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ARCHITECTURE OF AN EXPERT SYSTEM FOR DYNAMIC MANAGEMENT OF RENEWABLE ENERGY RESOURCES UNDER UNCERTAINTY CONDITIONS

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Abstract. This paper presents the concepts of designing an expert system intended to generate optimal decisions for dynamic management in the field of renewable energy. The system is aimed for solving technical and economic problems under uncertainty conditions, needing thus the use of fuzzy logic. The architecture proposed by author of such an expert system is depicted and several of its algorithmic base techniques, using triangular fuzzy number mathematics, are presented. The use of such an expert system for decision making is emphasized by presenting a comparative study on selecting between several types of renewable energy generators.

Key words: renewable energy; expert system; dynamic management; fuzzy logic.

1. Introduction

Energy management may have different meanings. The most general definition can be the efficient use of energy for maximizing profits (or minimizing costs) in order to increase the competitive level of a firm. Nowadays the society is concerned of attaining of performances related to the environment protection. In this context arises the need for a management of renewable

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energy sources.

Since the use of both renewable and classical energy sources is a process with a high degree of uncertainty and risk, energy management should be a dynamic management. This is a process based management, being an extension of classical management adapted to the needs of the knowledge based society. Dynamic management is one in which process execution must guaranty an evolving flexibility, its objectives themselves being uncertain, in some degree. These objectives can be unclear initially and can change in the future.

There are two classes of computer codes helping the implementation of dynamic management (Siler *et al*., 2005):

a) Decision support systems (DSS) that provide decision-making support in management activities, serving to make decisions for solving problems whose data can be variable and are not specified in advance (for unstructured and semi-structured decision problems).

b) Expert systems (Knowledge-Based Systems) that can reproduce the behavior and decision-making mode of a human expert in solving specific problems of a certain domain. In expert systems interconnections between processed data are made to meet a set of rules contained in a knowledgebase of the system. Expert systems are computer codes that are developed for making available the abilities of experts to nonexperts (Negnevitsky, 2005).

The objective of fuzzy expert systems is primarily to handle the imperfect information. Generally, there are five types of imperfect information (Bahri *et al*., 2005):

1º Inconsistency, which is a kind of semantic conflict that appears when some aspects of real-world are irreconcilably represented more than once in the database.

2º Imprecision, which is relevant to the content of an attribute value meaning that a choice must be made from a given range (interval or set) of values?

3º Vagueness, which is almost the same as imprecision but which is generally represented with linguistic terms.

4º Uncertainty, which is related to the degree of truth of an attribute value, meaning that we can allocate some, but not all, of our trust to a certain value, resulting from a lack of information, and being related to the designer and not to the object/concept being modeled.

5º Ambiguity, that means some elements of the model lack complete semantics, leading to several possible interpretations.

The application of fuzzy logic in expert systems has the following advantages (Siler *et al*., 2005):

a) Enhanced computational power, fuzzy systems performing faster than conventional ones, requiring fewer rules.

b) Better cognitive modeling, since fuzzy systems allow encoding knowledge in structures reflecting the thinking way of an expert in modeling imprecise information about complex problems.

c) The capacity to represent multiple experts' viewpoints, especially in areas such as management, where there are no simple solutions and conflicting viewpoints should be taken into account.

There are different data types that a fuzzy expert system should handle, in order to allow all kinds of imperfect information: simple numbers; approximate values; intervals; fuzzy ranges; fuzzy numbers; "less/more than" values; sets of possible numerical assignments; possibility distributions over discrete or ordered domains; matching degrees; unknown, undefined or null values; symbols; linguistic labels.

2. The Architecture of a an Expert System for Management of Renewable Energy

In order to obtain the goals of renewable energy management as a dynamic process, we propose the following architecture for an expert system based on fuzzy logic which is presented in Fig. 1.

