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DEVELOPMENT OF USER-FRIENDLY TOOL FOR ENERGY BEHAVIORAL CHANGE OF CONSUMERS

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Abstract ***This paper purposes to provide an user- friendly intelligent tool, integrating fuzzy controllers and multi-agent techniques, able to motivate and to support behavioral change of energy end- users, having as main objective to re-define the role of energy consumer in "prosumer" in the context of a reorganized decentralized energy market, now reported to intelligent grids (smart grids). Integration of interactive technologies in a decision support system for microgrids energy management optimizes: functioning from an economical point of view, active control of distributed generation, controlled consumption, loading the storage equipment. The added value of the proposed tool consists of integrating decision theory and artificial intelligence concepts in monitoring and control actions, allowing "prosumers": to make energy usage data accessible and to demonstrate that energy savings can be achieved without compromising comfort levels.***

Keywords: Decision support system, Fuzzy control, Multi-agent systems, Smart grid, Solar energy.

1. INTRODUCTION

In most of the existing economics energy models it is generally assumed that energy consumers behave in an economically rational way. However, empirical data show that consumers are rather "bounded rational", because of effects such split preferences, perceived financial barriers, lack of knowledge/ information, or the implicit costs of the transaction.

The different energy efficiency policies implemented in the European Union (EU) try to invest in cost- effective energy efficiency technologies. Thus, the current energy policy of the EU considers the security of supply, competitiveness and sustainability as central goals. In order to achieve these targets, through European strategies [1] are imposed a series of constraints ("objective 20-20-20"): 20% reduction in emissions of greenhouse gases compared to 1990, providing 20% of entire EU energy consumption by renewable energy sources (RES) and a reduction in energy use by 20% compared to a similar scenario in which no action regarding sustainability has been taken. To achieve these objectives and generate a "sustainable growth" a policy of encouraging distributed generation (DG) from RES (DG- RES) such as solar power must be followed. Our studies conducted in this field highlighted the need for an energy management system, implemented at local to global level.

On the other hand, researches are needed to better understand consumer's decision making to improve the design of future energy efficiency policies in such a way that existing barriers can be removed, to better reflect the behavior of consumers in energy models and also to better reflect the impact of energy efficiency policies on the different consumers' decision making processes in energy models.

In addition, for a large number of energy resources, the current energy systems are hardly scalable. The European Commission believes that the current energy infrastructure is inadequate to connect and serve all of Europe and recognizes the challenges [1].

The share of RES in the electricity production, in Romania context, is currently 24%. EU has set for Romania a 20% target for energy generation from RES by 2020, but there have also been identified needs for investments and large operating costs as main barriers for the successful implementation of an increased generating capacity. Compatibility with EU objectives in the field of clean energy and national levels is achieved through regional policy [2]. European policies had a national resonance since 2003, when the draft for the project strategy for the use of renewable energy [3] was proposed.

Two new important trends on the Romanian national energy market are to be noticed: firstly, the consumers involvement in the complex process of efficient management of the energy from RES and secondly the increased attention, paid to both: the technical plan and to the organizational and economical plan, for the energy production from RES.

Unfortunately Romania follows a centralized approach of the regional policy and although the country is covered adequately with electricity networks and the potential development for RES is high, its aging infrastructure (30% of it was built in the 1960s) causes significant losses along the energy supply chain.

Considering the aspects presented above, with this paper we try to motivate and to support behavioral change of energy end- users. Thereby, we purpose to consumers of energy an user-friendly intelligent tool, having as main objective to re-define the role of the energy consumer as "prosumer" in the context of a reorganized decentralized energy market, now reported to intelligent grids (smart grids). Integration of interactive technologies, fuzzy controllers and multi-agent techniques, in a decision support system for the DG- RES microgrids energy management optimizes: functioning from an economical point of view, active control of distributed generation, controlled consumption, loading the storage equipment.

In this respect, firstly a state of the art of the challenges in the field, as well as the issues in this area are presented. The second part, the identified criteria used for choosing a decision support system, made in fuzzy logic and intelligent agents context are implemented, tested on a hybrid system, fuzzy- multi-agent and analyzed. The design of the proposed hybrid system is made using MATLAB. The article ends with conclusions and work in progress.

