as several of them are combined to overcome challenges arising from operating them in a stand-alone mode. A study by Sharma et al. proposed multitarget dynamic optimization of candidate hybrid renewable energy systems using a genetic algorithm in which the operating cost of hybrid renewable energy systems, nonrenewable energy use, and fuel emissions were simultaneously reduced over a limited period [10]. In optimization, three strategies are evaluated by considering the profiles of wind, solar, and 24 h load (Strategy 1), past and 1 h ahead (Strategy 2), and 1 h ahead (Strategy 3). A comparison of the results shows that the energy to be purchased from the network for Strategy 1 is 8.7% and 10.7% lower compared with Strategies 2 and 3, and also the energy sold to the network is 19% and 22% higher than for Strategies 2 and 3, respectively, while meeting the specified load profile of 100 households.

One of the most important applications of the renewable energy system is installing a well-designed HES in remote areas where grid extension is complicated and expensive. However, the proper design of such a system is a difficult task, such as coordination between different energy sources. Energy storage and load are very complex. Hybrid renewable energy system optimization is selecting appropriate components, scaling, and control strategies to provide efficient, reliable, and cost-effective alternative energy to society. A work by Fulzele and Daigavane presents a design of a hybrid renewable energy system consisting of photovoltaic cells and a wind generator with a battery and an inverter [11]. The system was optimally simulated using the HOGA (Hybrid Optimization by Genetic Algorithms) tool developed by the Department of Electrical Engineering of the University of Zaragoza, Spain. In the same context, a work by Mahmoud et al. is concerned with the application of modern optimization methods to devote the optimal configuration of hybrid renewable energy sources, which include photovoltaic panels, wind turbines with battery storage systems, and diesel generators [12]. The cost function of the optimization problem was chosen to be the energy cost and energy supply potential loss for the hybrid renewable energy system, where the main function of the optimization algorithms is to reduce this cost function. However, the optimal configuration cannot be achieved without meeting system reliability and operational limitations. A comparison of their results was made in order to determine the most effective method. Furthermore, a statistical study was conducted to determine the stability of the performance of each optimization strategy. The results revealed optimal variables, including the number of photovoltaic panels, wind turbines, batteries, and diesel generator capacity. Over the course of a year, the optimal configuration was tested against the study of capital and fuel expenditures. The statistical results also proved the robustness of the developed algorithm. Cano et al. presented a comparative study between four optimization methods for autonomous HES, which include two energy sources (PV, wind), storage batteries, and fuel cells [13]. The first method is based on mathematical equations, the second uses the SDO program, the third uses the Homer optimization software, and the last uses genetic algorithms based on the HOGA software. The results show that the HES designed by each method guarantees reliability in the energy supply, and SDO is the best HES optimization method. Other contributions use AI approaches. Maleki and Askarzadeh propose four heuristic algorithms, PSO, TS, SA, and HS, on an autonomous HES (PV, wind turbine, fuel cell) [14]. This study showed that HES with energy storage batteries is the best choice economically, and PSO is the most reliable optimization technique. In the same context, Aydin et al. were interested in the development of a methodology based on the information of a GIS to identify the preferred sites for an HES based on wind and PV [15]. This study used the principle of fuzzy logic and the MCDM approach to determine the economic feasibility of wind and solar energy. Finally, the associated maps were superimposed to obtain the most feasible places for HES. The proposed methodology can help policymakers and investors easily adapt to other types of energy resources. Luna-Rubio et al. provided an overview of optimization methods. The study presented the different architectures of stand-alone or network-connected HES [16]. This study concluded with the following submissions:

- HES that includes solar and wind energy sources requires the addition of storage batteries or integration into the grid.
- Among the methods proposed (probabilistic, analytical, iterative, and hybrid), the hybrid methods are the most powerful for HES optimizing.

