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The application of fuzzy logic algorithms in controllers for controlling the use of renewable energy sources

***Abstract**. Optimal management of renewable energy devices in conditions of high variability and stochastic nature of energy supply and consumption is difficult to solve using conventional control methods. Management should be based on Fuzzy Logic algorithms, neural networks and genetic algorithms. This direction, due to its simplicity and proximity to biological systems, is widespread in various fields of scientific and industrial activity.*

***Streszczenie.** Optymalne zarządzanie urządzeniami wytwarzającymi energię odnawialną w warunkach dużej zmienności i stochastycznego charakteru dostaw i zużycia energii jest trudne do rozwiązania za pomocą konwencjonalnych metod sterowania. Zarządzanie powinno być oparte o algorytmy Fuzzy Logic, sieci neuronowe i algorytmy genetyczne. Kierunek ten, ze względu na swoją prostotę i bliskość układów biologicznych, jest szeroko rozpowszechniony w różnych dziedzinach działalności naukowej i przemysłowej. (**Zastosowanie algorytmów fuzzy logic w sterownikach do kontroli wykorzystania odnawialnych źródeł energii**)*

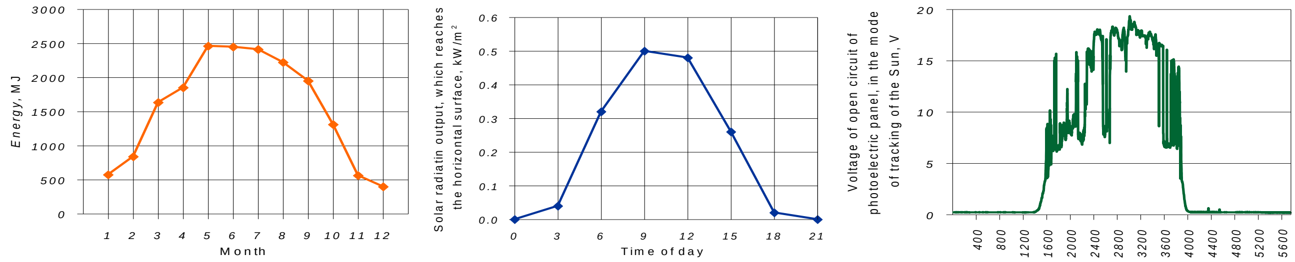
Keywords: renewable energy sources, fuzzy logic controller, solar hot water system, short-term weather forecast, fuzzy logic algorithms.
Słowa kluczowe: odnawialne źródła energii, sterownik fuzzy logic, instalacja solarna do podgrzewania wody, krótkoterminowa prognoza pogody, algorytmy fuzzy logic.

Introduction

The use of renewable energy sources is one of the rational ways to replace fossil fuels. The main types of renewable energy sources are energy from solar radiation and wind, energy from the environment and subsoil, energy from small streams, energy from biomass, etc. which can be converted into heat and electricity with parameters necessary for their use in technological processes. Considering that solar energy is a primary source for all of these energy resources, it can be considered almost inexhaustible. In addition to being inexhaustible, renewable energy sources are environmentally friendly, reducing the negative impact of energy on the environment, which experience shows is a top priority.

Formulation of the problem

Among the features of the use of renewable energy sources are a significant uneven supply and consumption, as well as a low density of energy flows. In terms of irregularity, it is deterministic and stochastic. The deterministic is seasonal and daily. The immediate one determines he stochastic nature of the change in environmental climatic conditions. As an example, we can consider the irregularity of solar radiation flows (Fig. 1).



a) b) c)

Fig. 1. Seasonal (a) and daily (b) and instantaneous (c) irregularities in solar radiation LabVIEW [1]

One of the main methods of compensation the uneven supply of renewable energy sources and their consumption is the use of hybrid energy systems that can partially improve the stability of energy generation. In addition, thermal energy systems (Fig. 2) and electrical storage are used for short-term reconciliation of energy generation and use. However, the use of batteries significantly increases the cost of the system and its operation. One way to reduce the cost of a power system is to use pseudo-accumulation systems that can be implemented using an "electrical battery" of an external power grid.

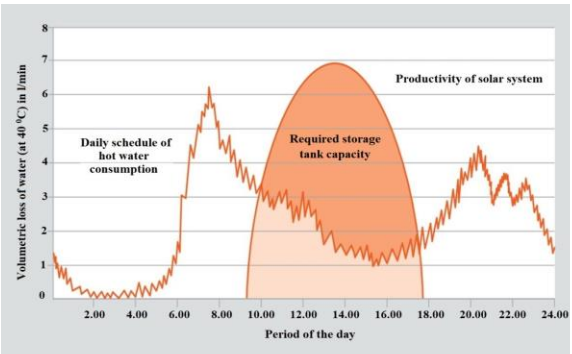


Fig. 2. Application of thermal storage in solar hot water systems [2]

In addition, connection to external power grids provides a backup power supply for the hybrid system with a certain level of substitution for traditional energy sources. An additional economic effect from the use of external grids can be achieved by the controlled application of the zone tariff for electricity.