2. STATE OF THE ART

The issues in the area of energy behavioral change of consumers are vast.

Insights from social and behavioral sciences should be used to understand: factors influencing consumer choices, and the impact of consumer behavior on the energy system.

In addition, the research directions in the field, identified by reviewing the scientific literature, are: to increase conversion efficiency [4] and [5], to identify new opportunities, complementary to the limitations of existing solutions [6], to limit the variability of the power production through integration of RES [7], to balance the insufficient number of providers reported to market needs [8], to supply with energy the increasing number of consumers [9], to provide and promote sustainable buildings and housing projects [10], to identify the new renewable energy sources in order to reduce risks, social and economic costs [11], to understand the effects associated with the use of RES and the increasing complexity of systems [12], to identify measures and solutions for ensuring the sustainability of renewable resources [13], to resize the impact of renewable energy for the final beneficiaries, in terms of cost / benefit ratio [14] and [15], and to highlight the importance of being efficiently informed in order to make better decisions about energy options [16].

Following the analysis performed, the electrical network stability is not considered as a service ensured in any country. However it is a typical problem for distributed generation from RES microgrid's connection to national electricity network because the system must be robust and the parameters oscillations must be amortized [17].

To support this interest, worldwide there are only a few tools which are able to perform dynamic assessment of electrical networks; none of them take into account the characteristics and the specificities of DG-RES microgrid [18].

To overcome the mentioned barriers, we propose to re-define the role of the energy "prosumer" in the context described above so as to optimize the functioning from an economical point of view of the microgrids. This objective formalised as an objective function means reducing the costs with energy consumed from national energy network by using green energy generated in microgrids with DG-RES.

3. TOOL DEVELOPMENT METHODOLOGY

3.1. System's architecture

The innovative aspects of the proposal consist of implementing, from the hardware and software points of view, a dynamic platform that can handle real-time data of the DG-RES microgrids operation and use advanced technologies for assisting consumers-producers of energy from RES. This solution addresses the energy efficiency integrating indoor and outdoor climate and building monitoring knowledge. The main functions implemented in the software application–the intelligent support system are: monitoring, diagnosis, prediction and control (Figure 1).

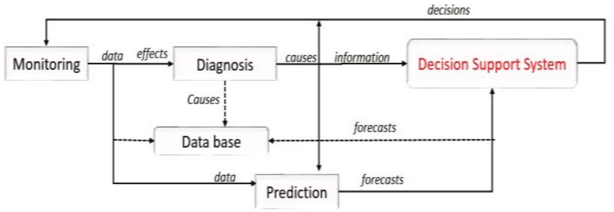

Figure 1. Functions of the hybrid system

The monitoring module. At this level, the data measured with smart sensors in real time, are collected in order to build the primary resources of electrical energy management system. Beyond the quantitative and qualitative aspects of these data, environmental factors (temperature, humidity, air quality and so on) are also monitored.

The diagnosis module. In order to assess the operational status of the installations, the diagnosis function is implemented within the proposed scheme. The diagnosis function, considers as inputs, effects, the functioning state of the generating/consuming installations. Its goal is to classify them into alarms, failures or state of emergency and to identify the causes, in order to be able to act in a proactive manner (Figure 2). The identified relations effects- causes will affect the credibility of each renewable energy producer and also the share of green energy on clean technologies market.

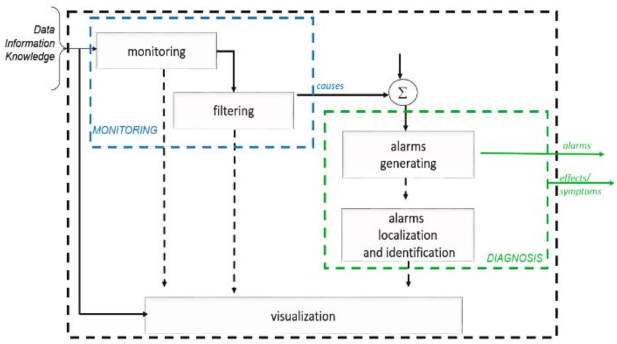

Figure 2. Monitoring and diagnosis modules

The prediction module. This module integrates from the beginning a minimal intelligence level, established in the design stage. The scenarios used for learning new situations are enriched continuously because the knowledge data base is updated permanently. This prediction function is integrated in order to provide short, medium or long time forecasts (forecasts) in respect of the energy load and production. Aspects like the cyclicality day/night, winter/summer are considered in forecasting process as well as the correlation between produced energy and the life cycle of the used installations. Accurate forecasts will impact on the action plans and the financial evaluation of green energy.

