Hybrid system of power supply with application of wind and solar energy

Serhii Syrotiuk[1], Valerii Syrotiuk[2], Borys Boltianskyi[3]

[1, 2]Department of Power Engineering of Lviv National Agrarian University
V.Velykoho Str. 1, 80381, Dubliany, Ukraine
[3]Department of Technical Systems of Animal Breeding Technologies of Tavria State Agrotechnological University, B.Khmelnytskoho Ave. 18, 72310, Melitopol, Ukraine.

Received Novemer 16.2017: accepted December 17.2017

Summary. Basing on the analysis of operating systems of hybrid wind and solar photovoltaic installations for power supply of distant objects, the authors of the article have developed a structure and algorithm of operation of an intelligent hybrid operating system. Application of Fuzzy Logic controller with the function of short-period forecast of natural conditions is a peculiarity of the developed system. Basing on the system, it is possible to make correction of the algorithm of hybrid system operating. The improved algorithm supports rational application of energy resources and raises their power efficiency.

Key words: hybrid system, wind-power installation, photovoltaic system, fuzzy logic, meteorological forecast, power flows controlling.

INTRODUCTION

Application of renewable energy sources, as an alternative for energy of fossil energy carriers, helps solution of two global problems, i.e. ecological and energy. Ecological problem is revealed in decrease of the intensity of growth of global warming by slowing of the rate of greenhouse effect spreading, which is caused by exhausts of dangerous substances of power-generating plants. The plants use fossil carbohydrates and, emitting the exhausts in the atmosphere, make harmful effect on the environment, causing deterioration of population health. Speaking about power problems, it is focused on support of sustainable development of power engineering by substituting of fossil energy carriers with renewable energy sources, particularly solar and wind.

A relatively small density of power flow (approximately 1000 W/m^2) and substantial irregularity of income are the main limiting factors of application of such available renewable sources as solar and wind energy [1]. It mainly deals with the systems of self-generated power supply for the objects, which are distant from central energy networks. Power supply systems, using solar and wind energy as the primary source of power, are characterized by scholastic character of their supply and application, i.e. seasonal, daily and casual. The last one is forced by climatic and weather changes [2].

MATERIAL AND METHODOLOGY

Continuous researches argue asynchronous supply of solar and wind energy, supporting less irregularity of total power supply under conditions of their combined application at hybrid power systems [3].

Scientists of different countries carry out researches concerning argumentation of a rational structure of hybrid power systems, operating on the base of wind and solar energy [4-11].

In most cases, the hybrid systems use energy storage devices, which substantially increase cost of the systems and reduce their total efficiency [12, 13].

Besides, at such hybrid systems, it is necessary to expect a possibility of use power surplus for power supply of technological processes, unregulated in time, e.g. heating of water in accumulator boxes by means of tubular heating elements; water lifting of the systems of water supply objects, transformation into mechanical energy, etc. [14, 15].

It is worth mentioning that, at hybrid systems with application of solar and wind energy, controlling of power flows is done without short-period forecast of weather conditions, influencing the algorithm of power flows controlling and regimes of thermal and electric energy accumulation.

Efficiency of application of short-period forecast of meteorological situation is in the fact that the system of accumulation and current extraction of energy should give an opportunity of its acceptance under favorable forecast. Thus, current application of energy for technological needs can be done under partial use of energy from accumulating systems.

Transfer of the energy into the central energy network is the best variant to accumulate the energy, produced by the system. However, at autonomous and semiautonomous systems of power supply, accumulating of the produced energy should be solved by application of electric, thermal, mechanic, gravitational and other types of storage devices.

Use of energy surplus for performance of technological operations, which are unregulated in time, e.g. for lifting of water in water tank towers or accumulation of it in reservoirs of non-tower water tanks, splitting into food stock, e.g. forage, forcing of air supply

into receivers, etc. is one of the efficient ways of energy accumulation. Using electric boilers for hot water supply or in case of thermal accumulators, it is reasonable to transform surplus of electric energy into heat. Reverse process is inefficient because of low efficiency of transformation processes. Usually, in boilers with electric heater of water, operation of a tubular heating element is supplied by built-in system of temperature support, regardless of the external conditions.