Djamel Saba et al. provided an optimization solution for HES based on the intelligent reasoning rules [17,18]. Then, this solution was improved to be generic. After implementing it, the results showed its effectiveness in choosing the optimization technique. In addition, it is characterized by various advantages, such as flexibility in its operation and updating [19]. Coelho et al. proposed a MAS solution to optimize the HES [20]. Amicarelli et al. proposed to minimize the costs, maximize the use of RE, and simplify the integration into the grid [21]. Elamine et al. present an intelligent method of HES energy management [22]. The solution is based on the MAS. This concept allows the different units of the MAS to work together to achieve the objectives. Morstyn et al. studied the performance of the control strategy by verification on a microgrid that includes storage batteries and a PV generator [23]. This study allows us to know the advantages that characterize distributed management compared with centralized management. L. Raju et al. developed a MAS for managing the energy of a microgrid containing two PV systems, two wind turbines, a battery unit, and a diesel plant [24]. This solution offers the consumer the possibility of choosing the actions to increase energy efficiency. A study adapted to the west African climate was conducted by Mbodji et al. It is based on the MAS for the control, where it was applied on an HES (PV, wind, batteries) [25]. In this study, three load profiles were considered in the simulations. Then, the control made it possible to reduce battery use by 3%, 5%, and 6%, for profiles 1, 2, and 3, respectively. It was made in 1 day to obtain 35 kWh for profile 1 and 20 kWh for profile 3. From an economic aspect, the strategy applied to profile 1 was allowed a gain of EUR 6 per day and EUR 2322 per year or more than EUR 46,442 for 20 years (lifetime of the project).

The present study is intended to face the problem of the absence of a generic optimization solution for hybrid energy systems. The main objective of this work is to set up a reliable and easy solution to optimize hybrid energy systems suitable for most sites (generic). For these reasons, this study proposes a generic optimization solution. With this solution, the user is not required to know much data about optimization techniques, energy sources, and climatic data. The user only chooses the installation site, and it is up to the adopted solution that provides the appropriate sources as well as the most reliable technique to calculate the optimal configuration of the system to be installed. This contribution is based on the ontology of the field of energies. The choice of ontology is mainly due to the nature of the studied system and its environment (energy system), which is dynamic over time. In addition, this technique makes it possible to precisely present a set of knowledge in a form that can be permitted for use by a machine, which allows users to introduce the necessary updates without occurrence of any damage to the rest of the data.

2. Materials and Methods

2.1. Proposed Approach for Ontology Construction

In this work, the problem revolves around the absence of a generic optimization solution for hybrid energy systems. The main objective is to set up a reliable and easy solution to optimize hybrid energy systems suitable for most sites (generic). In the same context, and to solve any research problem, two subproblems must be initially separated and finally integrated, which are: the conceptual subproblem and the operational subproblem. For this research, the following hypothesis is employed:

- "The development of an optimization generic solution for hybrid energy systems improves the choice of better technique and simplifies the task for setup of this type of systems". According to this hypothesis, two variables can be noted, which are "the developed solution" and "the hybrid energy systems".
- "The more energy sources there are at a site, the more efficient the hybrid energy system". It is characterized by the variables: "more energy sources" and "more efficient the hybrid energy system".
- "The importance of the solution increases with the increase in the number of cases treated". Two variables can be extracted from this hypothesis: "importance of the solution increases" and "increase in the number of cases treated".

In addition, the following main questions can be asked according to this hypothesis: what is the impact of the developed solution on the optimization of hybrid energy systems? It is also possible to extract from this question some subquestions, such as:

- During bibliographic research, to what extent (year) can it be conducted?
- What are the advantages and disadvantages of these previous solutions?
- What is the best way forward to develop a solution?
- What are the techniques that can be used to test the solution?
- How to ensure the degree of relevance of the solution under development?

- Is there a relationship between the characteristics of the site and the hybrid energy system that will be installed?
- What are the reasons for using a hybrid energy system instead of a nonhybrid energy system?

2.2. Proposed Approach

The goal of this solution is to find the optimal configuration of the HES. It is based on a knowledge base (KB) and includes some steps, as shown in Figure 1:

i. Site choice: the user chooses the site of HES installation and inserts the electrical requirement energy value.
ii. Display of parameters of the chosen site: in this step, all the parameters that will be used in the next steps are displayed, mainly those related to the characteristics of the energy sources.
iii. The development of intelligent reasoning rules: in this step, we develop intelligent reasoning rules based on ontology. These rules permit to select the appropriate energy sources and the best energy optimization technique.
iv. List of energy sources: the results of the previous step are displayed (the best and available energy sources).
v. Chosen optimization technique: the most appropriate technique is selected.

