Fuzzy- multi agent hybrid system for decision support of consumers of energy from renewable sources

Otilia Dragomir, Florin Dragomir, Eugenia Minca

***Abstract*—**This paper purposes an intelligent decision support system for low voltage grids with distributed power generation from renewable energy sources (InDeSEn). The added value of this innovative software tool consists in integrating decision theory and artificial intelligence concepts in monitoring, supervising, forecasting and control actions, allowing prosumers of energy from renewable sources: to control electricity consumption of the used devices, to reduce their monthly bills, carbon emissions, energy demand during peak periods and to use more efficient the energy from renewable energy sources. The application is accessible to users anytime, through the web interface attached, providing both: information for general use and technical information.

***Keywords*—** fuzzy logic control, fuzzy- multi agent, intelligent decision support system, renewable energy, smart grid

I. Introduction

SMART grids could be described as an upgraded electricity network to which two-way digital communication between supplier and consumer, intelligent metering and monitoring systems have been added. Intelligent metering is usually an inherent part of them.

The benefits of smart grids are widely acknowledged. Smart grids can manage direct interaction and communication among consumers, households or companies, other grid users and energy suppliers. They open up unprecedented possibilities for consumers to directly control and manage their individual consumption patterns, providing, in turn, strong incentives for efficient energy use if combined with time-dependent electricity prices. Improved and more targeted management of the grid translates into a grid that is more secure and cheaper to operate.

Smart grids will be the backbone of the future decarbonized power system. They will enable the integration of vast amounts of both on-shore and off-shore renewable energy and electric vehicles while maintaining availability for conventional power generation and power system adequacy.

European context. The current energy policy of the European Union (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 from RES (PD- RES), such as solar power must be followed.

Intense concerns at European level regarding the PD- RES were materialized by setting up a giant cluster of projects called Integration of Renewable Energy Sources and Distributed Generation into the European Electricity Grid - IRED cluster [2]. The studies that were conducted by this consortium highlighted the need for an energy management system at micro to macro level, the existing control strategies not being always successfully applied.

Romanian context. The share of RES in the electricity production in Romania is currently 17.8%. EU has set for Romania a 24% 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 [3]. European policies had a national resonance since 2003, when the draft for the project strategy for the use of renewable energy [4] 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.

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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].

In this global and local context, this paper purposes an intelligent decision support system for low voltage grids with distributed power generation from renewable energy sources (InDeSEn).

The added value and the originality of this innovative software tool consists in integrating decision theory and artificial intelligence concepts in monitoring, supervising, forecasting and control actions, allowing prosumers (producers and consumers of energy from RES): to control electricity consumption of the used devices, to reduce their monthly bills, carbon emissions, energy demand during peak periods and to use more efficient the energy from renewable energy sources. The application is accessible to users anytime, through the web interface attached, providing both: information for general use and technical information.

First of all, it is presented a state of the art of the main interest directions in the field as well as the problematic in this area. The second section describes the conceptual framework of the InDeSEn, from hardware and software point of view. The third part is dedicated to the implementation and the results analysis of the software tool. Precisely, the identified criteria used for choosing a decision support system, made in fuzzy logic and intelligent agents context are tested on a hybrid system, fuzzy- multi-agent. The tool design of the proposed hybrid system is built using MATLAB. The article ends with conclusions and work in progress.

II. InDeSEn framework

A. State of the art and the problematic

The problematic in the area of low voltage grids with distributed power generation from renewable energy sources is vast.

The main interest directions in the field, identified by reviewing the scientific literature are: to increase conversion efficiency [5] and [6], to identify new opportunities, complementary to the limitations of existing solutions [7], to limit the variability of the power production through integration of RES [8], to balance the insufficient number of providers reported to market needs [9], to supply with energy the increasing number of consumers [10], to provide and promote sustainable buildings and housing projects [11], to identify the new renewable energy sources in order to reduce risks, social and economic costs [12], to understand the effects associated with the use of RES and the increasing complexity of systems [13], to identify measures and solutions for ensuring the sustainability of renewable resources [14], to resize the impact of renewable energy for the final beneficiaries, in terms of cost / benefit ratio [15] and [16], to highlight the importance of being efficiently informed in order to make better decisions about energy options [17].

Following the analysis performed, the electrical network stability isn't considered as a service ensured in any country. However it is a typical problem for PD-RES microgrid connection to national electricity network because the system must be robust and the parameters oscillations must be amortized.