According to the above-mentioned, it is necessary to apply adaptive algorithms of the system operation, which are based on the results of short-period forecast of natural conditions with application of the instrument of fuzzy logic in order to raise efficiency of performance of hybrid power system on the base of wind and photovoltaic installations with an intelligent system of controlling for power flows.

RESULTS OF TEST AND DISCUSSION

To reduce misbalance between power income and needs for its use at hybrid systems of power supply, one makes intelligent controlling of power flows. The highest efficiency can be achieved by introduction of a link of short-period forecast of weather conditions into the operating system. The forecast is made on the base of processing of meteorological information, obtained from givers of barometric pressure, air temperature, level of solar radiation and wind flow with the reference to real time. For instance, transformation of electric energy into thermal one is reasonable only in case of high probability of windy and sunny weather in the nearest future.

An approximate power balance of the hybrid system $\overline{\Delta E_t}$ with application of solar and wind energy for supply of thermal and electric needs of an object is described by the following system of equations

$$\overline{\Delta E_t} \begin{cases} \Delta\overline{E_t^{unf}} = \sum_{i=1}^{n}\left(\overline{E_{en}^i} + \overline{E_{pv}^i} + \overline{E_w^i} + k_{dd}\cdot\overline{E_{ac}^i} - \overline{E_{ce}^i}\right) \\ \Delta\overline{E_t^{fav}} = p(fwf)\cdot\sum_{i=1}^{m}\left(\overline{E_{en}^i} + \overline{E_{pv}^i} + \overline{E_w^i} - k_{dd}\cdot\overline{E_{ac}^i} - \overline{E_{ce}^i}\right) \end{cases},$$

where: $\Delta\overline{E_t^{unf}}$, $\Delta\overline{E_t^{fav}}$ – an average level of the system power balance for the periods of unfavorable and favorable weather conditions, respectively, kWh;

$\overline{E_{en}^i}$ – an average level of energy, obtained from external electrical networks. kWh;

$\overline{E_{pv}^i}$, $\overline{E_w^i}$ – an average level of power income from photovoltaic and wind installations, respectively, kWh;

$\overline{E_{ac}^i}$ – an average level of energy of an accumulation system: used (sign “minus”) and supplied (sign “plus”), kWh;

k_{dd} – level of available depth of application of accumulation system energy; for electric accumulating storage devices – available depth of discharge; for thermal accumulating devices – the lowest temperature of heat carrier medium;

$\overline{E_{ce}^i}$ – an average level of energy consumption, kWh;

$p(fwf)$ – probability of favorable weather forecast, %.

Probability of favorable weather forecast, which influences formation of the algorithm of controlling for power flows of a hybrid power system, is one of the key components of energy balance.

Nowadays, there are two main methods of weather forecasting of small and medium advanced time, i.e. synoptic and computational. Better results concerning the forecast reliability can be achieved by application of computational method. However, the method expects application of complicated mathematic models in the form of a system of differential equations of high dimension and thus, numerous calculations and complicated, still not developed, algorithms of the solution, causing application of numerous methods of solution, which can include substantial deviations. Besides, one should note that wind flow is characterized by considerable space turbulence. Thus, impressive sizes of wind rotating elements force their elements operate spontaneously under different wind conditions and cause complexity in development of the models for investigation of dynamic characteristics of wind-power systems.

Main reasons for inaccuracy of numerous forecasts include incomplete physical scheme of the forecast, improper consideration of influencing factors in it, insufficient number or accuracy of observations, approximate way of the equations solution.

Experience of national and foreign scientists proves that such kinds of problems should be solved with application of the algorithms of fuzzy logic, which do not need complicated mathematic models and their solution [16-19].

Measured temperatures and humidity of air, air pressure, speed and direction of wind, level of solar radiation and dynamics of their changes in time are the input parameters for the forecasting link.