Analysis of researches and publications model

In systems of control and optimization of parameters of technological processes and means, the methodology based on fuzzy logic, neural networks and genetic algorithms is being increasingly used [3 ÷ 5]. Their application provides an accelerated solution to the problem of optimization in the absence of complex mathematical models.

Renewable energy is one of the industries where fuzzy logic has been used rapidly [6 ÷ 14].

Source [5] provides information on the development of a control system for a hybrid system based on wind, solar photovoltaic and heat pump installations, which can also provide battery charging and home electrical supply. A similar system is discussed in article [6], which provides information on modelling of a hybrid power system based on solar, wind, and bioenergy plants operating in micro-grid and combined modes using Fuzzy logic algorithms.

A variant of the Fuzzy logic control system for a hybrid installation consisting of electrical and thermal installations using solar energy is described in thesis [11]. The peculiarity of this work is that in the model of energy flow management, the prediction of parameters of power plants was applied.

In article [7], an analysis of the operation of another variant for a hybrid installation was performed, in particular, the development of a Fuzzy logic controller for a hybrid installation control system using wind and photoelectric plants, which supply their energy to storage systems containing a conventional battery for short-term accumulation, and also a fuel cell that uses hydrogen for long-term energy storage.

Hybrid systems include systems based on one or two renewable energy sources that are paired with an external power grid. In particular, the article [8] analyses the Fuzzy logic controller for a wind-driven hybrid installation with the accumulation of generated electricity and the connection to the system to an external power grid.

In addition to hybrid power systems, the use of the Fuzzy logic controller can also be found in stand-alone installations that use renewable energy. Thus, in thesis [9], an analysis of the operation of the Fuzzy logic control system of a solar dryer for fruit drying, equipped with an accumulation system using the phase transition energy of materials, is presented.

In article [10], a simulation of the Fuzzy logic process for controlling the modes of operation of a solar thermal power plant is presented.

A valuable tool for improving the efficiency of renewable energy is the use of intelligent control systems for their modes of operation. It is a common practice to use the Fuzzy logic controller to track the maximum power and efficient use of the autonomous photoelectric array controlled by linear and nonlinear loads, as shown in source [12].

It is also advisable to use the Fuzzy logic toolbox not only to develop controllers for operating modes, but also to develop energy conversion systems, accessory controls, and more. Thus, in thesis [13] the strategy of developing the Fuzzy logic of the network converter controller for wind power installation is presented, and in article [14] the development of a solar tracker control system that uses fuzzy logic algorithms is presented.

The authors also attempted to develop a simplified control system for solar thermal installation of hot water supply, which was based on the Fuzzy logic controller, which, however, is not characterized by functional completeness (Syrotyuk et al. 2014). Also conducted research on the development of wind power plant control system using the Fuzzy logic algorithm (Syrotyuk et al. 2015).

The Main Material Presentation

It is impractical to achieve full energy coherence in the context of stochastic changes in the real climatic conditions of the environment, based on economic considerations. Maximum economic and energy efficiency can be achieved with the optimum level of substitution of traditional energy from renewable energy. The solution to this type of problem can be implemented using automatic control of energy flows in hybrid power systems. However, appropriate information and hardware software is required to implement them. Energy flows are managed on the basis of continuous receipt of technological information, which always comes late. In such circumstances, short-term weather forecasting is of particular importance. The available short-term forecast information allows adjusting the algorithm for managing energy flows in conditions of variability and uncertainty. This class of problems is best solved using the theory of fuzzy sets (Fuzzy Logic).

The Fuzzy Logic toolkit allows you to enter the algorithm of the control system the intellectual component, presented in the form of concepts close to human thinking, and thus to present complex algorithms in a simple and accessible form. This is especially true for solving problems of short-term weather forecasting, which are quite difficult to solve by other mathematical methods and modelling. One aspect of fuzzy set theory application is that process modelling does not require the compilation of mathematical models in the form of differential equations and methods for solving them, which is especially important in the context of stochastic changes in input parameters. In addition, the use of fuzzy logic algorithms significantly increases the speed of the control system and reduces the duration of transients.

The procedure for the implementation of the fuzzy sets algorithm involves: fuzzification of the input signals that are received from the primary sensors in a clear form by using the functions of their belonging to the corresponding terms (translating the information in a fuzzy form); processing fuzzy information using fuzzy set algebra according to the knowledge base and rules; the formation of control signals based on fuzzy inference algorithms with subsequent defuzzification, on the basis of which the control signals are clearly formulated.

