FUZZY INTELLIGENT CONTROL FOR THE LOW VOLTAGE ELECTRICAL NETWORKS WITH DISTRIBUTED POWER GENERATION FROM RENEWABLE ENERGY RESOURCES

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Abstract. ***This paper proposes an engineering solution for the stability control of the low voltage electrical networks with distributed power generation from renewable energy resources. First there are presented generally, the existing problems in this type of systems, capable to be solved with automation intelligent control. In the second part, the comparative analysis between classical and intelligent control methods made over the scientific literature will show the advantages and the inconvenient of each one. The paper focuses over fuzzy controller. In the third section, the favorable arguments identified will be valorized in the proposed software example designed and realized with Matlab.***

Keywords: ***fuzzy logic control (FLC); renewable energy resources (RES), distributed power generation, intelligent system, simulation***

1. INTRODUCTION

Please follow the following instructions and the format of this paper to allow the final publication look professional Renewable energy resources (RES) have represented in balance of energy of European Union (EU), in 2000, only 6%. The actual tendency in EU countries is the use of the renewable energy in order to reduce the contribution of conventional power stations fact that will reduce the gas emissions and will protect the environment and will increase the networks security. The target of production of energy from RES is established in European directives [1], [2] at 22% for 2010. Considering the actual state in this field characterized by a growing rate of 1% per year, the important measures must be taken in order to encourage the implementation of distributed power generation from RES and to provide optimal solutions.

The major goal of this research work is to design and realize a fuzzy logic controller for the low voltage electrical networks with distributed power generation from renewable energy resources.

The major problem of the distributed power generation in the low voltage electrical networks problematic consists in ensuring the network stability. More precisely, by local power generation the lost of distributed power should be compensated, but also an excess of power can generate overloads of the electric line providing the instability of the network.

Hence, the rational management of the electrical energy has to be ensured to maintain the balance on each line of the network Pgen = Pcons (generated power equal to consumed power). The differences from this ideal case mean over or under production of energy and they are perturbing the stability of the energetic distributed system.

These negative effects can be annulated or transformed in positives ones by the use of an intelligent software system.

International research programs [3] in respect with the distributed power generation (from renewable resources) had been implemented in order to solve the specific objectives on medium and long term. In this context, a large project group (a cluster) named Integration of Renewable Energy Sources and Distributed Generation into the European Electricity Grid (IRED cluster) [4], which contains projects as SAVE, ALTENER, SYNERGY, SURE, ETAP, “Intelligent Energy for Europe" has been created.

There were several projects at national context in the field, since 1998 in Valahia State University was implemented the first project (ICOP-DEMO 4080/98) [5] for photovoltaic power stations connected to low voltage networks that integrate photovoltaic panels from buildings (the concept BIPV), a project financed by the European Union. This project was followed by the project CEEX CoFoTerm [6] that implemented the first experimental electrical network model with distributed power generation from Romania.

The paper is organized in three parts. Firstly, the low voltage electrical networks with distributed power generation from renewable energy resources will be presented and the existing problems capable to be solved with automation intelligent control systems will be pointed out. In the second part, the comparative analysis between classical and intelligent control methods made over the bibliographical literature will show the advantages and the inconvenient of each one. A special attention will be over the fuzzy controller. In the third section, the favorable arguments identified in the state of the art will be valorized with a proposed software example designed and realized with Matlab.

2. LOW VOLTAGE ELECTRICAL NETWORKS WITH DISTRIBUTED POWER GENERATION

Generally, the term Distributed or Distributed Generation (DG) refers to any electric power production technology that is integrated within distribution systems, close to the point of use. Distributed generators are connected to the medium or low voltage grid. They are not centrally planned and they are typically smaller than 30 MWe (DTI 2001). [7] The concept of DG contrasts with the traditional centralised power generation concept, where the electricity is generated in large power stations and is transmitted to the end users through transmission and distributions lines.