Applying algorithms of fuzzy logic on the base of data, obtained from the receivers concerning parameters of the environment and calculated tendencies of their change in time, one can form a short-period forecast of natural conditions with application of expert conclusions by specialists in the field of meteorology, which make base of rules and knowledge of Fuzzy Logic system [20-22].

Structural scheme of the hybrid system is characterized by similarity of power flows, which are transferred by power bus line with appropriate power keys, managed by controlling signals, which are formed with consideration of short-period forecast of weather conditions of Fuzzy Logic controller. It is fulfilled on the base of software product National Instrument LabVIEW with application of the instruments "Control Design & Simulation → Fuzzy Logic → FL Fuzzy Controller.vi".

According to the structure of Fuzzy Logic controller, input signals from the receivers of air pressure and air humidity are fuzzified and output information is defuzzified in order to measure probability of favorable weather forecast with appropriate formation of the signals of power key controlling by developing of corresponding terms with their membership functions at "Variables" tag of the work window of "Fuzzy Logic Designer" graphic pallet. They are presented at the fig. 1.

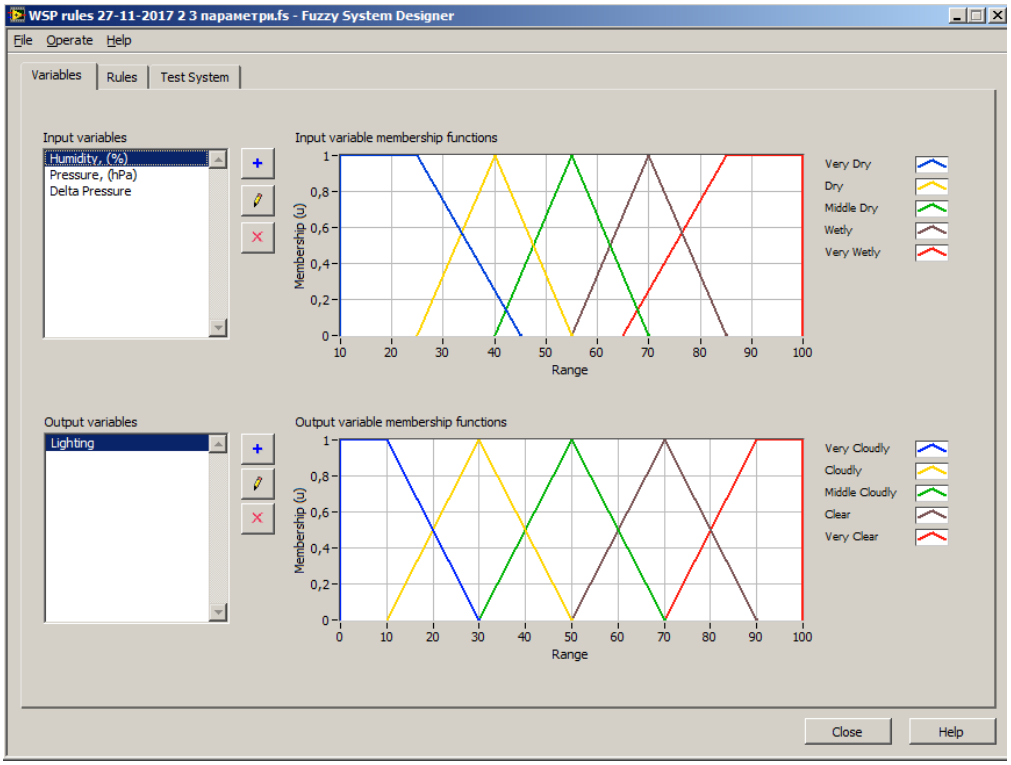

Fig.1. Fragment of the desktop of "Variables" tag of "Fuzzy Designer" graphic pallet

Not only absolute values of the expected input parameters, but also dynamics of their changes in time, are very important for weather forecast. Thus, in the list of variables, it is necessary to develop membership functions of speeds of their change in time, which are formed on the base of the data, obtained at different time periods.

At the next stage, in "Rules" tag, one develops a base of rules for information processing according to the algorithms of fuzzy logic with consideration of main combinations of input and output signals (fig. 2). Database of rules is an instrument, which performs the function of short-period forecast of weather conditions on the base of expert conclusions by meteorology specialists.