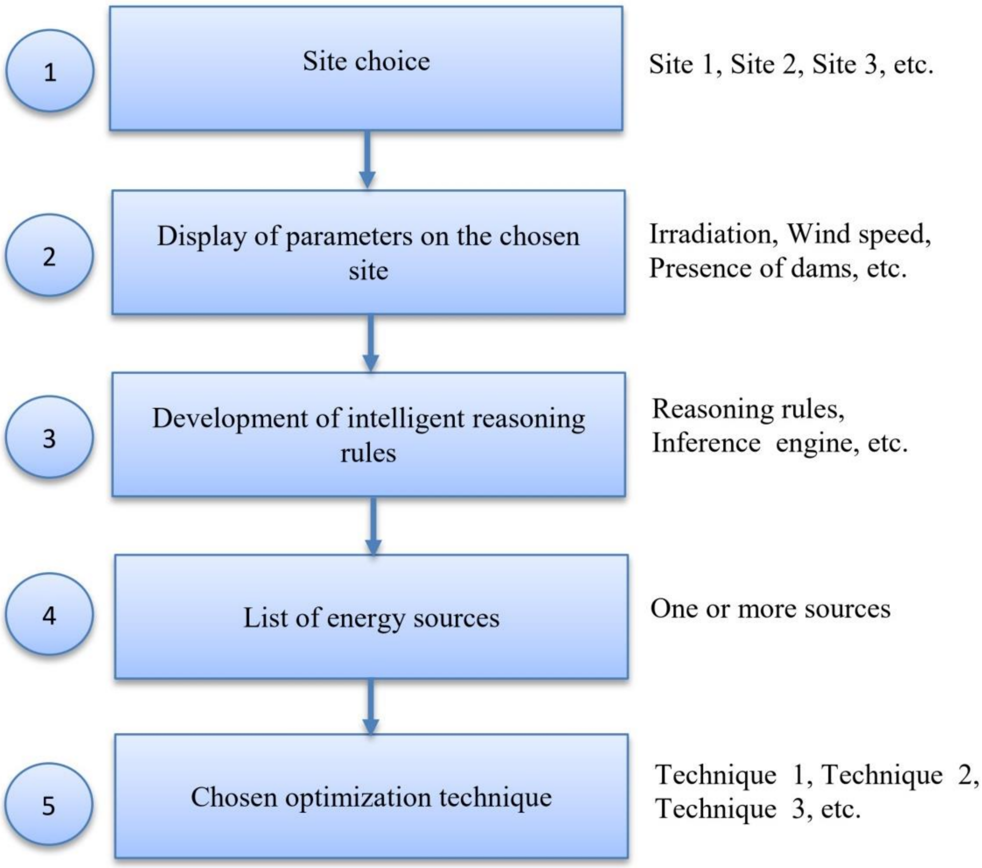

Figure 1. Proposed solution flowchart.

In addition, each optimization technique in the literature has been developed for a specific situation (types of energy sources, type of load, duration of application, etc.). The proposed solution at the start chooses the most appropriate optimization technique according to the data previously presented (concept, attribute, relation, etc.) and recorded in the knowledge base of the solution ontology. The second step concerns the import and execution of its algorithm to finally obtain the best optimal configuration.

2.3. Construction of Ontology

The modeling process consists of several steps, as itemized below [19,26]:

2.3.1. Define the Ontology Domain

This step is reserved for defining the ontology subject or domain. It includes a full understanding of the ontology subject. The ontology in this work would focus on the management of the energy required to model and optimize the HES.

2.3.2. Reuse of Existing Ontologies

After consulting previous works, many contributions concern the optimization of HES [27]. These works have achieved very encouraging results, but they still require some development through the introduction (or removal) of concepts and the development of intelligent reasoning [28–30]. For this work, the creation of the ontology was performed from the beginning, and we did not use previous ontologies.