Let us consider a solar hot water installation, which guarantees energy supply through the combined use of solar energy and energy from an external grid. The hybridization of such an installation is realized by the installation of a heating element in the battery tank, which is powered by an external power supply.

Typically, in serial installations, a heating element is controlled by an independent thermostat, which can lead to some over-consumption of electrical energy due to suboptimal control of its mode of operation. This, in turn, leads to an underutilization of solar energy potential, especially with favourable short-term weather forecasts.

Partially, over-consumption can be reduced by zone heating the battery tank, when the heating element can be placed in two spots: in the middle or at the bottom of the battery tank (classic placement) and at the top (additional or standby heating element). In case of favourable forecast and absence of sufficient hot water in the evening, its heating by a heating element is carried out only in the upper part of the storage tank, where a standby heating element is installed, which will mainly operate in the mode of express heating. In the case of unfavourable weather forecast and no hot water in the tank in the evening, water is heated by the main heating element, which is located in the lower part of the storage tank, or by two at the same time, in case of intensive water intake.

However, such a constructive change in the battery tank does not fully realize the potential of solar radiation to minimize electricity consumption from the grid. To ensure optimum use of solar energy, the Fuzzy Logic intelligent controller for operating modes of the solar hot water system should be used in conjunction with the electricity from the mains. Its main functions are the implementation of a short-term weather forecast, based on the information received from the sensors of temperature, humidity and atmospheric pressure, estimation of the dynamics of change of input information, as well as the formation of signals of optimal control of the modes of operation of the circulating pump and heating element.

The block diagram of the developed Fuzzy Logic controller is shown in Fig. 3.

In this controller, the fuzzy unit converts the input clear signals coming from the primary sensors of atmospheric pressure, humidity and air temperature, the temperature of the reservoir coolant and water in the tank and the level of illumination into signals of fuzzy logic based on the functions of each type of signal. The block of logical processing of information carries out its processing according to the algorithms of fuzzy logic, taking into account the knowledge base and rules, developed on the basis of expert evaluation. The clear control signals are generated in the defuzzification unit according to the fuzzy output algorithm selected. A special feature of the controller is the separation of functions between the two subsystems: the short-term weather forecasting subsystem for heating element control and the circulation pump control subsystem.

The control outputs of the controller are matched to the inputs of the actuators in the control signal generating unit.

Setting up controllers with a large number of input parameters is complicated by the difficulty of visually analysing their mutual influence on the output of control signals.

Therefore, it is advisable to use some simple FL controllers with a minimum number of input parameters. Then a block diagram of controlling a smart solar hot water system using Fuzzy Logic controllers will look like this (Fig. 4).

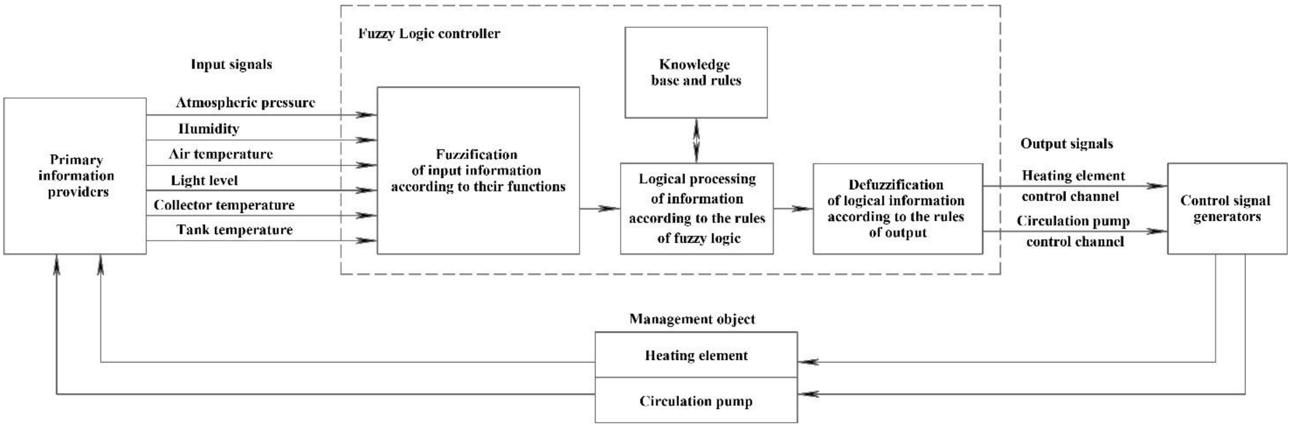


Fig. 3. Conceptual diagram of Fuzzy Logic controller of solar hot water installation control