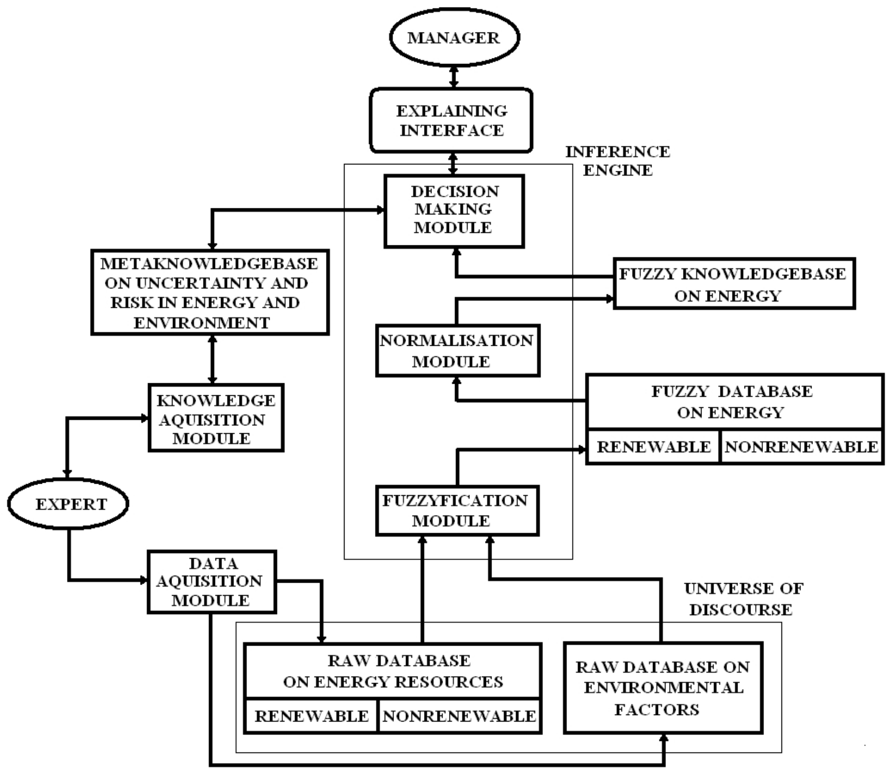

Fig. 1 – Proposed architecture for an expert system for management of renewable energy.

The universe of discourse of the system is composed of raw database containing information about renewable and nonrenewable energy sources and generators and a raw database on environmental factors.

The inference engine of this system is based on mathematics of triangular fuzzy numbers (Gherasim, 2005) of the shape:

$$\tilde{a} = (a_l, a_c, a_r). \tag{1}$$

In order to compare two fuzzy numbers we need the gravity center:

$$< \tilde{a} >= \frac{a_l + 2a_c + a_r}{4}, \tag{2}$$

and the absolute length of base:

$$l_b = |a_r - a_l|. \tag{3}$$

Generally, a fuzzy number is greater than other if its gravity center is greater, or, if the gravity centers are equal, if its absolute length is greater than the other.

The base triangular fuzzy number operations used in the system are:
Addition:

$$\tilde{a} + \tilde{b} = (a_l + b_l, a_c + b_c, a_r + b_r). \tag{4}$$

Subtraction:

$$\tilde{a} - \tilde{b} = (a_l - b_r, a_c - b_c, a_r - b_l). \tag{5}$$

Multiplying with a real number:

$$\tilde{a} \cdot r = (a_l \cdot r, a_c \cdot r, a_r \cdot r). \tag{6}$$

Reverse of a fuzzy number:

$$\frac{1}{\tilde{a}} = \frac{\tilde{a}}{< \tilde{a} >^2}. \tag{7}$$

Multiplying:

$$\tilde{a} \cdot \tilde{b} = \frac{< \tilde{a} > \cdot \tilde{b} + \tilde{a} \cdot < \tilde{b} >}{2}. \tag{8}$$

Division:

$$\frac{\tilde{a}}{\tilde{b}} = \frac{\tilde{a} \cdot \tilde{b}}{< \tilde{b} >^2} = \frac{< \tilde{a} > \cdot \tilde{b} + \tilde{a} \cdot < \tilde{b} >}{2 \cdot < \tilde{b} >^2}. \tag{9}$$

The fuzzyfication module of the inference engine processes these raw data, transforming them in fuzzy numbers in a fuzzy database on energy.

In order to obtain a coherent knowledgebase containing attributes that can be compared in order to trigger decisions, the fuzzy numbers in the database must be normalized by the normalization module of the inference engine, using the following formulas:
When a minimum value is the best:

$$\tilde{n}_{ij} = \frac{\tilde{a}_{\mathrm{Max}\,j} - \tilde{a}_{ij}}{\tilde{a}_{\mathrm{Max}\,j} - \tilde{a}_{\min j}} . \tag{10}$$

When a maximum value is the best:

$$\tilde{n}_{ij} = \frac{\tilde{a}_{ij} - \tilde{a}_{\min j}}{\tilde{a}_{\mathrm{Max}\,j} - \tilde{a}_{\min j}} . \tag{11}$$

The choosing of an optimal variant is then made by the decision making module of the inference engine, using decision techniques for uncertainty conditions (Nicolescu & Verboncu, 1999) applied to fuzzy numbers:
Bayes-Laplace proportionality method:

$$V_{\mathrm{optimum}} = \mathrm{Max}_i \frac{1}{n}\sum_{j=1}^{n} \tilde{a}_{ij} . \tag{12}$$