In addition, in networks distribution isn't taken in consideration the balance between productions and consume from RES as viable solution, for off-grid functioning of microgrids,

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 PD- RES microgrid.

The GARPUR (www.garpur-project.eu/) project designs, develops, assesses and evaluates new reliability criteria for transmission grids, based on a probabilistic approach. PEGASE project (http://fp7-pegase.eu/) aims at improving the performance of various computational tools for transmission network management and to propose novel routes about the sharing of dynamic models. REALISEGRID develops a set of criteria, metrics, methods and tools to assess how the transmission infrastructure should be optimally developed to support the achievement of a reliable, competitive and sustainable electricity supply in the EU (realisegrid.rse-web.it/).

In the next sections we will presents the main characteristics of the proposed solution, from the hardware and software point of view.

B. InDeSEn framework

To overcome the mentioned barriers, InDeSEn proposes 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). Integration of interactive technologies in a decision support system for the PD- RES microgrids energy management optimizes: functioning from an economical point of view, active control of distributed generation, controlled consumption, loading the storage equipment.

The innovative aspects of the proposal consist in: implementing the systems for producing electricity with RES and identifying the operating conditions in the public low-voltage grid, creating a database regarding the dynamic mode operation of distributed energy systems, and developing the functional models of low voltage hybrid networks that integrate renewable energy sources.

The original features of the project are: implementing a dynamic software platform that can handle real-time data of the PD-SER microgrids operation, improving the specific algorithms used in power management of the microgrids by integrating intelligent agents of the elements of artificial intelligence in order to optimize decisions and to assist consumers-producers, creating a database with information associated with different types of RES, using advanced technologies for online data acquisition and optimizing online communication of this type, using friendly interfaces such as display panels, used for working with virtual instruments, harmonizing the Romanian technological solutions with the international operation on-grid or off-grid.

C. *InDeSEn architecture: software and hardware*

InDeSEn integrates the following software and hardware components:

- software components: monitoring module; diagnosis module; prediction module; knowledge base; decision module; control module.
- hardware components: energy monitoring devices and power control units

The main functions implemented in the software application – the intelligent support system are: monitoring, diagnosis and prediction. (Fig. 1).

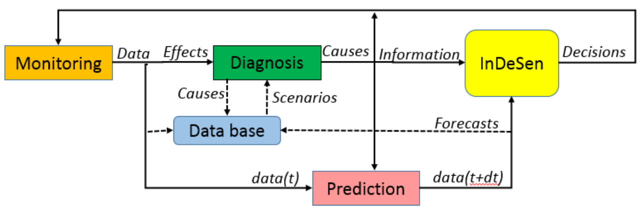

Fig. 1 Functions of InDeSEn

Monitoring. At this level, the significant parameters that characterize the electrical energy management the electrical energy quality and the environment factors (specific to the primary resources of renewable energy) are measured in real time. These values are stored in a data base. Data resulted from the monitoring represent, at this level, inputs. In addition, by primary processing is determined the performance report of the PV panels and the balance between the momentary and the rated power of the local network.

Diagnosis. In order to assess the operational status of the installations and electricity consumption and identify the causes of the state of emergency or alarm in the network, within the proposed scheme will be implemented the diagnosis function. The diagnosis function evaluates the functioning state of the generating/consuming installations and identifies the damage causes or an alarm in the network. These data will influence the dynamic of the trust of each renewable energy producer and also the price of the green energy so as to develop clean technologies.

Prediction. Once we have an updated knowledge base, enriched with new scenarios (input/output data) and with a minimal intelligence level established in the design stage, the prediction function can be used. This one provide short, medium or long time forecasts in respect of the consuming process evolution and energy generation. This information will be used by the Intelligent Decision Support System (INDES) in analyzing the forward decisions. The tendency to determinate the electrical energy generation is based on the cycle (day/night, winter/summer) of the environment factors (solar radiation, temperature, wind speed) and on the decrease of the efficiency of the installations because of the generators use. The results of the prediction have an important impact not only on the action plan but also on the financial evaluation of the green energy.

The architecture of the hardware infrastructure supporting the decisional system is presented in the block diagram from the Fig. 2.