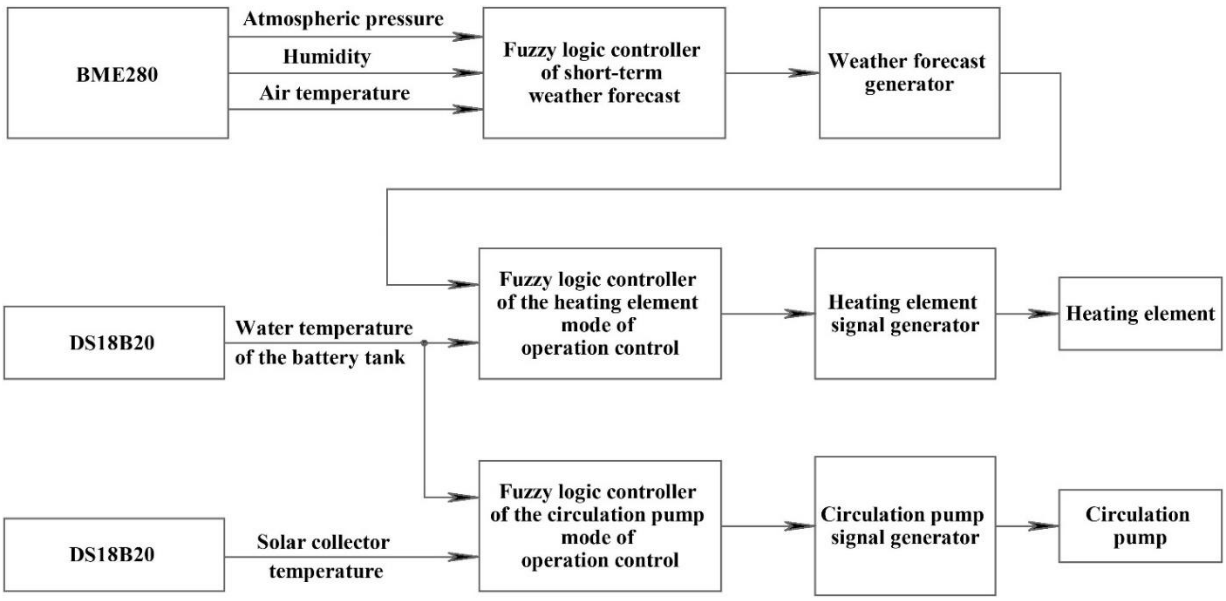


Fig. 4. Block diagram of a smart solar hot water system control using Fuzzy Logic controllers

Results

The computer model of wind flow adapted for LabVIEW software has been improved with the introduction of daily and seasonal non-uniformity of its change, which brings it as close as possible to the real wind flow.

The developed computer model of wind electric turbines allows carrying out the research of its dynamics by the stochastic change of wind speed.

The use of switches of the wind flow formation modes allows us to study the behaviour of the wind power turbine in statics and dynamics.

The long-term study of the developed computer model of wind flow may provide for its improvement using correcting the elements based on comparison with the data of meteorological measurements of wind speed.

The developed computer model of wind power turbine can be considered as a basis for its further improvement by introduction of additional submodules, for example, a system

We have developed a system for controlling the modes of operation of a solar water-heating system based on the hardware and software of the National Instruments Company, using the LabVIEW software environment. Formally, the control system is divided into three parts - controllers. The first one is responsible for determining the short-term forecast of favourable weather, and which is subsequently used in the control algorithm of the second controller, which is responsible for the energy-saving mode of operation of a heating element. The third controller generates control signals for the circulation pump, depending on the temperatures of the solar collector and the storage tank.

The control of heating element is carried out using the data of the short-term weather forecast and the data on the current period of the day with the help of an opto-thyristor switch, which also operates in pulse-width-modulated mode. Adjustment of the thermal mode of the solar system is made by changing the performance of the circulating pump, which operates in the pulse-width modulated mode from a separate subsystem Fuzzy Logic controller, whose input signal is an analog signal, which is formed by the control system developed by the algorithm, which is shown in Fig. 5.

The peculiarity of the developed system is the introduction of an intellectual component, which is implemented on the basis of the application tool "Control Design and Simulation", the use of which allows in the palette "Fuzzy Logic Designer" to design the solar controller. In particular, the development of membership functions, the formation of a knowledge base and rules and rules of withdrawal [17-21].

The first stage of designing the controller involves the development of the membership functions for each of the input and output signals in the "Variables" tab, with the choice of form and number of terms.

In particular, the design of membership functions for the fuzzification of input signals uses the tab "Input variables" displaying their appearance in the window "Input variables membership functions", and the development of membership functions for the defuzzification of output signals - tab "Output variables" with the corresponding display in the window "Output variables membership functions "(Fig. 6).

The second stage of controller design involves the development of a knowledge base and rules in the "Rules" tab. For this purpose, in the "Rules" window, on the basis of expert evaluation, a database of rules for processing information according to fuzzy logic algorithms is formed taking into account all combinations of input and output signals (Fig. 7), and in the "Defuzzification method" the output algorithm is selected. The developed controller uses the output method "Mamdani" (Center of Area).

