UDC 004.8(045)
DOI:10.18372/1990-5548.61.14219

[1]V. M. Sineglazov,
[2]A. T. Kot

COMPUTER-AIDED DESIGN OF HYBRID POWER SYSTEMS OF UKRAINE

[1]Aviation Computer-Integrated Complexes Department, Faculty of Air Navigation Electronics and Telecommunications, National Aviation University, Kyiv, Ukraine
[2]Technical Cybernetic Department, National Technical University of Ukraine "Ihor Sikorsky Kyiv Polytechnic Institute," Kyiv, Ukraine
E-mail: svm@nau.edu.ua ORCID 0000-0002-3297-9060, [2]anatoly.kot@gmail.com

Abstract—*It is shown that the problem of hybrid power systems creation is very important for Ukraine. The high quality of this problem solution can be achieved with help of computer-aided design systems. It is considered the modern. computer-aided design systems and executed their analysis. It is shown that they have some disadvantages. To overcome them it is developed a new hybrid genetic algorithm of unconditional multicriteria optimization, which is based on a new approach of equivalent transformation of conditional optimization problem into unconditional with further "curering" the Pareto optimal points which are located outside of area formed by restrictions. It is considered the examples of computer-aided design of hybrid power systems for different regions of Ukraine.*

Index Terms—hybrid renewable energy system; computer-aided design; genetic algorithm.

I. INTRODUCTION

Depletion of traditional types of energy resources, aggravation of a negative environmental impact of energy sector and, consequently, strengthening of environmental standards, significant fluctuations in energy prices, objective to strengthen energy and economic security, the politicization of energy supplies and other factors have led to the urgent need to revise current state in the energy sector and look for opportunities for its modernization and policy review [1].

Ukraine is one of many countries that are suffering from all of these problems. Its dependence on the import of expensive energy resources leads to considerable socio-economic problems. An extremely high degree of the infrastructure depreciation (in particular the one of energy sector) and consequently a very low efficiency of energy resources use are the factors explaining the position of Ukraine among the countries with high indexes of energy intensity of the economy.

Energy is essential to our society not only to ensure our quality of life but also for our economy. The demand of electrical energy has developed largely across the whole world; in every country, in every society we live. This demand has been stimulated by the relative ease with which electricity can be generated, distributed, and utilized, and by the great variety of its applications.

Due to intermittent natural energy resources and energy resources seasonal unbalance, a PV-wind hybrid electrical power supply system was developed for many remote locations where a conventional grid connection is inconvenient or expensive [2]. With the fast progression of renewable energy markets, the importance of combining different sources of power into hybrid renewable energy system (HRES) has gained more attraction. These hybrid systems can overcome limitations of the individual generating technologies in terms of their fuel efficiency, economics, reliability and flexibility. A hybrid energy system consisting of energy storage, renewable and nonrenewable generation can alleviate the issues associated with renewable uncertainties and fluctuations. Large number of random variables and parameters in hybrid energy system requires an optimization that most efficiently sizes the hybrid system components to realize the economic, technical and designing objectives.

II. DEVELOPMENT OF A HYBRID RENEWABLE ENERGY SYSTEM

Selection of technology and unit of measurement. At this stage of the design, the configuration of the system is synthesized, that is, it turns out what types of technology generation will be highlighted and integrated for the hybrid system. This is a very important aspect in the development, as there are usually many alternatives, the capabilities associated with the individual components will be included in the hybrid power system [3].

For this hybrid power system, this stage of development should determine:

– renewable energy system type;

– quantity and capacity of renewable energy sources to be installed;

– necessity of back unit use such as the diesel generator;

– possibility of energy storage system integration;

– hybrid renewable energy system is offline or network-connect.

III. Problem Statement

The choice of technology depends on the availability of renewable resources for a specific place where a system in which weather conditions play an important role should be established. Based on weather statistics (hourly data), for various studies of probable renewable sources using optimization to obtain optimal configuration. Then the number and size of optimized components to get a cost effective, efficient and reliable system.

Component dimensions are important and widely studied, for example. Several factors or restrictions directly affect the size of system components, such as system economics, the absence of greenhouse emissions and the reliability of the system. Excess of the components can lead to high cost of the system and, consequently, the system can become economically unviable. On the other hand, the lack of components will reduce the initial cost, but this will not ensure the reliability of the system. For a specific load, different criteria can be applied to a set of system components based on the goals to be achieved. Some of the criteria that are mainly considered when designing a hybrid power system [4]:

– reliability criteria: loss of load probability (LOLP), loss of power supply probability (LPSP);

– system cost criteria: system cost criteria may include total energy costs, power costs and social costs;

– performance optimization criteria, which may include fuel economy, emission reductions, reserve power and elimination of excessive generation of electricity. The development of hybrid energy systems has been extensively studied, and numerous optimization methods have been used to optimize the economic and reliable design of hybrid systems, such as linear programming, genetic algorithms, etc.

