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Intelligent Control of Renewable Holonic Energy Systems

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Abstract

Significant sources of energy production, of nuclear or fossil fuel type, which can assume all the needs of a country or region, are more strongly contested, either due to accidents of natural origin or following the observation of the dangerousness of the human effect on the global climate balance. Thus governments are encouraging the development of green energy. Any centralized control approach will be obsolete regarding, on one hand, the powers concerned and on another hand, the wide dispersion of these production sources: an irreversible movement to locally produce what is locally consumed is being developed. A decentralized control, based on intelligent entities, is presented. The holonic paradigm is used to represent a Holonic Energy Systems (HES) with multi-sources and multi-users. The several possible switching between the various energy sources are obtained by using a multicriteria decision aid method.

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Keywords: Control ; Holonic Energy System; Multicriteria decision aid ; AHP; Multi-energy sources ; Multi-users.

1. Introduction

In recent years, governments are encouraging the development of green energy [1]. Indeed, nowadays, new forms of energy management, both in terms of its production than consumption, should emerge. The established model of an unbounded consumer and inexhaustible sources of production, all centrally managed, has become obsolete.
The problem of balancing between production and consumption, with the need of controlling the electrical network in a decentralized manner, taking into technical and economic consideration and natural constraints, while maintaining a good service quality, was raised [2], [3], [4], [5]. These research works tend toward distributed control strategies of multi-sources renewable energy systems [6].

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Our research is consistent with these works. The objective is to propose, using the principle of holonic paradigm recursion, a decentralized energy system multi-sources and multi-users and to present the use of multicriteria decision aid method to ensure adequate and automatic switching between the different system components. First, the use of the holonic paradigm to control energy entities is presented. Then, the multicriteria decision aid method for the control of multi-sources and multi-users energy system is described.

2. Intelligent control for multi-sources and multi-users Holonic Energy System

[7] propose the holonic paradigm for modelling complex social systems. A Holon is defined as a conceptual entity based on the association of a material structure (the M_Holon) that represent the physical part (individual to supervise, gate..) and an informational structure (the I_Holon) providing the whole thing with a decisional intelligence giving the capability to operate in interaction with other holons [8]. All interacting holonic entities in the system are at the same decision level that corresponds to isoarchic concept: the system architecture is completely decentralized and its components are not of 'master-slave' type, but have a same decision power.

A Holonic Energy System (HES) is composed of a triplet ({RH}, {EH}, {SH}), see Fig 1.

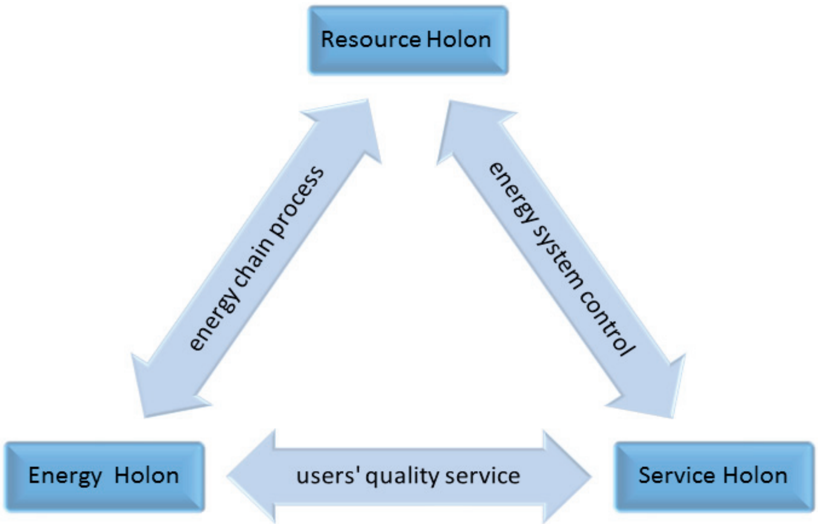

Fig. 1. Basic Holons of a HES, and their relations

A Resource Holon (RH) can only be producer or consumer of energy, or alternatively can play both roles. The Energy Holon (EH) corresponds to the produced or consumed energy by a RH with different electrical characteristics (power, voltage, current, form factor ...). It is linked to a RH by a numerical model of instantaneous production / consumption, which is relative to the energy chain processes. The Service Holon (SH) relates more particularly to the temporal description of this consumption: this is related to the fact that the energy system provides a service to users, and this service is broken down by user ... The link EH-SH can assess the users' quality service. The RH-SH relationships are used to organize the control of the energy system; by organizing the switching of RH producers to RH consumers based on SH validated by the links RH- SH-HS and EH-SH.