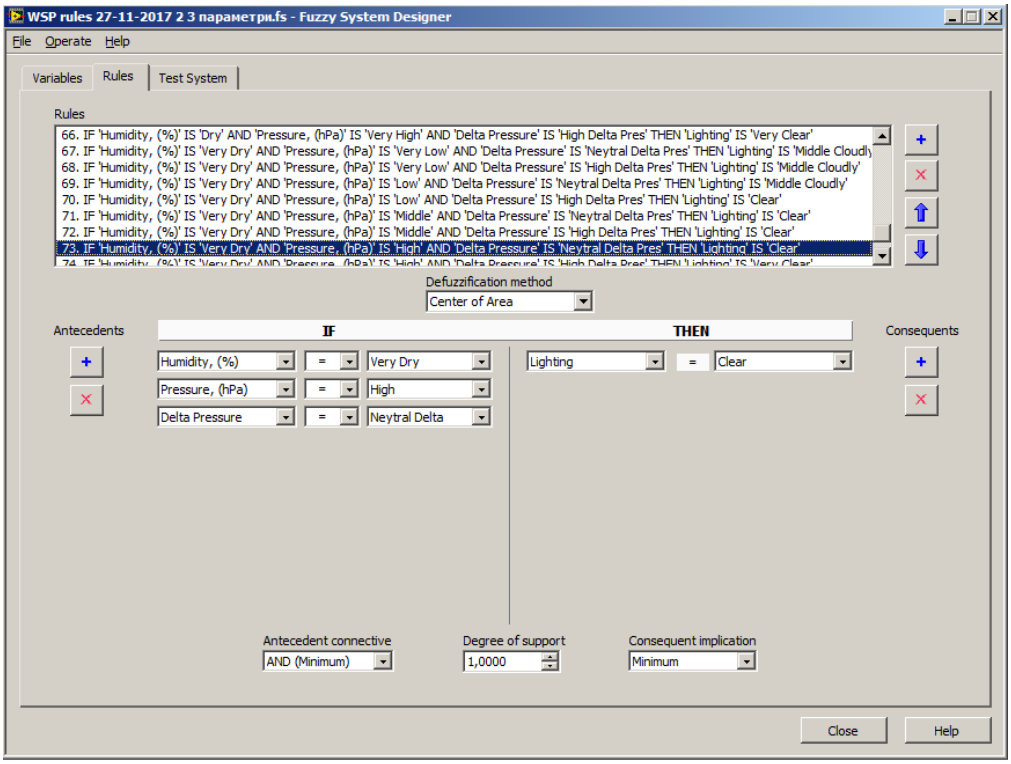

Fig. 2. Fragment of the work window of formation of the base of information processing rules

Applying "Defuzzification method" popup window, output algorithm is chosen in the same window. "Center of Area" method of output (so-called "Mamdani" method of output) is used in the present controller.

Process of arrangement of Fuzzy Logic controller is performed with application of "Test System" tag, where "Input/Output" window depicts response surface of the probability of favorable weather forecast from the values of input figures (fig. 3). Besides, the research expects visualization of input and output figures and current meaning of the rules, regulating their processing.