2.3.3. Interesting Concepts for the Ontology

The main concepts of this ontology are sources (photovoltaic, wind energy, etc.), load, and climatic data (temperature, wind speed, etc.).

2.3.4. Explain Classes and Their Hierarchy

The ontology concepts form a hierarchy [30]. There are some methods to developing a class hierarchy [31]:

- Development of the ontology hierarchy from top to bottom
- A bottom–up development process
- A combination of the two approaches, top–down and bottom–up

In this work, the first method (top–down) was chosen (Table 1).

Table 1. An extract from the classes of the system.

Class	Description
Source	Energy source
OptimizationTechnique	Optimization technique
Load	Load
ClimateData	Climate data
Site	HES installation site
PhotovoltaicSource	Photovoltaic energy source

2.3.5. The Properties of Classes and the Facets of Attributes

After the presentation of the concepts, it is essential to describe their interior structure [28,29]. Then, the attribute facet describes the types of values that can be assigned to the attribute [32] (Table 2).

Table 2. An extract of the attributes.

Attribute	Description	Type	Class
SiteName	Installation site name	Alphabetical	Site
HasRadiation	Irradiation that characterizes the site	Digital	Radiation
SocBat	Battery charge level	Digital	Battery
SocBatMin	Minimum battery charge level	Digital	Battery
EfficiencyCharg	Battery charging efficiency	Digital	Battery

2.3.6. Design Instances and Relationships

The last step concerns the creation of instances and relationships for the proposed solution (Tables 3 and 4). These two elements are necessary for the development of the ontology [30].

Table 3. An extract from the ontology relations.

Relationship	Classes	Description
FeedSourceLoad	Source, Load	Energy supply to the load by energy source
FeedStorageLoad	Storage, Load	Supply of the load by stored energy
LoadSourceStorage	Source, Storage	Energy source charges the batteries

Table 4. Examples of instances.

Classes	Instances
Site	Alger, Adrar, Annaba, Oran, Ouargla, Tamanrasset
Month	January, February, March, April,..., December
Radiation	3378 Watt/m^2, 3350 Watt/m^2, 2650 Watt/m^2
WindSpeed	4, 4.5, 6 km/h
SoilTemperature	15, 38, 45 °C

2.3.7. Intelligent Reasoning of the Solution

All intelligent reasoning rules are constructed through a detailed study of the internal and external environments of the hybrid energy systems (the main elements of a hybrid energy system, environmental data, geographic data, etc.). We mainly focused our attention on related aspects that influence the HES operation. In addition, through this study, we extracted a series of information, namely, optimization techniques, installation site, climate data, load, and so on. Finally, depending on the predicate logic, the programming language Python, and the essential elements of ontology (concepts, attributes, relationships, and instances), we can formulate the intelligent reasoning rules associated with choosing the optimization technique (Figure 2, Table 5).

R1: Site (x) ∧ Radiation (x, y) ∧ ≥ (y, r) ∧ WindSpeed (x, z) ∧ ≥ (z, w) ∧Load (LoadDaily)
⇨ Technique (t)
R2: Site (x) ∧ Radiation (x, y) ∧ ≥ (y, r) ∧ WindSpeed (x, z) ∧ ≥ (z, w) ∧ Load (LoadMonthly)
⇨ Technique (t)
R3: Site (x) ∧ Radiation (x, y) ∧ ≥ (y, r) ∧ WindSpeed (x, z) ∧ WindSpeed (x, z) ∧ Load (LoadAnnual)
⇨ Technique (t)

Figure 2. Examples of the solution rules.

Table 5. Description of R1, R2, and R3.

Rule	Description
R1	If a site (s) is characterized by radiation greater than or equal to r Wh/m^2, the wind speed is greater than or equal to w m/s and the load is of the daily type, then the reasoning proposes the optimization technique (t) [33].
R2	If a site (x), characterized by radiation greater than or equal to r W/m^2 and a wind speed greater than or equal to w m/s, and the load is of the monthly type, then the rule proposes the optimization technique (t) [34].
R3	If a site (s) is characterized by radiation greater than or equal to r W/m^2, a wind speed greater than or equal to w m/s, and the load is of annual type, then the reasoning proposes the optimization technique (t) [34].