IV. Review of Known Approaches

Optimum configuration can be found by using computer simulations, by comparing the performance and energy production cost of different system configurations. Several software tools are available for designing of the hybrid systems, such as HOMER, HYBRID2, HOGA and HYBRIDS.

Hybrid Optimization Model for Electric Renewables (HOMER) is user friendly software produced by national renewable energy laboratory. It uses hourly simulations and environmental data for the assessment of the hybrid renewable energy system and performs optimization based on Net Present Cost. HOMER has been used extensively in various case studies HOGA is hybrid system simulation software developed by the Electric Engineering Department of the University of Zaragoza Spain.

HYBRID2 is the hybrid system simulation software developed by Renewable Energy Research Laboratory (RERL) of the University of Massachusetts. The simulation is carried out from 10 min-1h intervals. Hybrids is produced by Solaris Homes, It is Microsoft Excel spread sheet-based assessment application and design tool. Unlike HOMER, HYBRIDS can only simulate one configuration at a time.

General problems occurring with the elements of hybrid systems are not only specific for hybrid systems, but also common for the use of the single elements.

The HOMER micropower optimization model is a computer model to assist in the design of micropower systems and to facilitate the comparison of power generating technologies across a wide range of applications. HOMER allows the designer to compare many different design options based on their technical and economic merits.

It may employ any combination of electrical generation and storage technologies and may be grid-connected or autonomous, meaning separate from any transmission grid.

HOMER performs three principal tasks [5]: simulation (models the performance of a particular micropower system configuration to determine its technical feasibility), optimization (simulates many different system configuration to determine the best one which satisfies the technical constraints at the lowest life-cycle cost) and sensitivity analysis (helps assess the effects of uncertainty or changes in the variables which impossible to control).

The main quality of HOMER is possibility to simulate a wide variety of micropower system configuration, comprising any combination of different energy plants. The system can be grid connected [5].

The disadvantages of this approach include: absence of precise mathematical models of different energy plants under presence of external disturbunces.

V. Problem Solutions

There are several optimization techniques available for the hybrid system, such as graphical construction methods, probabilistic approach, iterative technique, artificial intelligence methods, and multi-objective design. In this work it is chozen multi-objective design.

In accordance to the given problem statement this task relates to the multicriteria optimization. For the solution of given optimization problem with the purpose of local extremum overcome it is efficient to use a multicriteria evolutional algorithm which in its general form has a number of disadvantages.

In particular under the solution of problems with restrictions the received solutions aren't always satisfactory:

– they can not contain the point of conditional extremum;

– resulting points can be scattered in searching space;

– part from the found solutions can lie outside the settled area.

That a decision the set problem, every limitation, became possible the methods of multicriterion optimization transformed in a separate objective function and, therefore the task of the constrained optimization (with one or a few criteria – objective functions) in the total is taken to the absolute multicriterion task.

However, as a result of such approach part of the found optimal points can not belong to the set area determined by limitations. For the removal of this defect it is suggested to treat (clarification) the nondominated points got after the stop of genetic algorithm, by means of Pareto local search algorithm.

Features of developed hybrid genetic algorithm:

– transition from limitations to the additional criteria;

– use of conception of Pareto-optimality, domination and density of solutions for the calculation of solution fitness function;

– choice size of population and number of iterations;

– adaptive determination of probability of crossing and mutation;

– use of the special type of crossover – neighborhood crossover;

– support of external set of individuals (archive) for realization of elitism;

– clusterization for liquidation of clots of points and increase of representativeness of solution;

– "treatment of chromosomes" in area of initial limitations for clarification of solutions.

VI. The Principle of Choosing the Area of Ukraine to Create a Hybrid Power System

To select a location for creating a hybrid power plant in Ukraine, it is considered places where renewable sources of energy, such as solar energy and wind energy are presented. It is also an advantage to choose the location of water objects presence. One of the main advantages for a hybrid power plant will be access to grid electricity. Ukraine is among the countries with remarkable potential in solar energy.

Ukraine is among the countries with remarkable potential in solar energy. Annual Average of Global Horrizontal Irradiance 3.06 (kW·h/m²/day). The highest solar radiation was estimated at (6.02 kWh/m^2) in July while the lowest was (1.12 kWh/m^2) in December.