Distributed generation (DG) is currently being used by some customers to provide some or all of their electricity needs. There are many different potential applications for DG technologies. Benefits for environmental quality may come from distributed generation's role in promoting renewable energy sources, less-polluting forms of fossil energy, and high-efficiency technologies. DG allows power to be delivered in environmentally sensitive and pristine areas by having characteristically high efficiency and near-zero pollutant emissions. [8]

The classical structure of a distributed power system is reconfigured due to RES implementation. The architecture of a “green power” system is presented in the figure 1 [6]. The electrical power parameters (effective voltage, current, power factor) are surveyed in real time in each node of the network and they are sent to the local network supervisor/central computer (PC) that will run the control support system. Moreover, the environment parameters will be measured: solar radiations, temperature and wind speed.

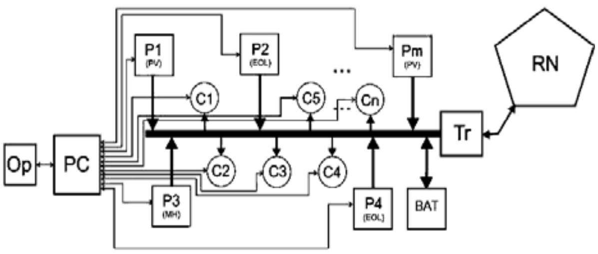

Figure 1. Low voltage electrical networks with distributed power generation architecture

Legend: P1, P2, ..., Pm – electrical energy generators (PV systems, wind turbine, micro hydro centrals, etc); ;C1, C2, ..., Cn – electrical energy consumers; PC – personal computer; OP – network operator; Tr – medium or low voltage transformer; RNE – national electricity network.

The elements of the network are: uncontrolled generators (those of renewable energy that have not dead times in which they don't generate the energy), controlled generators (diesel groups, fuel cells, battery invertors, groups of power stations, generators that are fuel consumers and work only in critical situations), controlled consumers (stocks, batteries, electrolyses), Uncontrolled consumers (all the housework and industrial consumers that can be only estimated and influenced by the variation of the electricity price) and main consumers (those of the first degree, i.e. 100% dispose).

Objectives of the decision support system are: the determination of the energetically under load or overload periods in the local networks, periods indicating the moments of decision taken in national power generation, the identification of the abnormal situations in generators or consumers functioning in view of the energy generation and transport process and in the main consumers feeding (local island type networks) and the on line data interface for each generator/consumer in respect of the energy generation/consuming process in the local network so as to evaluate the electricity cost in a free market.

We also must consider in the implemented optimization, the necessary energy in the case of isolated functioning (islands of energy). The main consumers will be established by their degree of importance, by the existing energy in stocks or in the permanent generators (Diesel generators, fuel cells).

In the context describe above and taking into account the problematic in the field, in the next paragraph we will present the identified solutions suite of a scientific literature analysis.

3. AUTOMATION INTELLIGENCE CONTROL TECHNIQUE. FUZZY LOGIC CONTROL

Many physical systems are very complex in practice so that rigorous mathematical models can be very difficult to obtain, if not impossible. An alternative to the classical control techniques and tools is represented by fuzzy logic algorithms. Many applications show that fuzzy logic controller (FLC) is superior to conventional control algorithms in terms of design simplicity and control performance. In particular, the FLC methodology appears very appealing when the processes are too complex for analysis by conventional quantitative techniques or when the available sources of information are interpreted qualitatively, inexactly or uncertainly. Thus, FLC may be viewed as an approach combining conventional precise mathematical control and humanlike decision-making.

The greatest drawback of fuzzy logic is in the theoretical ground, the lack of rigorous stability and robustness analysis techniques. Although, both stability tests and robustness analysis have been investigated for lower-order systems, most stability analysis methods for FL are based on approximations, and there is no rigorous way to obtain a measure of robustness [9],[10], [15].

We consider that the adaptive characteristics of FLC are well fitted to our case. Thus the paper will focus over this intelligent control technique in order to minimize the energy loses in correlation 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 national energy network will minimize the lost in the energy transport.

In the next paragraphs, the favorables arguments for FLC will be argued with the results obtained with the proposed software application realized with Matlab 6.0 Fuzzy Logic Toolbox.[11].

4. INTELLIGENT STABILITY CONTROL OF LOW VOLTAGE ELECTRICAL NETWORKS WITH PD-RES

In the following paragraphs will be presented the major steps made to design and realize a fuzzy logic controller for the low voltage electrical networks with distributed power generation from renewable energy resources, in order ensure the network stability and to support with an intelligence tool the process.