2.4. Ontology Editing and Presentation of a Scenario

2.4.1. Choice of Editor

For the editing of ontology, the "Protégé OWL 3.4.4" software was used because of the following advantages [19,35]:

- It is compatible with standard languages.
- It has a modular interface, which allows it to be enriched with additional modules (plugins).
- It provides a comfortable expression editor.
- It provides an API (or GUI) that allows the manipulation of the ontology created by the "Protégé" editor in Java code. It also provides a Java API, allowing developers to integrate with their Protégé OWL applications, import or export the ontology in different languages, and implement the ontology.

2.4.2. Choice of Reasoning Tools

Most inference engines can process rules added to the ontology. Rules-specific engines can be used, such as the Jess engine [36]. Most inference engines can process rules added to the ontology. Rules-specific engines can be used, such as the Jess engine [34]. The latter has a language for the expression of knowledge in the form of rules. It can be used from "Protégé-OWL API," thanks to the existence of a bridge that allows for the translation and execution of an ontology model in the language of Jess to retrieve the result in the "Protégé" software.

2.4.3. SWRL

This is a rules language for the semantic web combining OWL-DL and RuleML [37]. It makes it possible to enrich the semantics of an ontology presented in OWL and to manipulate instances by variables (? X, ? Y, ? Z). It simply allows you to add relations according to the values of the variables and the satisfaction of the rule. However, SWRL does not allow the generation of concepts or relationships.

2.4.4. Editing the Ontology

The ontology elements edited in Protégé are the concepts, attributes, relationships, and instances (Figure 3).

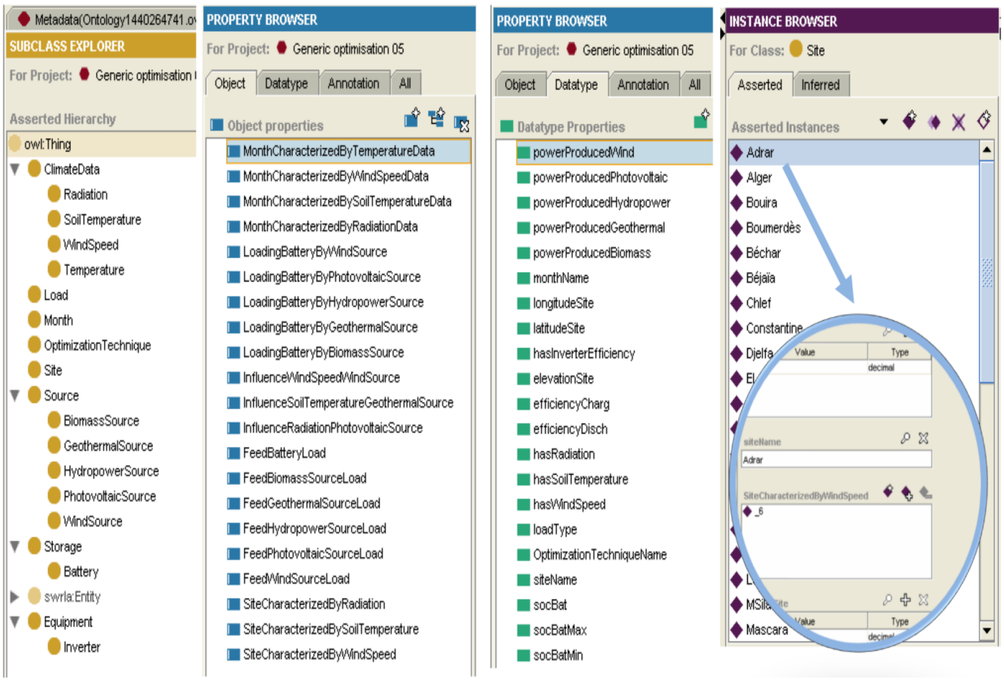

Figure 3. Elements of ontology in Protégé-OWL 3.4.4.

2.4.5. Implementation of Intelligent Reasoning Rules

The SWRL rules editor operates in Protégé OWL and provides a very interactive interface for editing rules (supporting all the features of the SWRL language). Rule engines, such as Jess, can be integrated with this editor, which helps provide richer rule-based reasoning (Figure 4).