The third stage of designing a solar controller involves adjusting it using the "Test System" tab, where the response surface of the control signals from the values of the input values is displayed in the "Input/Output relationship" window (Fig. 8). Displaying the response surface allows us to analyse the pairwise relationship of the input parameters to the value of the output. This tab also contains a digital visualization of the input and output values, as well as the current value of the rules under which they were processed.

The three-part breakdown of functions in the control system improves the visual analysis of the response functions and their impact on individual factors.

To simulate the operating modes of the solar hot water installation, a software part of the virtual controller was developed (Fig. 9).

Conclusions

The developed smart system for automatic control of operating modes of hybrid solar-electric hot water installation built on the basis of hardware and software of National Instrument company provides the ability of computer simulation to adjust its optimal modes and parameters.

Based on the simulation, a software can be developed on the basis of a microcontroller, such as the Arduino platform, which will allow the operation of the solar hybrid installation in an autonomous mode.

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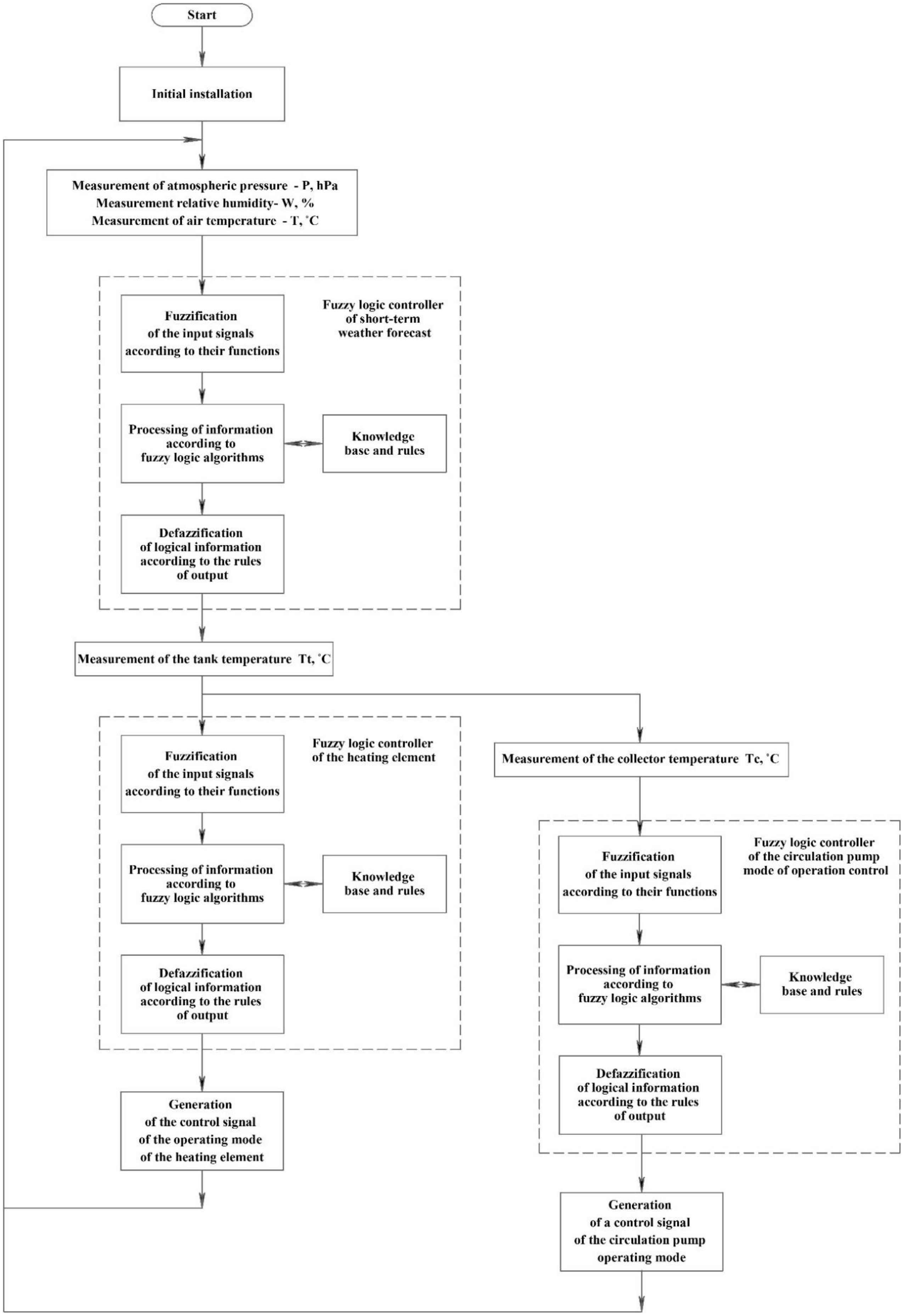