The decision support system module. This module is a control module because firstly analyses the forward decisions. Then the evaluation is performed in order to take the right decision. The assessment of predicted evolution of the system at a given time, as well as the information and the knowledge given by diagnosis and monitoring modules, will be made with regards to an evaluation referential or a performance function (Figure 3).

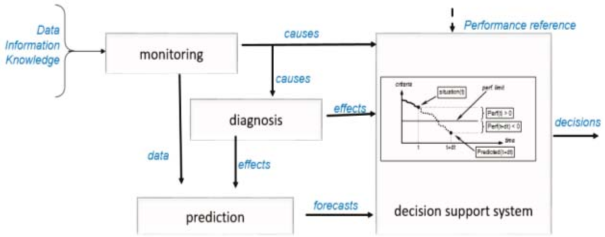

Figure 3. Relative positioning of monitoring, diagnostic, prediction and decision activities

The architecture of the hardware infrastructure [19] supporting the above hybrid system is presented in the block diagram from Figure 4.

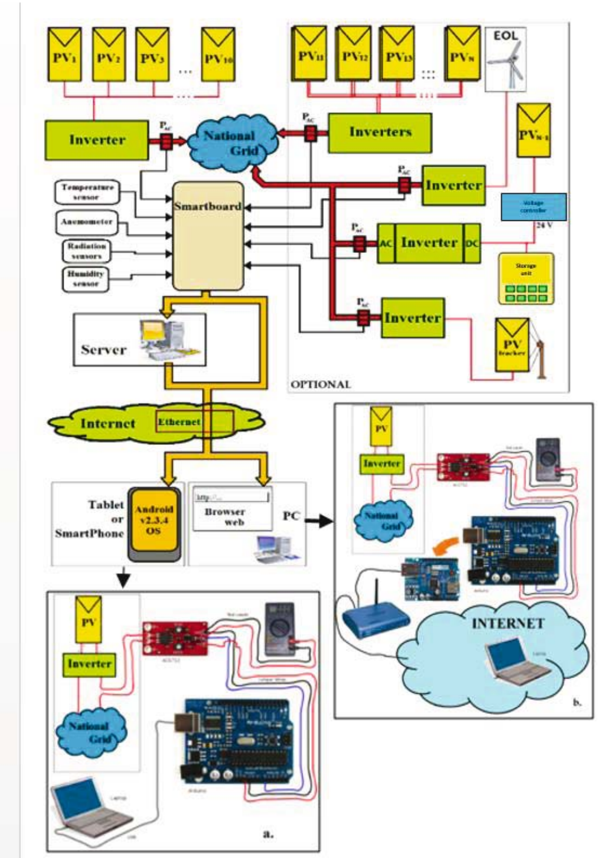

Figure 4. The hardware infrastructure

The modules integrated in the hardware platform are: photovoltaic panels (PV), wind power station (EOL); storage units, inverters; PV tracker, personal computer (PC) with data acquisition card (DAQ) or tablet or smart phone. Due to the initial configuration concept the hardware platform manifests modularity and adaptability in operation.

Integrating fuzzy logic reasoning techniques and intelligent agents, the proposed decision support systems gets an adaptive characteristic. From economical point of view this character ensures low energy losses correlated with the new scenarios that occur in the environment or at the consumers.

Using artificial intelligence techniques in power management actions in a low voltage grid through a software tool is a new technique and also expresses the complexity of the proposed solution.

3.2. Implementation

In this section we will present a part of the entire software application supporting the hardware platform presented in Figure 4, precisely the design of the decision support system build as a fuzzy multi- agent system able to assist the user's decisions. The block diagram showing the subsystems of the proposed tool is presented in Figure 5.