The annual average wind speed for the Ukraine is (5.5 m/s) with the anemometer located at height 20 m. The monthly average wind speeds are calculated. It indicates that the annual average wind speed is (5.5 m/s). It can be also observed that in December to February the wind speed is lower than the annual average wind speed.

It was chosen such places of Ukraine: Khmelnytsky, Kyiv, Donetsk and area near the Carpathians because they meet the requirements of hybrid power construction.

VII. Experimental Results

A. For Khmelnitskiy (Figs 1–6).

Average Load: 78 kWh/day.

Annual Average of Global Horrizontal Irradiance 3.06 (kW·h/m²/day).

Average annual temperature, ° C +7.3.

Wind speed: Annual Average 5.13 (m/s).

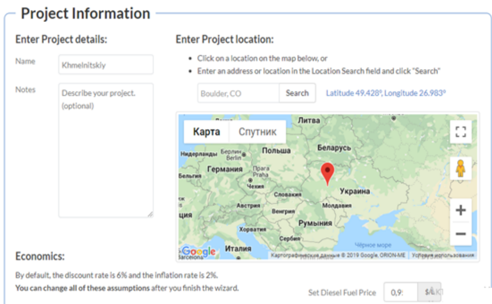


Fig. 1. Project Information

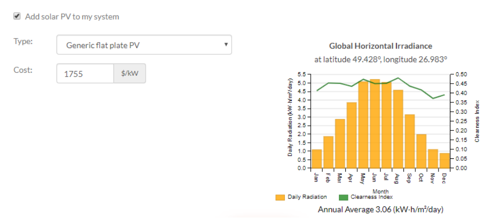


Fig. 2. Solar Photovoltaic (PV)

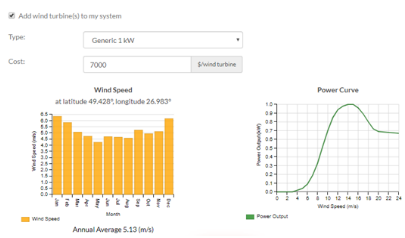


Fig. 3. Wind Turbine

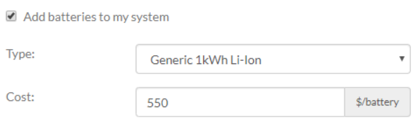


Fig. 4. Battery

⚠	Generator	Wind	PV	Converter	Battery	Dispatch	Initial Capital	Operating Cost	COE	NPC ($) ▲	Fuel
	13	16	23.6	6.0	9	CD	$53,100	$4,512	$0.28	$124,171	2,682
	13		28.8	8.0	10	CD	$48,323	$5,931	$0.32	$141,747	4,104
	13	31		7.0	10	CD	$37,515	$8,196	$0.37	$166,620	5,410
	13			8.2	10	CD	$14,456	$12,546	$0.47	$212,084	9,625

Fig. 5. Experimental results

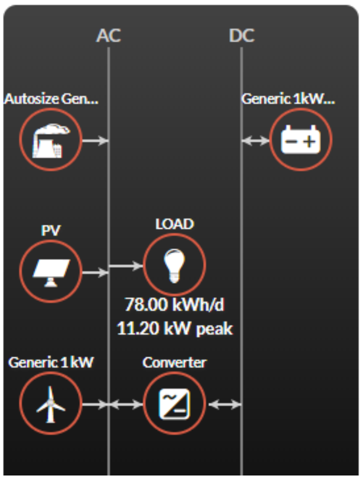


Fig. 6. Scheme of the project for Carpathian Mountains

B. Area near the Carpathians (Figs 7–11).

Average Load: 76 kW·h/day.

Annual Average of Global Horrizontal Irradiance 3.16 (kW·h/m²/day).

Wind speed: Annual Average 6.89 (m/s).

Average annual temperature + 8.5.