Fig. 5. Algorithm for managing the modes of operation of the solar hot water system using the Fuzzy Logic controller for forecasting the probability of weather conditions

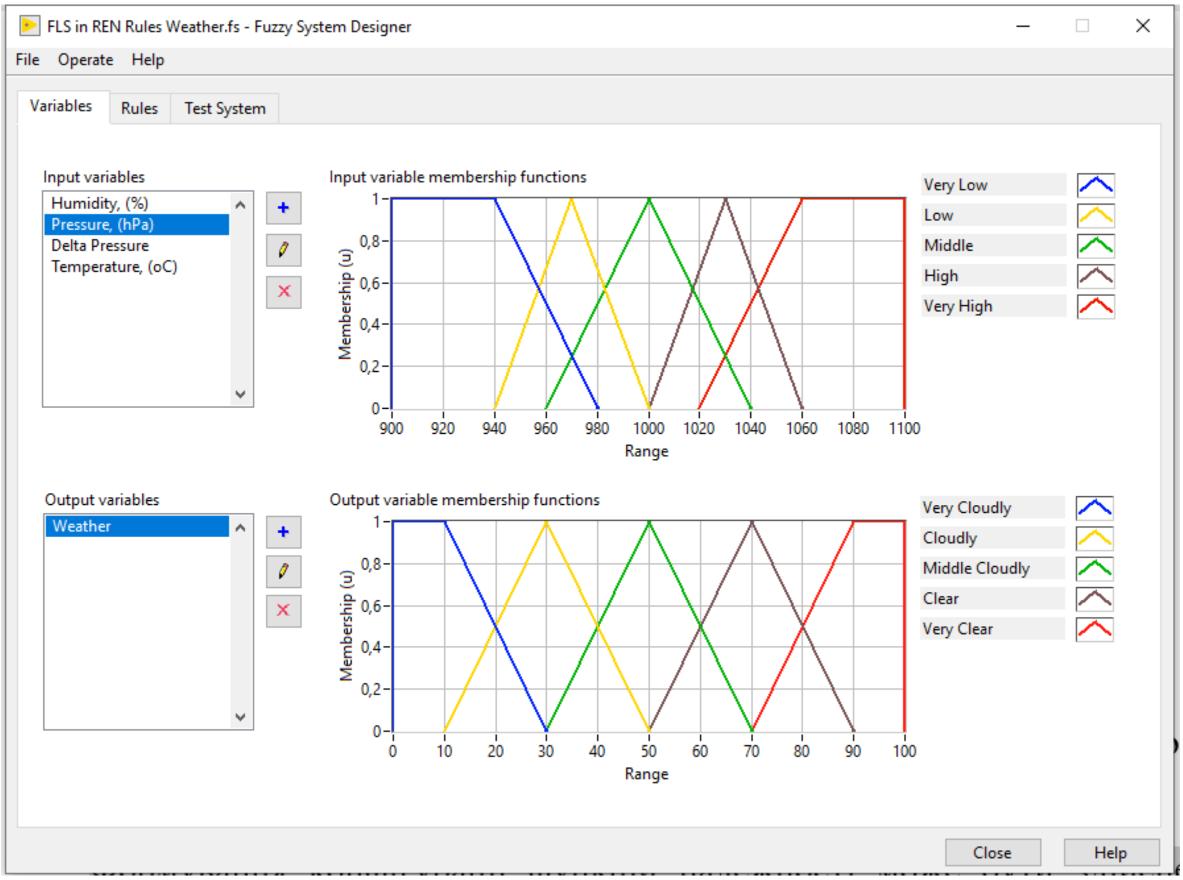

Fig. 6. Fuzzy Logic Fragmentation of Functional Desktop Window of a short-term weather forecast controller