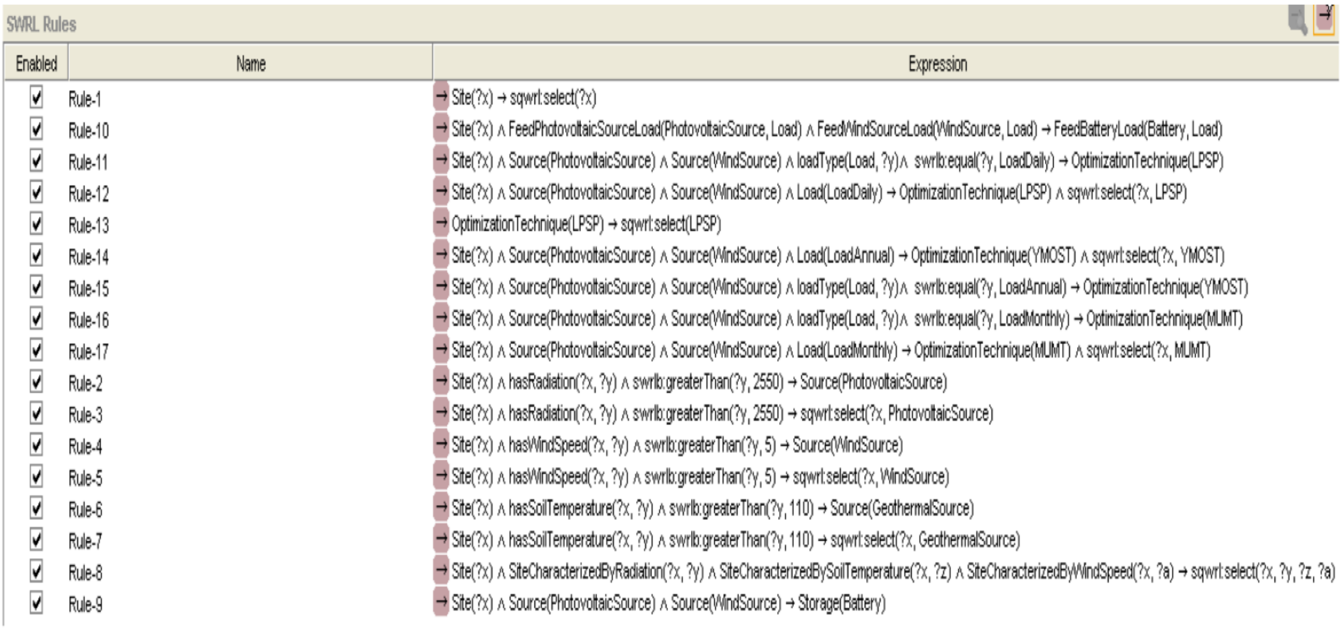

Figure 4. Rules of inference in Protégé-OWL.

2.4.6. Presentation of a Scenario

In this scenario, three Algerian cities were taken—Adrar, Annaba, and Illizi—which have different climatic characteristics. The three cities are presented with the average and annual radiation, the average and annual wind speed, the average and annual soil temperature, and the type of energy load (Tables 6 and 7).

Table 6. Example of KB data.

Site	Average Annual Radiation (Wh/m^2)	Average Annual Wind Speed (m/s)	Average Annual Soil Temperature (°C)	Load Type
Adrar	3378	6	65	LoadDaily
Annaba	2550	4	65	LoadAnnual
Illizi	3350	4.5	45	LoadMonthly

Table 7. Criteria for selecting energy sources.

Criteria	Energy Source
Average and annual radiation => 2550 Wh/m^2	Photovoltaic
Average and annual wind speed => 5 m/s	Wind
Average and annual soil temperature => 110 °C	Geothermal

The criteria for selecting renewable energy sources are defined (Table 7):

Regarding the values of 2550 Wh/m^2 for solar radiation, 5 m/s for wind speed, and 110 °C for soil temperature, they are considered the minimum acceptable values for electrical energy production for solar energy source, wind energy source, and geothermal energy source, respectively. For this reason, they were selected for the case study.