An energy system may itself be composed of others energy systems at a lower level, the lowest being that of the basic equipment that constitute a basic wind, a solar panel ... So, with the holonic paradigm applied to distributed energy systems, an HEQ (High Environmental Quality) building should be considered as a holon composed of holons, as well as a farm or a self-autonomous installation. These holons fit into neighbourhood holons, themselves being components of a larger scale (district, city, region, ...), where these different holonic entities exchange their needs and their excess energy...

HES can be composed of components that can be themselves HES, see Fig 2. Each component is associated to a decisional intelligence entity allowing to ensure individual and collective operation.

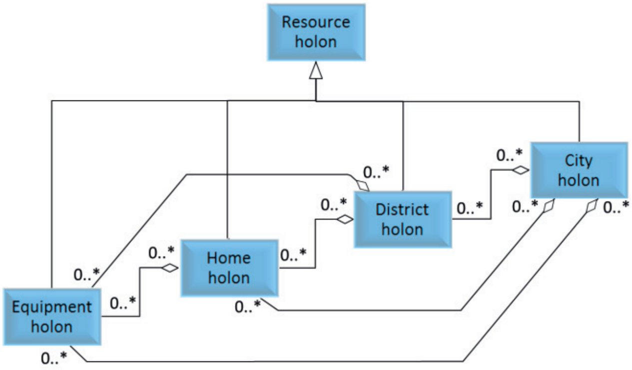

Fig. 2. Aggregation of resource holons

Each Resource Holon can be a producer and/or a consumer of energy. According to their power, equipment producers contribute to the energy production of a house (for the smallest), a district or a city (for the larger), see Fig 3.

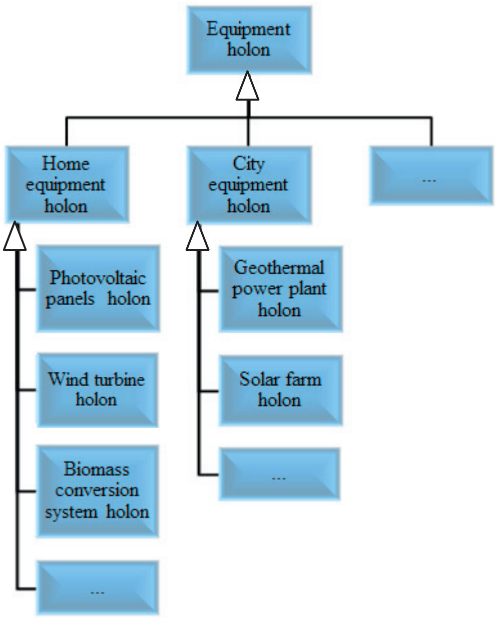

Fig. 3. Specialisation of resource holons

The holons that integrate production and consumption (home holon, ..., city holon…) are 'positive energy' if they produce more energy than they consume at times.

The main difficulty of such a distributed management of the energy problem is to use the most possible appropriate way all the possible sources of production in relation to all identified needs. Using a hierarchy to structure the holons enables to deal with the complexity arising from the interaction between a large number of low-level holons [6] [9].

For this, it should switch on an *ad hoc* manner some sources to some users, depending on the state's energy system at time t and on the forecasts of its operation in the near future. The various connection configurations constitute solutions of such HES.

Thus the control of HES consists in choosing the connection configuration that will be the most appropriate at a given time, and this according to the actual and estimates state of the different Holons of the HES. For that, a multicriteria decision aid method is used.

3. Multicriteria decision aid for renewable Holonic Energy System

Multicriteria decision aid provides solutions to problems expressed in terms of multiple and conflicting objectives. It becomes a technique increasingly used for the management of renewable energy systems. For multi-energy sources based on more conventional technologies (gas turbine, internal combustion engine with fuel ...), the need for optimization is proved [10], [11] and multicriteria analysis is of great interest [12], [13]. [14] have assessed the design of an optimized energy system for residential buildings in Japan, using a multicriteria decision support integrating economic criteria, energy and environment. [15] have described an autonomous system combining photovoltaic, wind turbine, diesel and battery storage, including a multi-objective optimization using a genetic algorithm. [16] have used multicriteria analysis to define the most appropriate configuration of energy sources to meet local rural poor demand in developing countries. Closer to our problem, [17] uses a decision aid method to select as connection configuration one of a possible switching between sources and users. However, this corresponds to the choice of the configuration of a multi-sources system, and it is not possible to directly use this approach to change in real time switching mode.