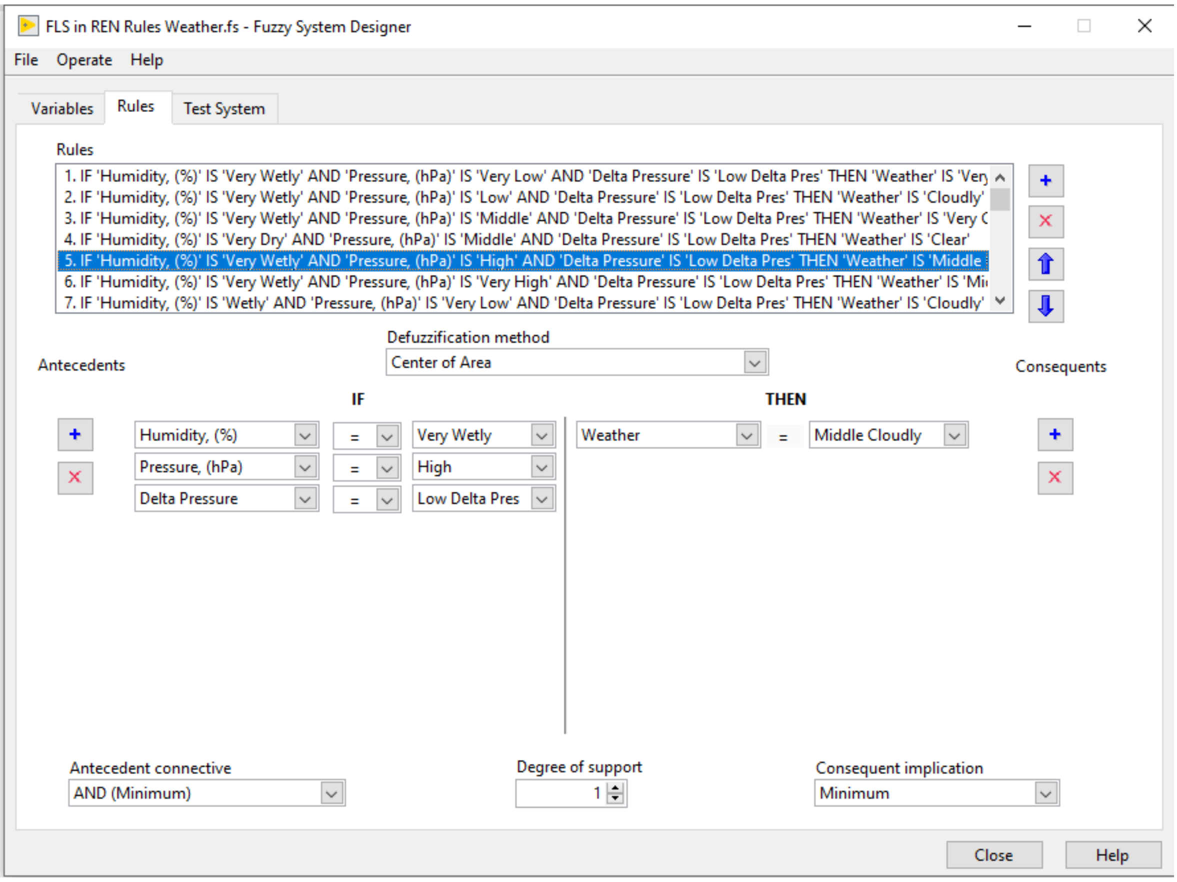

Fig. 7. Fragment of the Fuzzy Logic Information Processing Rules Database Fragment of the Short-Term Weather Forecast Controller