In this case study, we tested three techniques: LPSP, MUMT, and YMOST. In addition, the first technique is applied to loads of the “Load Daily” type. The second technique is applied to loads of the “Load Monthly” type. The third technique is applied to loads of the “Load Annual” type.

The execution of the solution includes a set of steps:

Step 1:

This step is reserved for the choice of the site based on the rule form presented in Figure 5.

R4: Site(?x) ⇒ sqwrl:select(?x)

Figure 5. Rule form.

In this example, the choice is Adrar City.

Step 2:

The objective in this step is to choose the energy sources. This operation is realized based on the intelligent reasoning rules (Figure 6).

R5: Site(?x) ∧ hasRadiation(?x, ?y) ∧ swrlb:greaterThan(?y, 2550)

⇒ sqwrl: select(?x, PhotovoltaicSource)

R6: Site(?x) ∧ hasWindSpeed(?x, ?y) ∧ swrlb:greaterThan(?y, 5)

⇒ sqwrl:select(?x, WindSource)

R7: Site(?x) ∧ hasSoilTemperature(?x, ?y) ∧ swrlb:greaterThan(?y, 110)

⇒ sqwrl:select(?x, GeothermalSource)

R8: Site (x) ∧ Source (PhotovoltaicSource) ∧ Source (WindSource)

⇒ Storage (Battery)

Figure 6. Examples of intelligent reasoning rules.

- In rule (R5), by replacing the variables “x” and “y” with “3378” and “Adrar” sequentially, it can be seen that “y” is greater than 2550, which means that the Adrar site is characterized by a very high solar potential. The reasoning of the solution proposes the first source of energy, which is the solar photovoltaic.
- By replacing the variables (x = Adrar, y = 6) in rule (R6), we notice that “y” is greater than 5, which means that Adrar is characterized by an interesting wind potential. The reasoning of the solution proposes the second source of energy, which is the wind turbine.
- By replacing the variables x = Adrar and y = 65 in the rule (R7), we notice that “y” is less than 110, which means that the geothermal source is not interesting for the production of electricity on the site of Adrar.
- Based on the previous results and rule (R8), the reasoning of the solution proposes energy storage batteries as an essential element to ensure the good reliability of HES.

Step 3:

In this step, the objective is to choose the optimization technique by using the R1, R2, and R3 reasoning rules, then by replacing the variable “y = DailyLoad” in the three rules, (R1), (R2), and (R3). The “LPSP” technique is proposed by the reasoning of the solution.

Due to the complexity of using and mastering the software and optimization tools for HES, this solution was proposed. It allows the selection of the appropriate tool to calculate the optimal configuration. This selection is made in a simple, easy way. It also makes it possible to relieve the user of any knowledge of energy sources or optimization techniques.

The use of other methods requires knowledge of several aspects (sites, techniques, energy sources). On the other hand, with this solution, the user only chooses the site concerned with the installation, and the rest of the steps are ensured by the developed solution.

3. Results and Discussion

Evaluation of the Proposed Solution

To have an alignment of a proposed solution of a research question, which presents the key to evaluating solutions from a research point of view, requires the good formulation and use of hypotheses and conceptual subproblems. Research is only feasible if we can establish the validity of the hypotheses and conceptual subproblems proposed through a good review of the literature. Additionally, the correct answers to the conceptual subproblems allow a good alignment.

Through the results obtained in this work, we can see that all responses to the elements mentioned in subsection "*2.1. Proposed Approach for Ontology Construction*", respond to the sub-questions stated in the same sub-section (Table 8).

Table 8. Samples of evaluation of the proposed solution.