Max-min pessimistic method (Wald):

$$V_{\mathrm{optimum}} = \mathrm{Max}_j \min_i \left(\tilde{a}_{ij}\right). \tag{13}$$

Max-Max optimistic method:

$$V_{\mathrm{optimum}} = \mathrm{Max}_j \mathrm{Max}_i \left(\tilde{a}_{ij}\right). \tag{14}$$

Hurwicz optimality method:

$$\tilde{h}_i = \alpha \mathrm{Max}_i (\tilde{a}_{ij}) + (1-\alpha) \min_i (\tilde{a}_{ij}) , \tag{15}$$

where: α – optimism coefficient ($0 < \alpha < 1$);

$$V_{\mathrm{optimum}} = \mathrm{Max}_j \left(\tilde{h}_i\right). \tag{16}$$

Before applying these techniques the decision criteria selected from the fuzzy knowledgebase are multiplied with weightening factors triggered from a meta-knowledgebase on uncertainty and risk in energy field, as fuzzy linguistic variables (Alecu, 2012). Thus can be studied various scenarios that can influence the decision making in a dynamic management.

3. Sample of Using of the Expert System

The use of such an expert system is demonstrated for obtaining a decision in selection between three renewable energy generators such as photovoltaic panels with Monocrystalline silicon, Polycrystalline silicon and Amorphous silicon cells.

The decision process is influenced by uncertainty arising from physical factors such as the variation of total solar irradiation revealed by NASA measurements during the Sorce program (Woods & Snow, 2010), as we can see in Fig. 2.

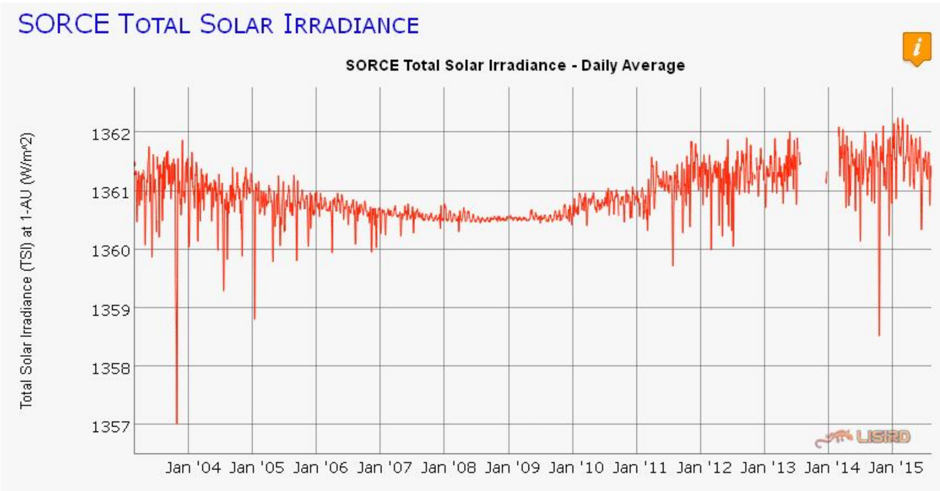

Fig. 2 – Uncertainty of total solar irradiations measured by NASA during the Sorce program (Woods & Snow, 2010).

Also uncertainty arises from environmental factors as revealed by the Berkeley Earth project, as we can see in Fig. 3.

Other uncertainty arises from economical factors such as the variation of energy prices on international market.

In order to compare the three types of generators the selection criteria choosed from the database were: Specific power [W/m^2]; Specific price [Euro/W] and Investment payback time [Years] (calculated in comparison with an gasoline engine generator). The values of these criteria are presented as triangular fuzzy numbers in Table 1. These data are then normalized and transferred to the fuzzy knowledge base by the normalization module (see Table 2). Then by the means of weightening factors triggered from a meta-knowledgebase, three scenario were used, one in which each factor has an equal importance, one in which the energy production is most important and one in which the investment payback time is the most important. Then the decision techniques, using fuzzy triangular numbers, are used in order to obtain an optimal solution. In Table 3 are presented the results obtained in these three scenarios. It can be seen that, generally, the V_2 variant, Poly-crystalline Silicon Cells Generator is the optimum variant, but V_1 variant, Mono-crystalline Silicon Cells Generator, can also be a good variant if a high energy production is needed.