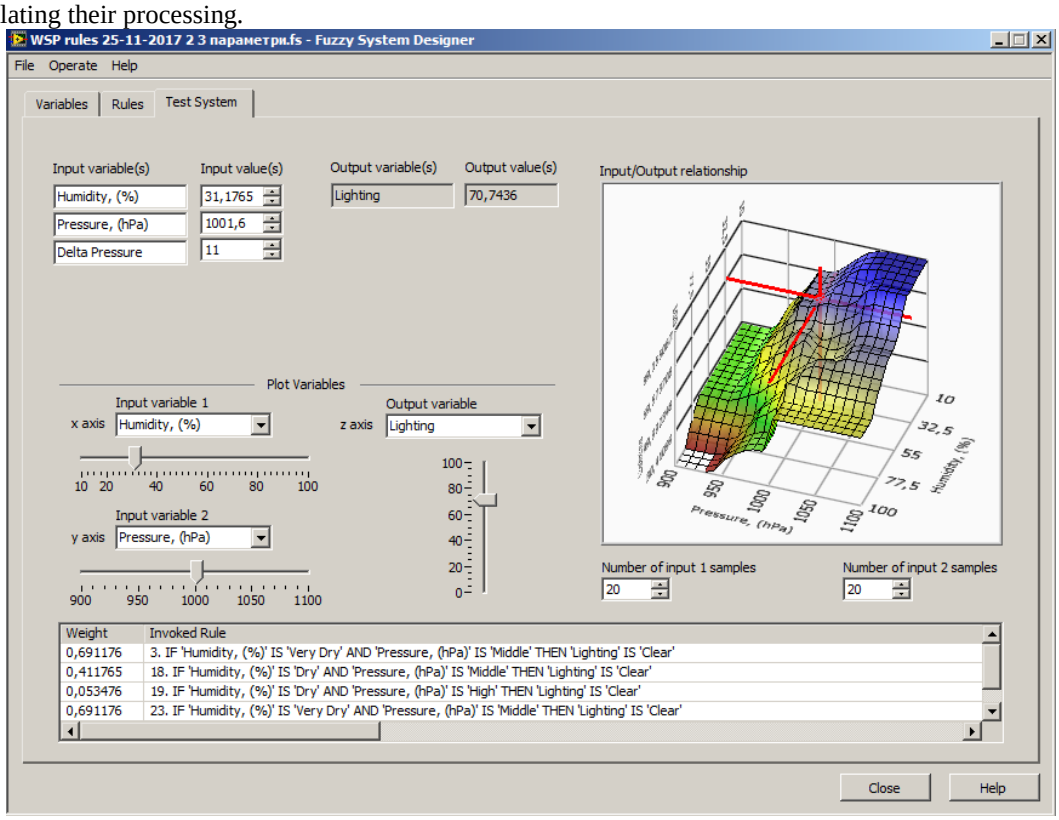

Fig. 3. Fragment of a work window of the system arrangement

According to the results of the formed response surface, experts estimate correspondence of the forecast to input signals and, if necessary, make correction of the rules and membership functions for each of the signals and their terms.

At the exit of Fuzzy Logic controller, the researchers obtain values of probability of the prospects of favorable weather forecast, which makes base for formation of the signals of external devices operating in a clear form.

In the hybrid power system, executive appliances are presented by a set of corresponding power keys:

- adjustment of photovoltaic panels and rectifier of a power generator wind power installation to a storage battery charge unit;
- adjustment of photovoltaic panels and rectifier of a power generator wind power installation to tubular heating elements of water-heating appliance;
- adjustment of a storage battery to tubular electric elements of water-heating appliance;
- adjustment of photovoltaic panels and rectifier of a power generator wind power installation to a self-commutated inverter;
- adjustment of a storage battery to a self-commutated inverter;
- adjustment of a thermoelectric pump and water-lifting pump to a storage battery.

Key elements of each of the power channels include optothyristors of appropriate voltage and current, which supply change of power flow capacity by pulse-width modulation. Besides, application of optothyristors supplies galvanic isolation of power circles and operating circles.

Mode of operation of the hybrid power system should be subjected to the following priorities: wind-power installation is always loaded on tubular heating elements of an accumulator box by means of appropriate controller; solar photovoltaic system is always loaded on tubular heating elements of an accumulator box by means of its controller; a storage battery can be charged in case of its discharge, regardless of weather conditions; load of a consumer is always charged from a storage battery by transit in order to minimize losses of electric energy in “charge-discharge” regime due to its low efficiency; in case of no need for electric energy by consumers, under conditions of complete heating of an accumulator box and energy surplus from solar photovoltaic and wind power installations, it is possible to direct electric energy to a drive component of heat pump and/or water-lifting installation; Fuzzy Logic controller supplies formation of probability of weather forecast, which influences changes of the algorithm of redistribution of power flows of the hybrid system.