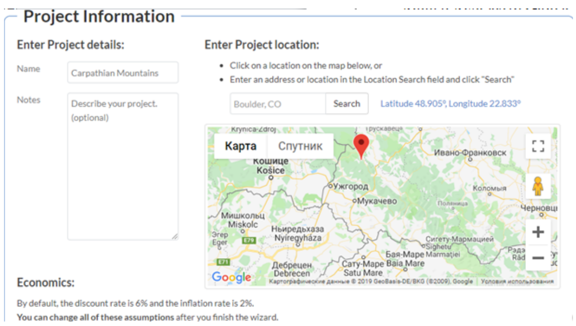


Fig. 7. Project Information

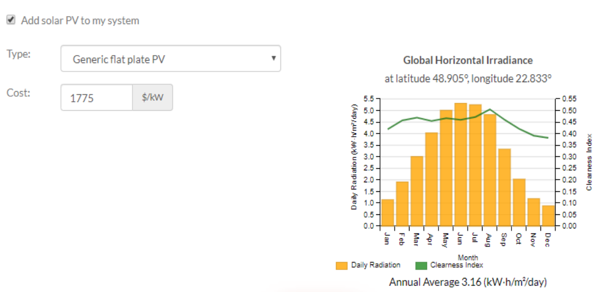
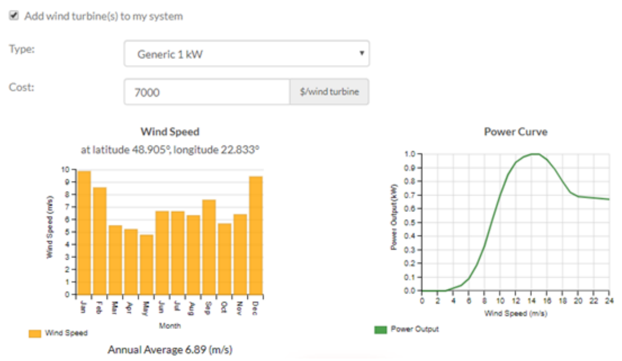


Fig. 8. Solar Photovoltaic



Fig, 9. Wind Turbine

⚠	Generator	Wind	PV	Converter	Battery	Dispatch	Initial Capital	Operating Cost	COE	NPC ($) ▲	Fuel
	13		21.3	7.9	10	CD	$52,191	$6,335	$0.35	$151,980	4,358
	13	1	20.8	8.1	10	CD	$58,338	$6,010	$0.35	$153,010	3,926
	13	2		8.0	10	CD	$28,395	$11,461	$0.48	$208,926	8,215
	13			8.8	11	CD	$15,203	$12,423	$0.48	$210,894	9,335

Fig. 10. Experimental results

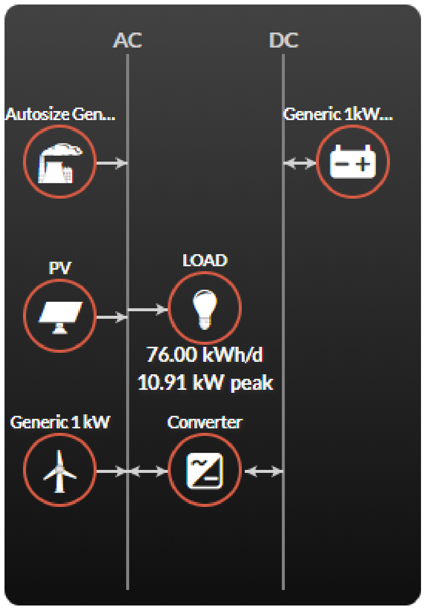


Fig. 11. Scheme othe Project

C. For Donetsk (Figs 12–15).

Average Load: 80kW·h/day

Annual Average of Global Horrizontal Irradiance 3.06 (kW·h/m²/day)

Wind Speed Annual Average 5.71 (m/s)