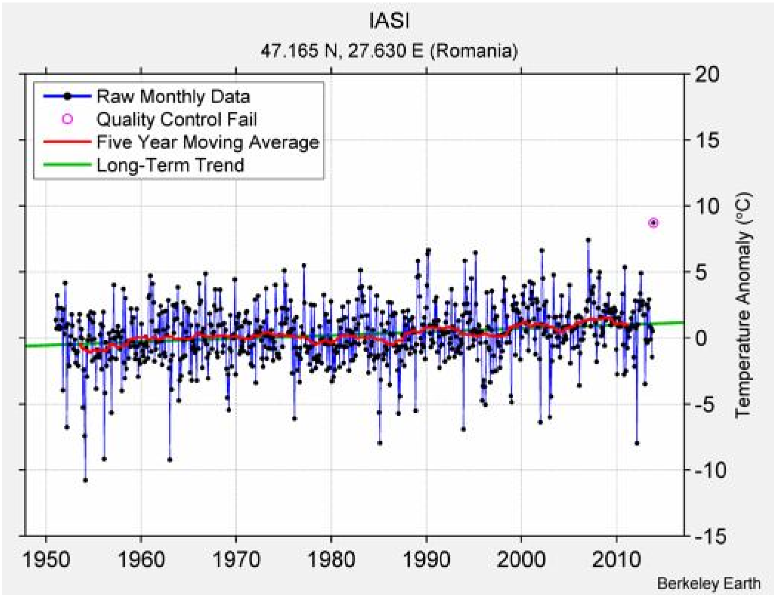

Fig. 3 – Uncertainty of annual temperature for Iaşi, Romania (Berkeley Earth project).

Table 1
The Fuzzy Database

Generator type	Specific power W/m^2			Specific price Euro/W			Investment payback time Years		
Mono- crystalline Silicon	(121.5,	146.9,	171.3)	(1.27,	1.75,	2.00)	(0.14,	0.17,	0.19)
Poly-crystalline Silicon	(129.1,	140.2,	147.8)	(1.03,	1.21,	1.39)	(0.13,	0.14,	0.15)
Amorphous Silicon	(59.4,	81.1,	121.5)	(0.61,	0.73,	1.25)	(0.16,	0.16,	0.29)

Table 2
The Fuzzy Knowledge Base

	C_1			Gravity center	C_2			Gravity center	C_3			Gravity center
V_1	(0.28,	0.39,	0.50)	0.39	(0.53,	0.18,	0.00)	0.22	(0.99,	0.76,	0.67)	0.79
V_2	(0.31,	0.36,	0.39)	0.36	(0.70,	0.57,	0.44)	0.57	(1.00,	0.97,	0.91)	0.96
V_3	(0.00,	0.10,	0.28)	0.12	(1.00,	0.91,	0.54)	0.84	(0.82,	0.85,	0.00)	0.63

Table 3
The decisional variants

	Bayes-Laplace	Max-min	Max-Max	Hurwicz
$K_1 = 1$; $K_2 = 1$; $K_3 = 1$.	$V_2 > V_1 > V_3$	$V_2 > V_3 > V_1$	$V_2 > V_3 > V_1$	$V_2 > V_3 > V_1$
$K_1 = 1$; $K_2 = 0.5$; $K_3 = 0.5$.	$V_2 > V_1 > V_3$	$V_2 > V_3 > V_3$	$V_1 > V_2 > V_3$	$V_2 > V_1 > V_3$
$K_1 = 0.5$; $K_2 = 1$; $K_3 = 1$.	$V_2 > V_1 > V_3$	$V_2 > V_1 > V_3$	$V_2 > V_3 > V_1$	$V_2 > V_3 > V_1$

4. Conclusions

The management of renewable energy is a main component of an organisation if it wish to restrain its costs or to maximise its profits.
Energy managment is a dynamic one imposing decision making in uncertainity conditions. For acomplishing a dynamic management of renewable energy expert systems based on fuzzy logic should be used. We have proposed the architecture of such an expert system based on triangular fuzzy numbers mathematic applied to decision techniques used in uncertainty conditions. We have use this architecture in an expert system in order to obtain decision in selecting a certain type of renewable energy generator from multiple variants in uncertainty conditions.

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ARHITECTURA UNUI UNUI SISTEM EXPERT PENTRU MANAGEMENTUL DINAMIC AL RESURSELOR ENERGETICE REGENERABILE ÎN CONDIȚII DE INCERTITUDINE

(Rezumat)

Sunt prezentate conceptele de proiectare ale unui sistem expert care să genereze decizii optime pentru managementul dinamic în domeniul energiilor regenerabile. Sistemul este destinat pentru rezolvarea problemelor tehnico-economice în condiții de incertitudine. Este expusă arhitectura propusă de autor pentru un astfel de sistem şi sunt prezentate unele din tehnicile algoritmice de bază, folosind matematica numerelor fuzzy triunghiulare. Utilizarea unui astfel de sistem expert în procesul de luare a deciziilor este subliniată prin prezentarea unui studiu comparativ în selectarea dintre câteva tipuri de generatoare de energie regenerabilă.