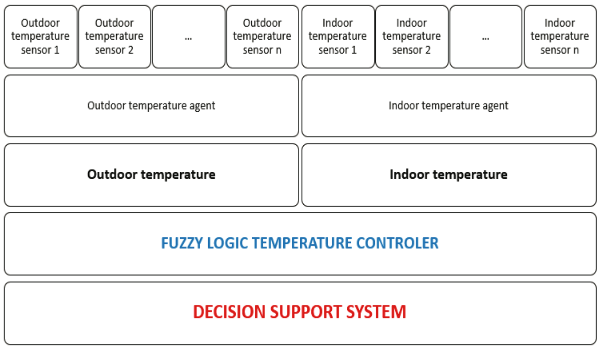

Figure 5. The block diagram

The decision support system has a hierarchical structure, meaning that the information is firstly selected with a heuristic approach based on fusion of physical sensors and implemented using local intelligent agents (outdoor temperature agent and indoor temperature agent). This selection presumes that inputs are independent and give no priority or importance of the selected input variables.

The second level of the hierarchical structure contains the fuzzy logic temperature controller (FLC-Figure 6). This one can be viewed as an approach combining classical control techniques and decision algorithms based on human reasoning.

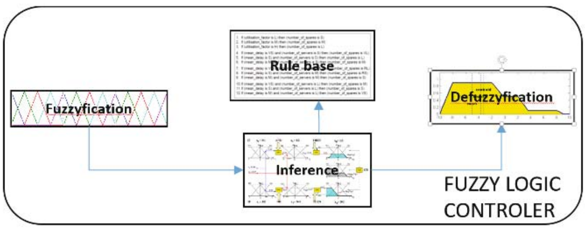

Figure 6. The fuzzy logic temperature controller

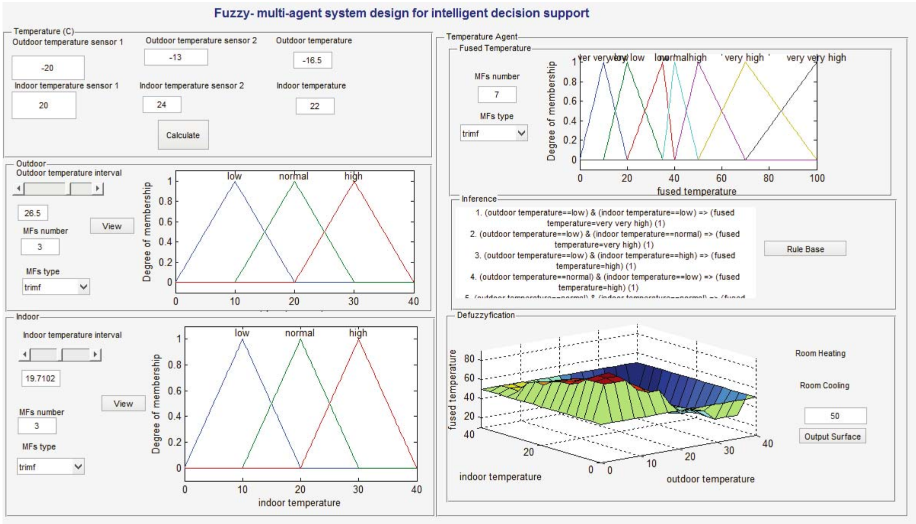

Figure 7. The graphical user interface of the temperature decision support module

The monitored data measured with temperature sensors, located indoor and outdoor, are the main sources of information, in our case. The entire application also integrates modules for luminance, air quality, humidity, noise and sound level, safety, movement etc. These data are crisp values.

The FLC considers as inputs in the fuzzyfication process. Fuzzyfication is the process of decomposing an input/ output into one or more fuzzy sets. Many types of curves can be used, but triangular or trapezoidal shaped membership functions are the most common because they are easier to represent. The process of fuzzyfication allows the system inputs and outputs to be expressed in linguistic terms so that rules can be applied in a simple manner to express a nonlinear relationship in a complex system. The universe of discourse of the crisp input variables is therefore converted by membership functions.

The inference block determines how the fuzzy logic operations are performed and together with the knowledge base compute the output of each fuzzy if-then rules. Those are combined and converted to crisp values with the defuzzyfication block. The output crisp value can be calculated by the center of gravity or the weighted average.

3.3. Simulation

Figure 7 shows the five primary distinctive panels integrated in the graphical user interface (GUI) for building the FLC, corresponding with the inputs/ outputs fuzzyfication, rule-base editing, inference engine and defuzzyfication [20].