Hypothesis/Question	Response
The development of an optimization generic solution for HES facilitates the choice of an appropriate technique and simplifies the task for the setup of this type of systems. (Hypothesis)	The proposed solution allows choosing the best technology to improve HES and is easy to use.
The more energy sources there are at a site, the more effective the hybrid energy system is. (Hypothesis)	Through this work, it was confirmed that there is a direct relationship between the number of energy sources available at the site and the efficiency of the hybrid energy system.
The importance of the solution increases with the increase in the number of cases treated. (Hypothesis)	The proposed solution can be applied to the majority of cases (despite changing locations) and is, therefore, a generic solution.
What is the impact of the solution developed on the optimization of hybrid energy systems? (Main question)	According to the obtained results, the optimization of hybrid energy systems using the developed solution makes it possible to gain a system that is more efficient, reliable, and economical.
To what extent can research be performed in previous works? (Subquestion)	Bibliographic research focused on recent works concerning the optimization of hybrid energy systems. Consequently, this research was very positive and allowed us to elaborate on the problematic with precision.
What is the appropriate approach (technique) that can be used to develop a solution in this work? (Subquestion)	Through the use of the ontological approach, we discovered that it is a very suitable tool for representing all knowledge as well as in the processes of developing rules of intelligent reasoning. Then, ontology-based solutions make it possible to perform all the necessary updates on the knowledge base without damaging the overall structure, unlike classic databases.
Is there a relationship between the characteristics of the site and the hybrid energy system that will be installed? (Subquestion)	Through the work carried out, it is confirmed that there is a strong relationship between the characteristics of the site (available energy sources, climatic data, geographical location, etc.) and the characteristics of the hybrid energy system that will be installed.
What are the reasons for using a hybrid energy system instead of a nonhybrid energy system? (Subquestion)	The use of a hybrid energy system has several benefits, including ensuring the continuity of supply and energy needs.

To assess the hypotheses proposed in this work, the following steps are realized:

(1) Proposing the null hypothesis (the set of hypotheses and questions that have been proposed);
(2) Suggesting methodologies and choosing the necessary means to develop the solution (programs, algorithms, etc.);
(3) Testing the solution using data for real sites located in Algerian cities, where the results for this test were very positive, and all the questions that were set were answered.

4. Conclusions

This work focused on the problem of optimizing HES. In this context, it was proposed to develop an optimal solution based on ontology.

The HES are systems that combine multiple energy sources to meet electricity needs. They allow improvements in terms of energy efficiency and increasing integration of RE sources. However, the process of optimizing these systems is complex, especially with its distributed and interactive nature with the external environment.

In an HES, energy sources and storage tools are combined to meet consumer demand for electricity while ensuring the lowest cost. These tasks are the main goals for HES optimization. However, because of the intermittent nature of RE, the optimization of the HES is difficult, which depends principally on the data of energy sources and climate. Responding to the optimization problem is precisely the objective of this work.

There is a set of tools for HES optimization, such as algorithms and software, where each is based on one or hybridization between several approaches (probability, linear programming, fuzzy logic, neural networks, etc.). There is also some software for HES optimization, the most popular being Hybrid, TRNSYS [38], Hybrid2, Homer [39], and HOGA [40]. However, the choice between these tools is considered a real problem. First, a generic optimization solution for HES was developed. This contribution shows its reliability following an explanatory scenario and based on real data from Algerian sites. The results indicate the importance of the proposed solution for real uses, where the user can benefit from many advantages, such as saving time, accuracy, and ease of use.

For future works, this solution needs collaborative work with experts in many fields, which will allow the development of the existing solution in many points, as well as the introduction of some other technologies, such as multiagent systems, especially the mobile agent, which can navigate to the source of information to take it instead of staying in a fixed address and communicate with the rest of the agents based on network protocols, which makes the solution more effective. Finally, extensive testing must be performed for other case studies to find the limits of the use of this solution.

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Abbreviation

AI	artificial intelligence
API	application programming interface
GIS	geographic information system
GUI	graphical user interface
HES	hybrid energy system
HOGA	Hybrid Optimization by Genetic Algorithms
HS	harmony search
KB	knowledge base
kWh	kilowatt hour
LPSP	loss of power supply probability
MCDM	multicriteria decision making
MUMT	most unfavorable month technique
OWL-DL	Web Ontology Language–Language Description
PSO	particle swarm optimization
PV	photovoltaic
RE	renewable energy
RuleML	Rule Markup Language
SA	simulated annealing
SDO	Simulink Design Optimization
SWRL	Semantic Web Rule Language
TS	tabu search
YMOST	yearly monthly overage sizing

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