In general, considering the above-mentioned, one can determine two variants of operating modes of a hybrid power system, i.e. operation modes under probability of favorable and unfavorable weather forecast.

Particularly, if there is a high probability of favorable weather forecast, there is a permission for complete use of the energy of power accumulator; operation of tubular heating elements of water heating in an accumulator box of the system of hot water supply from power networks is locked; photovoltaic and wind-power installations are adjusted to the load with transit of a storage battery; application of electric energy from an external power network is minimized up to the moment of the storage battery discharge; in case of surplus of electric energy from wind and solar installations, the system is additionally loaded by adjustment of thermal pump and/or water-lifting installation.

If there is a high probability of unfavorable weather forecast, consumers continue to get power from wind-power and photovoltaic installations with transit of a storage battery, not allowing its discharge; lack of energy from renewable sources of energy in a hybrid system is, thus, supplied by its consumption from an external power network.

Scheme of the mentioned algorithm of operation of a hybrid system with Fuzzy Logic controller of forecasting of weather conditions probability is presented by the fig. 4.

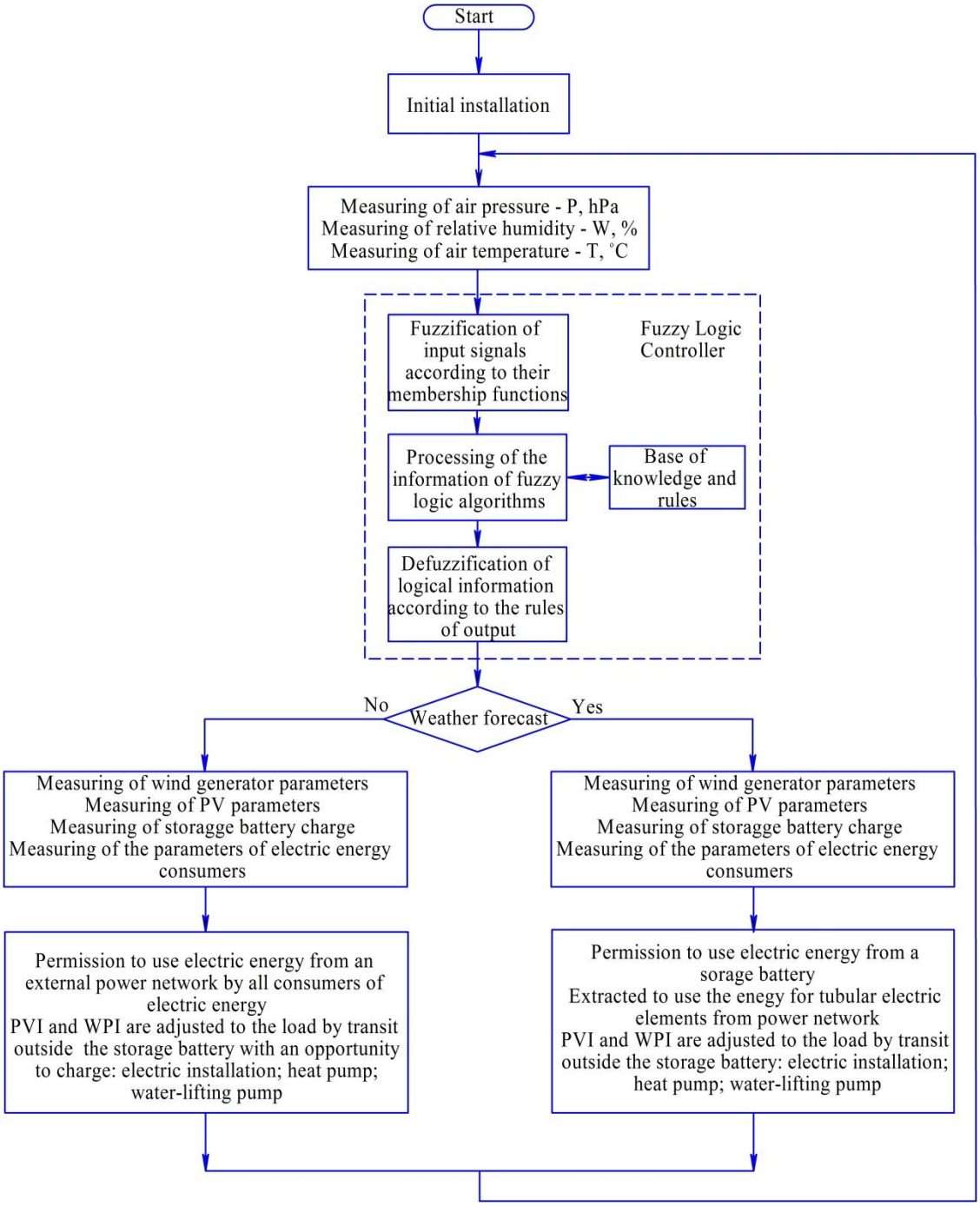

Fig. 4. Algorithm of controlling of operation modes of the hybrid system with application of Fuzzy Logic controller of forecasting of weather conditions probability

CONCLUSIONS

According to the research, application of Fuzzy Logic controller to forecast probability of weather conditions improves efficiency of operation of the hybrid system of power supply with application of wind-power and photovoltaic installations by means of an intelligent component in the system of power flows controlling. Optimal controlling of power flows is supported by minimization of consumption of electric energy from an external power network and adaptation of accumulating systems to the next period of energy extraction under high probability of favorable weather forecast, i.e. minimization of losses of the energy, produced by wind-power and photovoltaic installations.