The setup of the fuzzy controller having an architecture of a Mamdani technical fuzzy controller has been integrated with Matlab and GUIDE toolbox [21]. It has two inputs (called: outdoor temperature and indoor temperature) and one output (called fused temperature).

The proposed user-friendly application gives to the end-user the possibility to choose the number of the membership functions for each input/ output and their shapes: triangular, Gaussian, etc.

The universe of discourse is imposed through programming at: [0 40] Celsius degrees for indoor temperature, [-30 40] Celsius degrees for outdoor temperature and [0 100] Celsius degrees for fused temperature. These were considered in relation with the range of variability of the used sensors and the climate characteristics of the geographical zone (Figure 8 a, b).

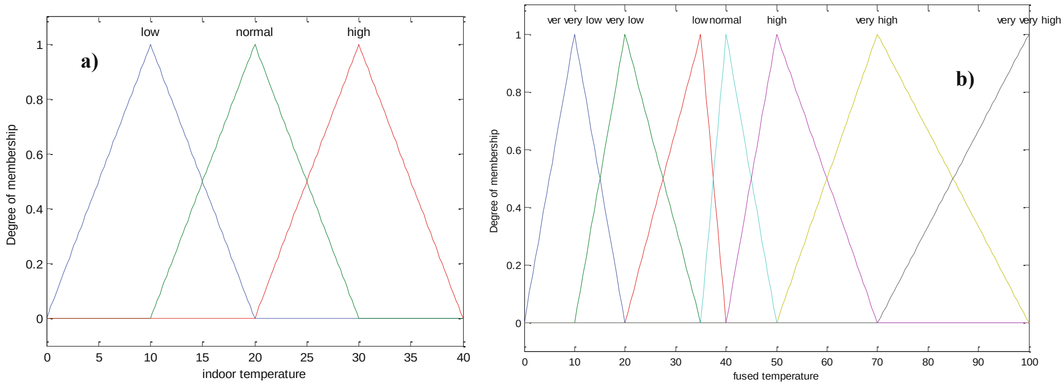

Figure 8. a). The indoor temperature input divided in 3 fuzzy regions, triangular shapes; b). The fused temperature output divided in 7 fuzzy regions, triangular shapes.

Based on the descriptions of inputs and output variables, made in fuzzyfication panel, the rule base editor panel allows constructing the rule statements in IF-THEN format. The representation of these ones in a matrix of inference rules facilitates checking there are not contradictory rules. The accepted modification without a deterioration of system performance implies modifying/ removing the neighbors' rules and replacing them with an average value.

4. TESTS AND RESULTS

We found in testing phase of our tool that having two inputs variables and 3 membership functions for each one, the resulted number of rules, in the inference process, equals with 3^2=9. A bigger number of MFs or/and inputs increases exponentially the number of rules from fuzzy controller's rule base and slow down the computational process. Even this approach increases, on the other hand, the accuracy of decisional process, the gain is not considerable to be considered. Thus, the smallest number of MFs, giving satisfactory results is 3 MFs, triangular shape for each input and 7 MFs, triangular shape for the output.

We have built our FLC rule base in relation with Hagras's [23]. The fuzzy rule decision table, in indexed format, used for FLC inference, using our reasoning and Hagras's, is shown in Table I.

The fuzzy output: fused temperature is represented as a surface. It represents the decision to be made. It's crisp format is obtained applying standard center of-gravity defuzzyfication method.

Table 1. Rule base in indexed format

Indoor temp. MFs	Outdoor temp. MFs	Fused temp. MFs		Weight	Inference Method
		Dragomir	Hagras		
1	1	7	6	1	1
1	2	6	4	1	1
1	3	5	4	1	1
2	1	5	4	1	1
2	2	4	2	1	1
2	3	3	1	1	1
3	1	3	2	1	1
3	2	2	4	1	1
3	3	1	1	1	1

Legend: 1-Low , 2-Normal, 3-High for MFs associated with inputs and 1-Very Very Low, 2- Very Low, 3- Low, 4- Normal, 5- High, 6- Very High, 7- Very Very High for MFs associated with the FLC's output. The AND inference method is denoted with 1 and the OR inference method is denoted with 2.