We chose to use the Analytic Hierarchy Process (AHP) method, developed by T-L. Saaty [18], because this latter allows one hand the measure of the consistency of the decision maker's preferences and also the consideration of both independence and interdependence of considered criteria. Therefore, this method allows the use of complete lists of criteria without excluding any one and enables the consideration of qualitative and quantitative criteria.

3.1. Presentation of the multicriteria decision aid method

AHP method enables to express preferences and choices among multiple criteria and alternatives, within hierarchical structures or networks [19], in order to obtain a ranking of all alternatives using the criteria weights. AHP is a decision making process that directly interprets data and information and can be automated. AHP involves two main phases: Configuration and Exploitation phases [20].

The configuration phase allows to adjust the settings of the relative importance of criteria and their indicators. This configures the pairwise comparison between the different criteria regarding to their importance in the decision. This 'static' phase of the algorithm must be validated by a mathematical verification of consistency. Then, regarding all criteria, a ranking of each set of indicators, regarding its criterion Ck, is established. To do this, preference matrix is built with consistency checking of judgments. The relative importance vector of indicators regarding its criterion is then calculated.

The exploitation phase (dynamic phase) of the AHP algorithm allows to classify the possible solutions. A ranking of the solutions (alternatives) regarding each indicator of each criterion is established. An aggregation matrix representing the relative importance of alternatives regarding the indicators is then obtained. Then, the relative importance of alternatives regarding the overall goal is calculated.

3.2. AHP method and HES

The AHP method is used in the control of Holonic Energy System to allow the ranking of possible switching between different energy sources with different characteristics (storage at short or medium term, production of energy sources), with an output which varies randomly, and intended to be exploited by several users. It will be necessary to consider the constraint related to users who have a quasi-periodic regular consumption but also a random consumption. In order to rank the alternatives, it is essential to identify at first the decision structure (overall objective, criteria, indicators (from the information system's sensors), and alternatives (all direct switching and combined switching)). In a second step, it is necessary to identify the setting of the relative importance of criteria and their indicators. Under the second phase (Exploitation), allowing to rank the alternatives regarding the overall goal, it is necessary to define the sources of information (electrical parameters) allowing to identify the indicator values (by adaptive observers) for each alternative.

The application of the multicriteria method requires the elaboration and formalization of an adequate system of criteria / indicators. We have proposed a decision process taking into account six criteria, see Fig 4.

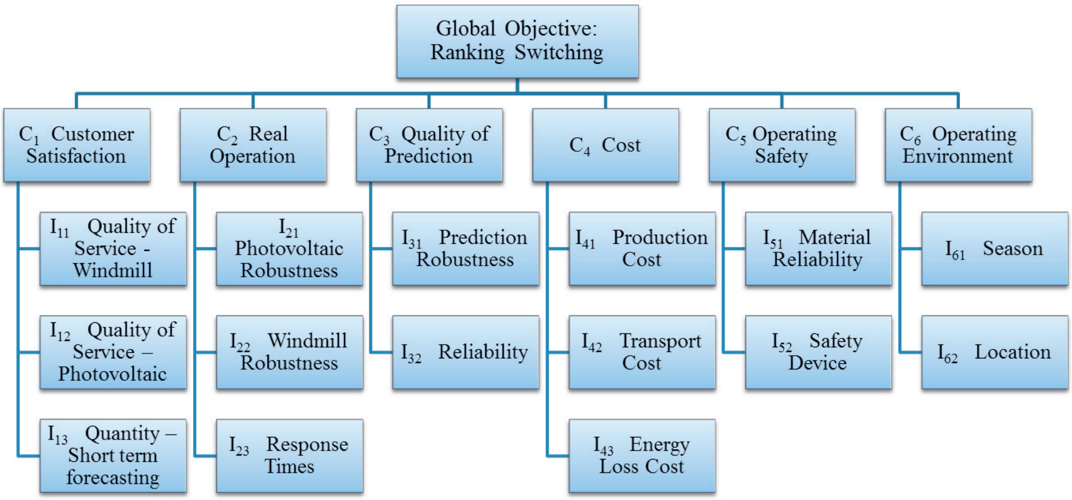

Fig. 4. AHP Decision structure

- C_1 (Customer Satisfaction) criterion: it refers to whether the alternative is able to meet customer energy demand in terms of quality (I_{11}) and (I_{12}) or quantity (I_{13}).