REFERENCES

1. **Mukund R. Patel. 1999.** Wind and Solar Power Systems. CRC Press. Boca Raton, London, New York, Washington, D.C. 350.
2. **Syrotyuk S. 2011.** Mathematical model of system of complex use of renewable energy sources in technological processes of agrarian production. Annals of Warsaw University of Life Sciences – SGGW: Agriculture (Agricultural and Forest Engineering). Warsaw. № 58. 79-84.
3. **Boyarchuk V., Syrotyuk V., Syrotyuk S., Halchak V. 2012.** Concordance of power providing of objects with potential of renewable energy sources in relation to western region of Ukraine. Scientific herald of the Tauria State Agrotechnological University. Issue 2, Vol. 4. Melitopol. 117–124. (In Ukrainian)
4. **Mai Ngoc Thang, Ha Van Muon, Kamaev V., Shcherbakov M., Thay Quang Vinh. 2013.** Simulation and optimal control of intelligent hybrid renewable energy system. / Management of large systems. Vol. 46. Moscow: ICS of RAS. 293-309. Access mode: http://ubs.mtas.ru/search/search_results_ubs_new.php?publication_id=19167&IBLOCK_ID=20. (In Russian)
5. **Syrotyuk V., Syrotyuk S., Halchak V. 2014.** Fuzzy Logic controller solar hot water system. Motrol. Lublin. Vol. 16. № 4. 32-37. (In Russian)
6. **Syrotyuk S. 2012.** Management by modes of operations of autonomous wind-electric setting. Motrol. Lublin. Vol. 14. 126-130. (In Russian)
7. **Wojcicka-Migasiuk D., Chochowski A., Syrotyuk S. 2014.** The local hybrid power system. Motrol. Commission of motorization and energetics in agriculture. An international journal on operation of farm and agri-food industry machinery. Vol. 16. No 4. Lublin – Rzeszow. 105-111.
8. **Chochowski A., Czekalski D., Obstawski P. 2009.** Monitoring of renewable energy sources hybrid system operations. Przegląd Elektrotechniczny 85 (8). 92–95.
9. **Muttakka S. Annigeri, Dr. Suresh H. Jangamshetti, 2017.** Techno-economic Assessment of Hybrid Energy System for Electrification of a Farmhouse in North Karnataka, India. J. Energ. Technol. Res. 1, 1. 19-27. Access mode: https://www.researchgate.net/publication/312418811_Techno-economic_Assessment_of_Hybrid_Energy_System_for_Electrification_of_a_Farmhouse_in_North_Karnataka_India
10. **Maouedj R., Mammeri A., Draou M. D., Benyoucef B.. 2015.** Techno-economic Analysis of a Standalone Hybrid Photovoltaic-wind System. Application in Electrification of a House in Adrar Region. Energy Procedia. Vol. 74, August. 1192-1204. Access mode: http://www.sciencedirect.com/science/article/pii/S1876610215015301
11. **Thilo Bocklisch, Johannes Lindner, 2016.** Technical and economic investigation and comparison of photovoltaic – wind energy – hybrid systems with battery and heat-storage path. Energy Procedia 99. 350 – 359. Access mode: http://www.sciencedirect.com/science/article/pii/S1876610216310864