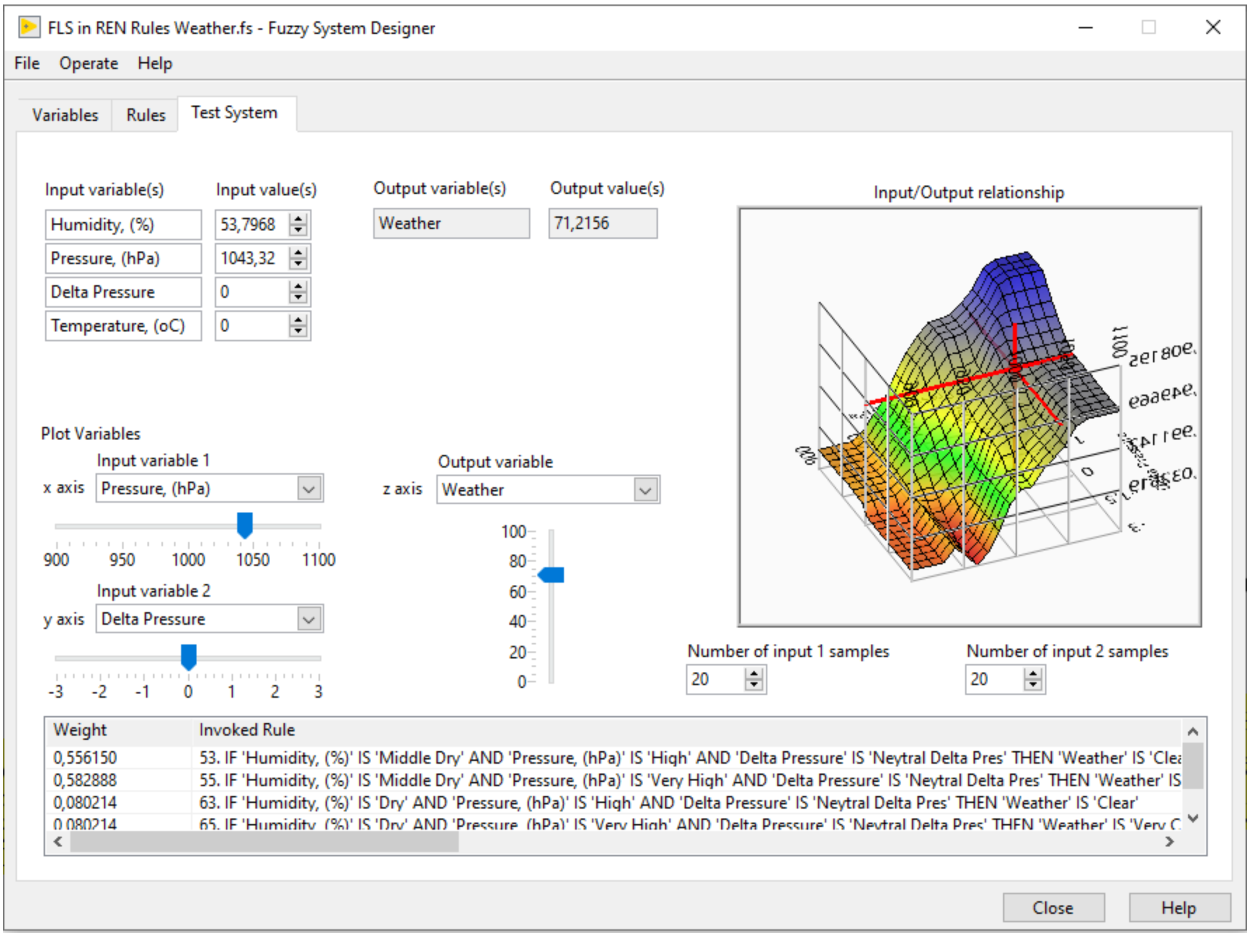

Fig. 8. Fuzzy Logic Debugging Window Fragment of Short-Term Weather Controller

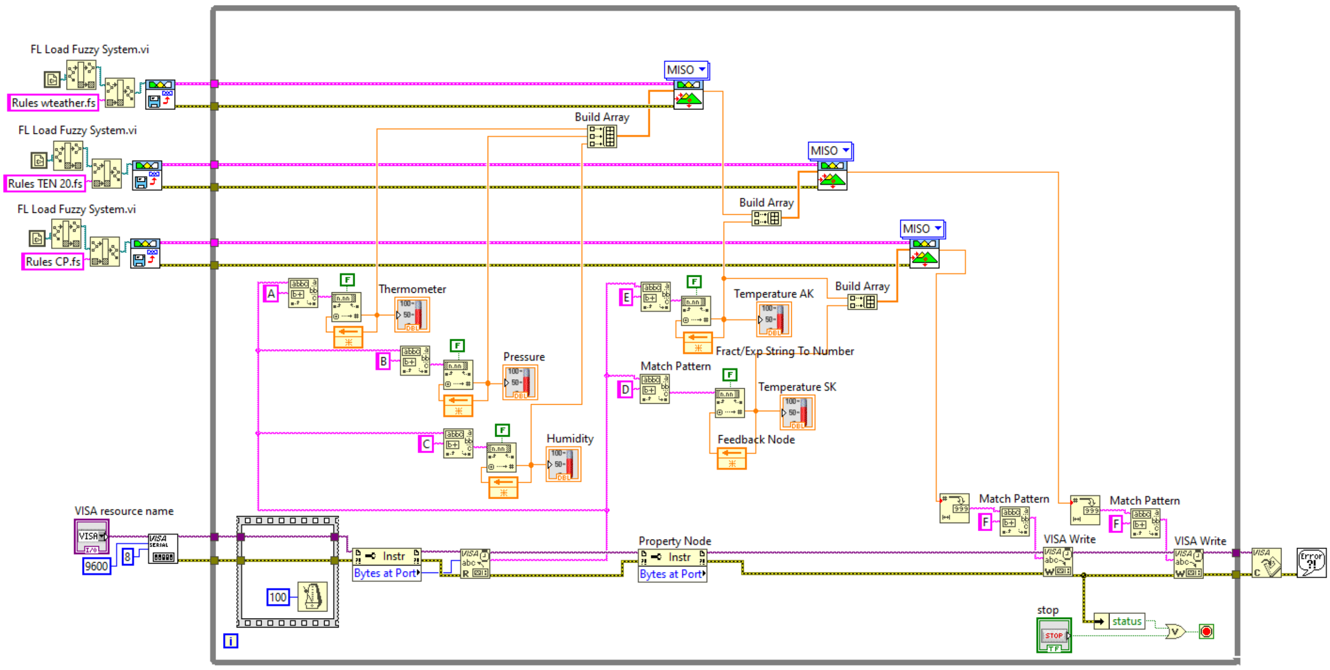

Fig. 9. Fragment of the software part of the virtual controller

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