The I_{11} indicator (Quality of Service – Wind turbine), refers to the continuity and stability of the energy received by a wind turbine. Different values will be associated to this indicator depending on the strength and / or regularity of the wind.
The I_{12} indicator (Quality of Service – PV (Photovoltaic)) is similar to the previous one. The values are assigned according to the sun. The data will be identified from a weather information source or from a database.
I_{13} indicator (Quantity – Short Term Forecasting): the given value to this indicator is a compromise between the level of production, demand forecasting and the instantaneous state of the storage system. In fact, more the storage system is loaded, more significant efficiency is provided. It will thus be necessary to take into account the limits of the operating area of the system for the charge and discharge.

- C_2 (Real Operation) criterion: it focuses primarily on the efficiency of the material, based on its used and on the manner of its operation.
  I_{21} indicator (PV Robustness): generally, the panels are tilted at 25° angle to reduce their wind pressure and minimize shadowing of a row of modules on the next row. Therefore, the values provided to this indicator will depend on the implemented angle.
  I_{22} indicator (Wind turbine Robustness): there are different types of wind turbine (vertical axis windmill, horizontal axis wind turbine .... We know that the horizontal axis wind turbine is more robust and is cheaper. So, the values of this indicator will be linked to the type of wind turbine used.
  The I_{23} indicator (Response Times), is related to the quick response to a change of parameters: if the data related to the climate, production, consumption, change, how long takes the material to give the adequate new output values. We know that the super capacitor (short term storage) gives the shorter response time.

- C_3 (Quality of prediction) criterion: it gives a judgment on the performance and on the capacity modelling to represent and analyse real situations to provide the necessary information (consumption forecast, forecast production and its quality, ...)
  I_{31} indicator (Prediction Robustness): the robustness of an estimator is its ability to maintain the same values at the output following a disturbance of the data values at the input. The values associated to this indicator are derived from the difference between the response of the model (estimated output) and the actual output due to random disturbances.
  I_{32} indicator (Reliability): the level of reliability is the percentage of correspondence between the simulation results and those obtained experimentally (by measurement).

- C_4 (Cost) criterion: we estimate the cost generated by each switch (alternative) to provide a certain amount of energy or even production costs, transport costs and losses in the process itself.
  I_{41} indicator (Production Cost): is the ratio between the required expenditure and the produced quantity. The expenditures correspond to the sum of material's costs (taking into account the hourly depreciation cost) and operating costs.
  I_{42} indicator (Transport Cost): is the ratio between the quantity transported and the total cost of this operation such as installation costs (transformers ...: taking into account depreciation) and operating costs.
  I_{43} indicator (Energy Loss Cost): is the cost of energy lost during transport and during production.

- C_5 (Operating Safety) criterion: it refers to the reliability of the system (process) at the operation level (no failures), and at the safety of users (no accidents).

I_{51} indicator (Material Reliability): it refers to its ability to not fail, it can be determined using the reliability methods (MTBF, MTTR ...).
I_{52} indicator (Safety Device) highlights the level of risk of accidents towards users' facilities or even the neighbouring population (we can take an example of comparison between the loss of wind turbine blade and an accident where the glass of a photovoltaic panel breaks).

- C_6 (Operating Environment) criterion: it focuses on the adequacy of the production means with external constraints such as the season, its location and the type of use (industrial, domestic ...).
  I_{61} indicator (Season) highlights the influence of climatic conditions on the level of production and profitability. For example, photovoltaic cells have more important efficiency in summer than in winter.
  I_{62} indicator (Location): the site has its own influence on the climatic conditions and parameters.

4. Conclusion

An intelligent control of renewable energy system based on three type of holons (RH, EH, SH) was presented. Then, the multicriteria decision aid method (AHP) was identified. Its application to multi-sources and multi-users energy system was described. Future works will be focused on testing the proposals on a case study. An analysis of the obtained results will be conducted using various performance indicators.

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