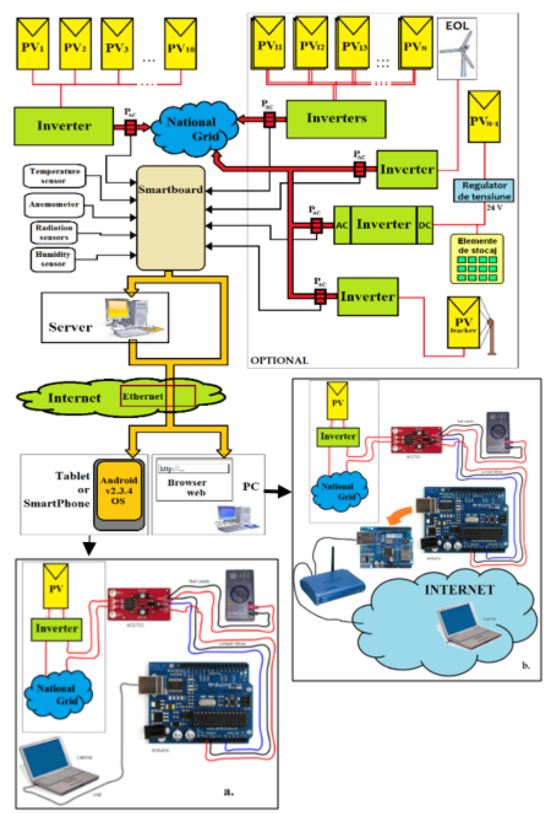

Fig. 2 The hardware infrastructure

Thanks to the initial configuration and components provided in the architecture, the platform manifests flexibility and adaptability in operation. Any electricity generator can be integrated with the solar central, wind, hydroelectric plants or diesel generators. The key characteristics of the platform's modules structure are: photovoltaic panels and wind power station; storage unit; inverters; PC with DAQ and software application and loads.

The adaptive character of the decision support system will permanently ensure low energy lose correlated with the new scenarios that occur in the environment or at the consumers. The damages repair will provide a higher utile energy in the local network, a low energetic transfer from RNE and will minimize the losses in the energy transport. The implemented optimization algorithm will take into account the necessary energy in the case of isolated functioning (islands of energy). 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.

III. InDeSEn as Fuzzy- Multi Agent Hybrid System

A. *System design*

In this section we will present only a part of the application InSeSEn, due to the length restrictions imposed by the publisher. It is about the design a fuzzy multi- agent system able to assist the users' decisions.

The exploration and the assessment of criteria used for choosing a decision support system are made in fuzzy logic and intelligent agents context. In this respect, firstly are presented the criteria used for choosing the best parameters, in relation with each step of the tool design. Precisely, the identified criteria used for choosing a decision support system, made in fuzzy logic and intelligent agents context are tested on a hybrid system, fuzzy- multi-agent. The tool design of the proposed hybrid system is build using MATLAB.

The flow diagram showing the steps of tool design is presented in the fig. 3. It is related only to the temperature sensors information modeling and processing. The application InDeSEn also integrates modules for luminance, air quality, humidity, noise and sound level, safety, movement etc.

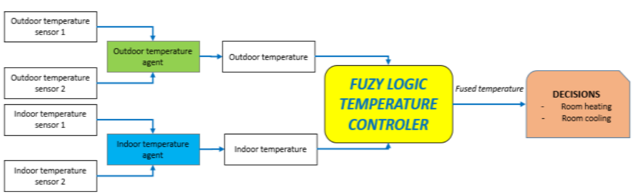

Fig. 3 The flow diagram

The measured data monitored by temperature sensors, located indoor and outdoor are the main sources for a deeper understanding of the system behavior and environmental status.

The tool has a **hierarchical structure**, meaning that 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.

On the second level of the hierarchical structure in placed the fuzzy logic temperature controller (FLC). This one can be viewed as an approach combining conventional precise mathematical control and humanlike decision-making.

The architecture of the temperature decision support module is presented in fig. 4. There are five primary distinctive panels integrated in the graphical user interface (GUI) for building the FLC corresponding with: the inputs/ outputs fuzzyfication and membership functions (MFs) editor, editing, building and viewing the fuzzy inference systems and the last one, the defuzzyfication and output surface viewer.