A multivariate Mamdani fuzzy logic controller informational structure with its fundamental input-output relationship consists of four components namely: the fuzzifier, the inference engine, the defuzzifier, and a fuzzy rule base (Figure 2.).

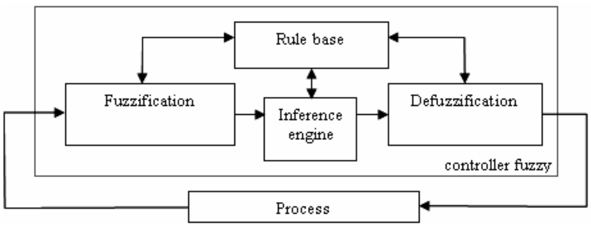

Figure 2. Blocks of a fuzzy controller

In the fuzzifier, crisp inputs are fuzzified into linguistic values to be associated to the input linguistic variables. After fuzzification, the inference engine refers to the fuzzy rule base containing fuzzy IF-THEN rules to derive the linguistic values for the intermediate and output linguistic variables [12], [13], [14]. Once the output linguistic values are available, the defuzzifier produces the final crisp values from the output linguistic values.

This type of architecture is considered as an alternative for classical control structures based on human experts experience usually implemented in low voltage electrical networks with distributed power generation.

4.1. Fuzzification of input variables

Through the use of membership functions defined for each fuzzy set for each linguistic variable, the degree of membership of a crisp value in each fuzzy set is determined.

The numerical variables units:

- "PGenCon" (the difference between generation and consuming power) was fuzzified using 3 gaussian membership functions
- "CostEnergie" (the cost payed by national energy supplier to local power generation from renewable energy resources producer) was fuzzified using 3 triangular membership functions
- "Stocaj" (the existing energy level in stocks or in the permanent generators) was fuzzified using 2 gaussian membership functions

As a result of fuzzification, to the linguistic variables are assigned linguistic values like: positive, negative, low, load, unload etc. (Figure 3 a, b).

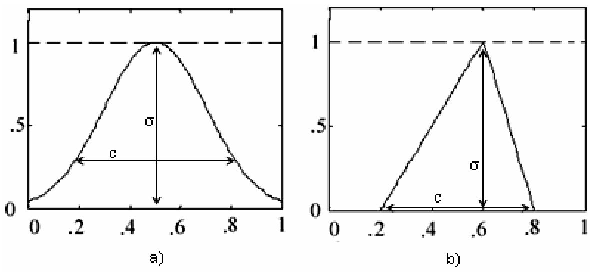

Figure 3. Membership function a). gaussian b). triangular

An important signification over the control outputs has the input variable labeled "CostEnergie" because it offers information related to dinamique of consumers. For example, during the journays is supposed to be the energetically overload periods in the local and national networks and consequently the "green" energy price will be low. On the other hand, during the holydays or the evenings is supposed to be the energetically under load periods because the over consuming and consequently the "green" energy price will be high.

The membership assigned to the controller output is "ReteauaLocala" and is supposed to have gaussian shape with 5 fuzzy partitions. The linguistic term sets are labeled function of the assigned performed action: the on/ off of the storage units, the production in national energy network or the alimentation from national energy network. The network stability is obtain for the value "asteapta" of the FLC output.

4.2. Inference Engine

The two main steps in the inference process are aggregation and composition. Aggregation is the process of computing for the values of the IF (antecedent) part of the rules while composition is the process of computing for the values of the THEN (consequent) part of the rules.

During aggregation, each condition in the IF part of a rule is assigned a degree of truth based on the degree of membership of the corresponding linguistic term. From here, we have beed choose the minimum (MIN) of the degrees of truth of the conditions is usually computed to clip the degree of truth of the IF part. This is assigned as the degree of truth of the THEN part.

The fuzzy rules describing the dynamic of the analyzed process are:

R1: IF (***PGenCon*** is *Pozitivă*) AND (***CostEnergie*** is *Mic*) AND (***Stocaj*** is *Incarcat*) THEN (***RețeauaLocală*** is *debiteazăInRN*)

R2: IF (***PGenCon*** is *Pozitivă*) AND (***CostEnergie*** is *Mare*) THEN (***RețeauaLocală*** is *debiteazăInRN*)...

All the fuzzy rules are contained in the fuzzy rule base.