12. **Antipov E. 2015.** Combined system energy consumers using traditional and alternative sources of energy and batteries. "Power engineering and automation", № 1, Kiev. 72-81. (In Ukrainian)
13. **Bykov M. A. 2013.** Integrated system WP-PV as a source of power supply for various branches of agriculture. Scientific works of the Southern Branch of the National University of Bioresources and Natural Resources of Ukraine "Crimean Agrotechnological University". Kiev. Vol. 156. 121-128. Access mode: http://nbuv.gov.ua/UJRN/Npkaut_2013_156_21.
14. Electronic resource. Access mode: https://www.atmosfera.ua/uk/rishennya/sistemi-fotoelektrichnogo-garyachogo-vodopostachannya/ (In Ukrainian)
15. **Borowy, B.S., Salameh, Z.M., 1996.** Methodology for optimally sizing the combination of a battery bank and PV array in a wind/PV hybrid system. IEEE Transactions on Energy Conversion 11 (2), 367–373.
16. **Gostev V. I. 2008.** Fuzzy controllers in automatic control systems. Kiev: Radioamator, 972. (In Russian)
17. **Lavanya N., Pasha J. 2014.** To Improve the Active Power in Wind Power Generation by Using Fuzzy Logic Controller. International Journal of Engineering Research & Technology (IJERT). Vol. 3 Issue 1, January, 92-96.
18. **Owino L. A., Nyakoe G. N. 2012.** Maximum Power Tracking in Horizontal Axis Wind Turbine Using Fuzzy Logic Controller. International Journal of Advances in Engineering, Science and Technology (IJAEST). Vol. 2 No. 2 May-July, 131-138.
19. **Vignesh P. 2015.** PMSG Based Wind Power Regulator Using Fuzzy Logic Controller. International Journal of Innovative Research in Science, Engineering and Technology. Vol. 4, Special Issue 6, May, 1303-1309.
20. **Shevri F., Geli F.** Fuzzy Logic. Access mode: http://www.academia.edu/6528962/_Schneider_Electric
21. LabVIEW: PID and Fuzzy Logic Toolkit User Manual. Texas, 2009. 126. Access mode: http://www.ni.com/pdf/manuals/372192d.pdf.
22. **Kravets P., Kirkalo R. 2009.** Decision-making systems with fuzzy logic. Journal of National University "Lviv Polytechnic". № 650. 115 – 123.

ГИБРИДНАЯ СИСТЕМА ПИТАНИЯ С ПРИМЕНЕНИЕМ ЭНЕРГИИ ВЕТРА И СОЛНЕЧНОЙ ЭНЕРГИИ

Сергей Сыротюк, Валерий Сыротюк, Борис Болтянский

Аннотация. Основываясь на анализе операционных систем гибридных ветровых и солнечных фотогальванических установок для электроснабжения отдаленных объектов, авторы статьи разработали структуру и алгоритм работы интеллектуальной гибридной операционной системы. Применение контроллера нечеткой логики с функцией краткосрочного прогноза естественных условий является особенностью разработанной системы. Основываясь на системе, можно выполнить коррекцию алгоритма работы гибридной системы. Улучшенный алгоритм поддерживает рациональное использование энергетических ресурсов и повышает их энергоэффективность.

Ключевые слова: гибридная система, ветроэнергетическая установка, фотогальваническая система, нечеткая логика, метеорологический прогноз, управление потоками энергии.