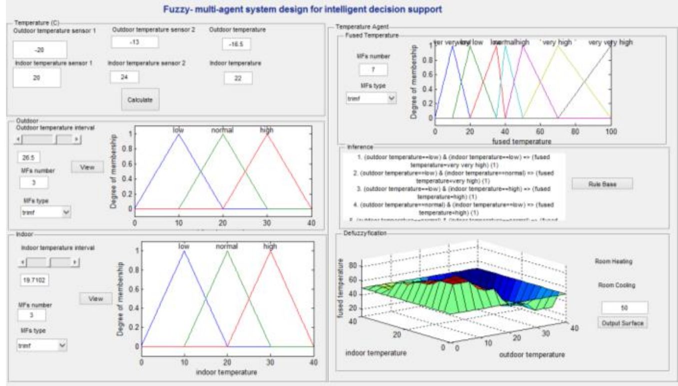

Fig. 4 The graphical user interface of the temperature decision support module

B. *Fuzzyfication*

The structure of a fuzzy controller is essentially the structure of a Mamdani technical fuzzy controller. It has two inputs (*outdoor temperature* and *indoor temperature*) and one output (*fused temperature*).

The GUI proposed give to the user the possibility to choose the number of the membership functions for each input/ output and these ones shapes: triangular, Gaussian etc. The universe of discourse is: [0 40] Celsius degrees for *indoor temperature* and [-30 40] Celsius degrees for *outdoor temperature* and [0 100] Celsius degrees for *fused temperature.*

The users' choices are made by clicking in the GUI: the outdoor/indoor/ fused temperature interval slider, editing the MFs number and selecting the MFs type (Fig. 4).

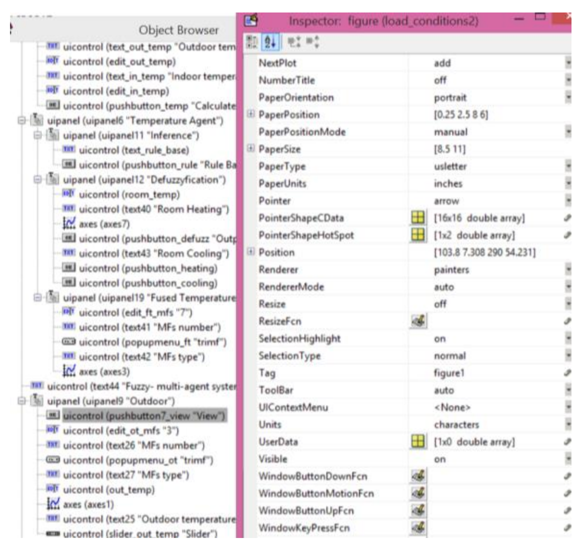

Fig. 4. The source code

Considering these options, in the source code of universe of discourse of each variable is divided into fuzzy regions. The method used is a trial and error one. The number of regions equals with (2N+1) [19], where N represent the number of MFs selected by user. For each fuzzy region is assigned the membership function with the shape imposed by user in the

ISBN: 978-1-61804-287-3

GUI.

Fig. 5(a), 5(b), 5(c) show an example where *indoor temperature* is divided in 3 fuzzy regions, triangular shapes, the *outdoor temperature* is divided in 5 fuzzy regions, Gaussian shapes, and *the fused temperature* is divided in 7 fuzzy regions, triangular shapes.

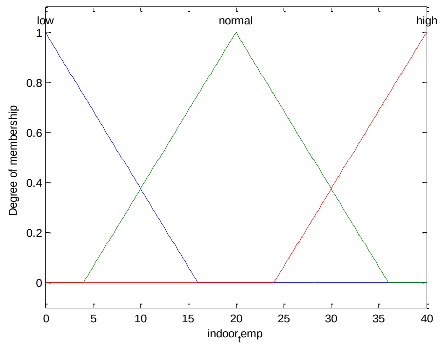

Fig. 5a. The indoor temperature input divided in 3 fuzzy regions, triangular shapes

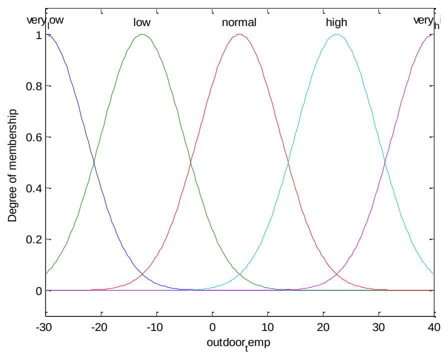

Fig. 5b. The outdoor temperature input divided in 5 fuzzy regions, Gaussian shapes