4.3. Defuzzification

The last phase in the modeling fuzzy expert system is the defuzzification of the linguistic values of the output linguistic variables into crisp values. The most common techniques for defuzzification are Center-of-Maximum (CoM) and Center-of-Area (CoA).

CoM first determines the most typical value for each linguistic term for a output linguistic variable, and then computes the crisp value as the best compromise for the typical values and respective degrees of membership.

The most typical value of each linguistic term is the maximum of the respective membership function. If the membership function has a maximizing interval, the median of that interval is taken.

The other common method, CoA, or sometimes called Center-of-Gravity (CoG), first cuts the membership functions of each linguistic term at the degrees corresponding to the linguistic values. The superimposed area under each cut membership function is balanced to give the compromised value. A disadvantage of this technique is the high computational demands in computing for the areas under the membership functions.

There are other variants of computing for crisp values from linguistic values. These are Mean-of-Maximum (MoM), Left-of-Maximum (LoM) or Smallest-of-Maximum (SoM), Right-of-Maximum (RoM) or Largest-of-Maximum (LoM), and Bisector-of-Area (BoA).

The method used in this research work is the Center-of-Maximum (CoM) due to its simplicity and popularity.

4.4. Simulation Results

In order to achieve a simplified and users' friendly Computer Aided Design package for this stage, MATLAB 6.0 software package is employed, precisely Fuzzy Logic Control Toolbox. [11]

In the figure 4 is represented the FLC output. The assigned significations are: in case of over generation and favorable price for suppliers they have to supply national energy network with energy from RES. Otherwise, if the price isn't favorable for them, the storage units will be charged. The local network stability is ensured for the Pcons=Pgen (the yellow surface of the fig. 4). In case of under power generation and/ or defavorable process, the alimentation will be ensured by storage units.

Using a Mamdani FLC give us the possibility to access the intermediary outputs of the internal units of the controller. Thus, the overload and under load energy period in local network can be identified regarding "PgenCon" membership shapes: the "positive" membership (for PGenCon>0 case) corresponds to overload period, the "negative" (for PGenCon<0 case) corresponds to under load period and "nula"(for PGenCon=0 or with +/-10% case). We precise that the membership functions did not interlacing

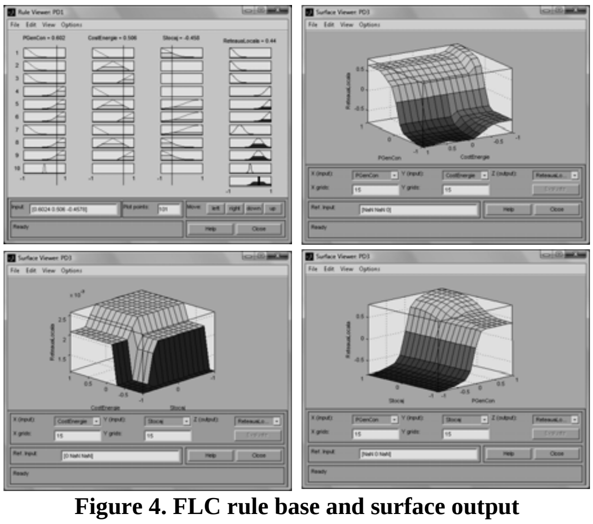

Figure 4. FLC rule base and surface output

5. CONCLUSIONS AND PERSPECTIVES

This paper proposes an engineering solution for the stability control of the low voltage electrical networks with distributed power generation from renewable energy resources. First there are presented generally, the existing problems in this type of systems, capable to be solved with automation intelligent control. In the second part, the comparative analysis between classical and intelligent control methods made over the scientific literature will show the advantages and the inconvenient of each one. The paper focuses over fuzzy controller. In the third section, the favorable arguments identified will be valorized in the proposed software example designed and realized with Matlab.

The performances of this software instrument will be outperforming with an optimal modeling of rule base an inference engine. We precise that out proposal is only the simply version of an intelligent management system that will be implemented on the experimental model of a the low voltage electrical networks with distributed power generation from renewable energy resources, existing in DCEM - UVT research department. In order to test the conformity of the results with the energy quality standars, the simulations test will be made with real monitoring data and the FLC architecture will be impoved with new scenario in order to increase minimal intelligence level established in initial modeling phase.

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