The tests results show differences between the analyzed methods. Dragomir's (Figure 9a) is an offline rule extraction method who needs an expert to supply his expertise formalized in a set of desired values. Hagras method (Figure 9b) is an online learning and control method.

The advantage of the proposed method consists in the integration of Dragomir's fuzzy controller into a hierarchical structure, even it is only a local control module. On the top of this structure is the decision support system, integrated in the tool's GUI, that gives suggestions to the users, in relation with the environmental conditions and the imposed level of comfort imposed by user in fuzzy logic controller' s rule base.

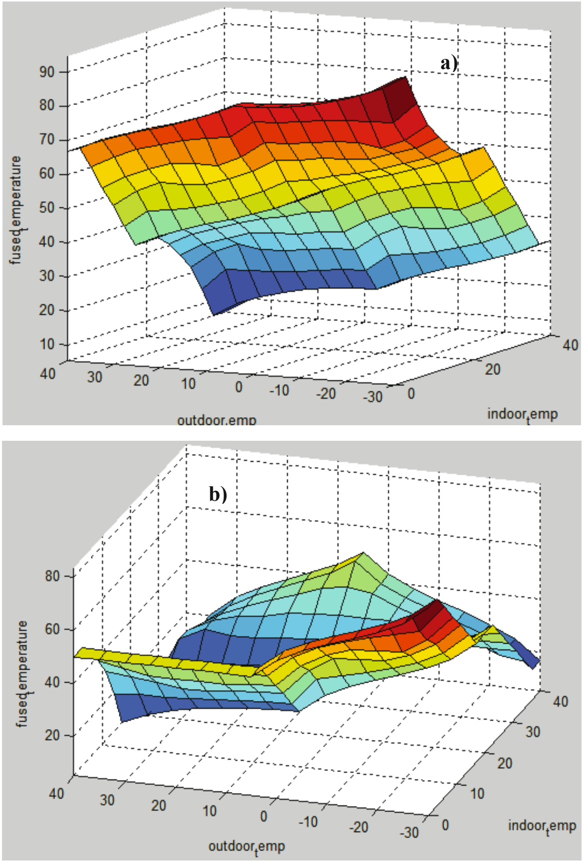

Figure 9. a). The fused temperature output divided, approach Dragomir; b). The fused temperature output divided, approach Hagras

Depending on surfaces generated by FLC, the user receives in the GUI, suggestions for smart decision making. Thus, the user has the possibility, in the interface, to set threshold values above/below which the reference value calculated by the fuzzy logic controller is valued as follows: if the calculated value is less than the prescribed limits (a deadband is considered in order to avoid continuous operation of fuzzy control) the suggestion for the consumers is to heat the room. If the calculated value is higher than the dead band set limits, the situation is considered to be for the consumers is to cool the room.

5. DISCUSSION AND CONCLUSIONS

This article proposes an intelligent decision support system for the low voltage grid with distributed generation from renewable energy resources, based on fuzzy- multi agent intelligent tools. The aim of this paper is to design, using Matlab, a graphical user interface able to assist the users to integrate a proactive management system based on a multi-objective decision-system.

The main issue of this work is guaranting the energy consumer comfort with minimum energy consumption. Simulation results have clearly shown that the proposed solution responds to the challenge of new research issues, that are studing methods and approaches based on user feedbacks.

The fuzzy solution searches the best tradeoff between consumer will and inside comfort level. The tool has been tested using real scenarios provided by the Multidisciplinary Science and Technology Research Institute of Valahia University of Targoviste.

Integrating fuzzy controllers and multi-agent techniques the proposed tool is able to support behavioral change of energy end- users, having as main objective to re-define the role of consumer of energy in "prosumer" in the context of a reorganized decentralized energy market, now reported to intelligent grids (smart grids).

The added value of the proposed tool consists of integrating decision theory and artificial intelligence concepts in monitoring and control actions, allowing “prosumers”: to make energy usage data accessible and to demonstrate that energy savings can be achieved without compromising comfort levels.

The work is still in progress in two directions: validation of the software in respect with the energy quality standards and integrating advanced control algorithms to energy distribution in smart grids with DG-RES.

6. ACKNOWLEDGMENTS

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