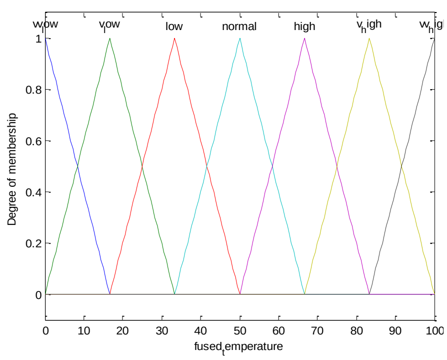

Fig. 5c. The fused temperature output divided in 7 fuzzy regions, triangular shapes

It was found that, in our case, the smallest number giving satisfactory results is 3 MFs, triangular shape for each input and 7 MFs, triangular shape for the output.

C. *Inference system*

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.

We have built our FLC rule base in relation with Hagar's method [20]. The fuzzy rule decision table, in indexed format, used for FLC inference, using our reasoning and Hagras's, is shown in the Table 1.

Table1. Rule base in indexed format

Indoor temp. MFs	Outdoor temp. MFs	Fused tem. 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.

Having two inputs variables, 3 membership functions each, the number of rules equals with $3^2=9$. The representation 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.

D. *Defuzzyfication*

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 (Fig. 6a and 6b).

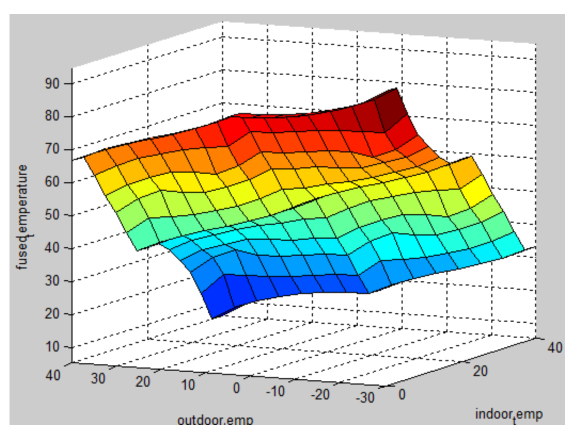

Fig. 6a. The fused temperature output divided, Dragomir approach

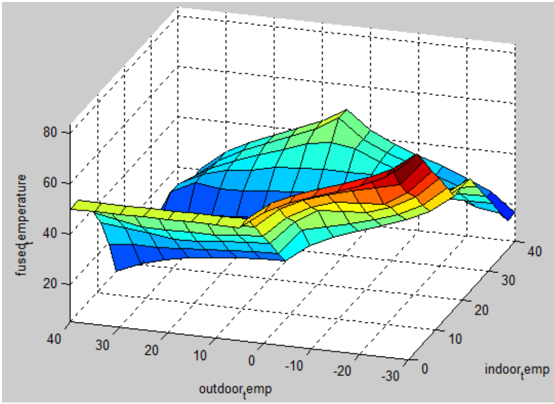

Fig. 6b. The fused temperature output divided, Hagras approach

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

On the other hand for InDeSEn intelligent decision system, the GUI presented is only a local control module who will be integrated in a hierarchical structure with cascade control loop.

IV. CONCLUSIONS AND WORK IN PROGRESS

Novelty of this proposal consist in creating an intelligent decision support system for the low voltage grid with distributed power generation from renewable energy resources, allowing customers to control electricity consumption of the used devices, to reduce their monthly bills and carbon emissions, also reducing the demand during peak periods. InDeSEn informs customers about network status and consequently they will be able to program their appliances, as washing machines, during off-peak hours in a proactive manner.

The beneficiaries of InDeSEn software innovative platform are: green energy producers; universities, schools and research institutions - students and specialists in training, giving them the useful tool in their work in a new field of academic and professional specialization; individual electrical energy consumers; researchers from the energetic field and environment agencies; Ministry of Finance and Ministry of Environment and Sustainable Development which will establish and coordinate more effectively and faster exchange of information between policy makers and the public will be able to correlate better environmental protection plans with the development of RES and last, but not least the citizens as consumers that will be informed about the advantages of the systems with RES.

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 DP-RES.

ACKNOWLEDGMENT

This work was supported by a grant of the Romanian National Authority for Scientific Research, CNDI–UEFISCDI, project code PN-II-PT-PCCA-2011-3.2-1616.

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