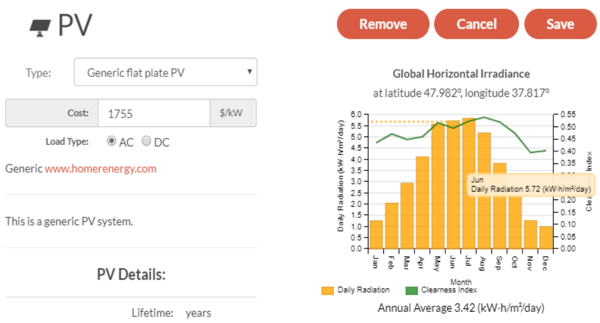


Fig. 12. Solar Photovoltaic

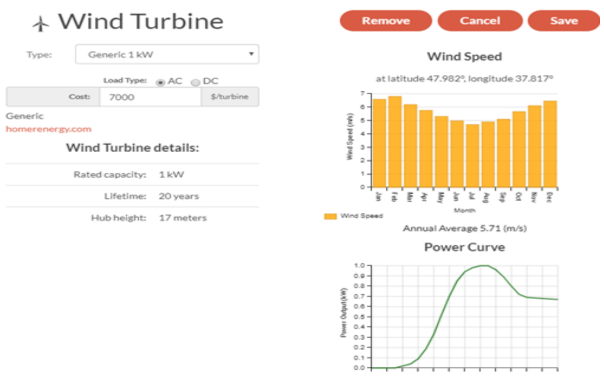


Fig. 13. Wind Turbine

⚠	Generator	Wind	PV	Converter	Battery	Dispatch	Initial Capital	Operating Cost	COE	NPC ($) ▲	Fuel
	13		19.9	9.7	12	CD	$50,915	$6,869	$0.35	$159,121	4,551
	13	1	20.8	8.0	10	CD	$57,818	$6,749	$0.36	$164,125	4,383
	13			8.9	11	CD	$15,231	$13,338	$0.49	$225,335	9,780
	13	1		8.9	11	CD	$22,215	$13,105	$0.50	$228,655	9,419

Fig. 14. Experimental results

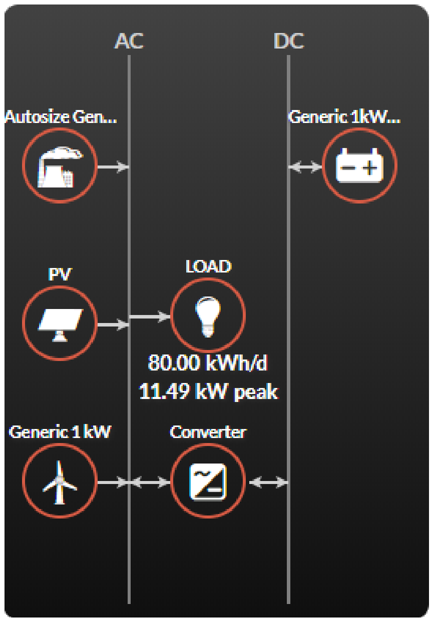


Fig. 15. Scheme of the project

D. For Kiev (Figs 16–20).

Average Load –91kW·h/day.

Annual Average of Global Horrizontal Irradiance 3.10 (kW·h/m²/day).

Wind Speed – Annual Average 4.18 (m/s).

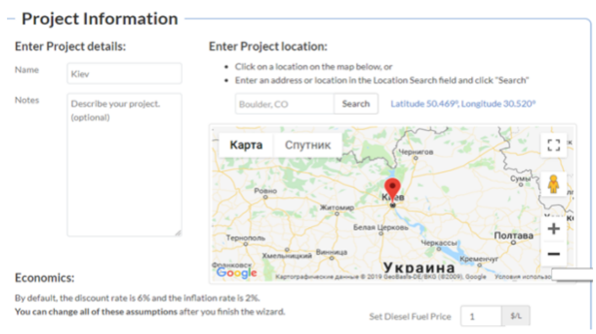


Fig. 16. Project Information

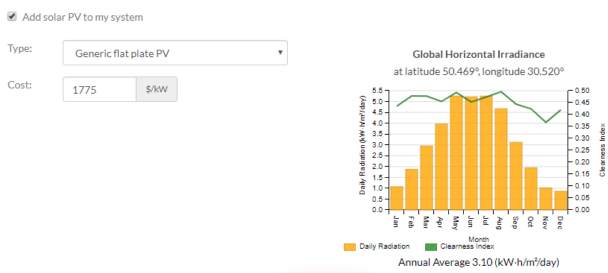


Fig. 17. Solar Photovoltaic

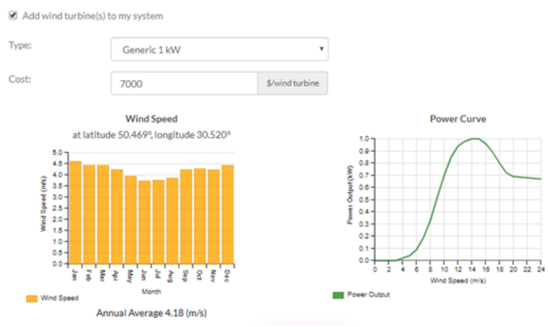


Fig. 18. Wind Turbine

⚠	Generator	Wind	PV	Converter	Battery	Dispatch	Initial Capital	Operating Cost	COE	NPC ($) ▲	Fuel
	15		26.8	9.4	12	CD	$64,555	$7,872	$0.36	$188,560	5,174
	15	1	26.6	9.8	13	CD	$71,845	$7,940	$0.38	$196,916	5,006
	15			9.3	12	CD	$16,880	$15,591	$0.50	$262,477	11,189
	15	1		10.8	13	CD	$24,901	$15,591	$0.52	$270,498	10,995

Fig. 19. Experimental results

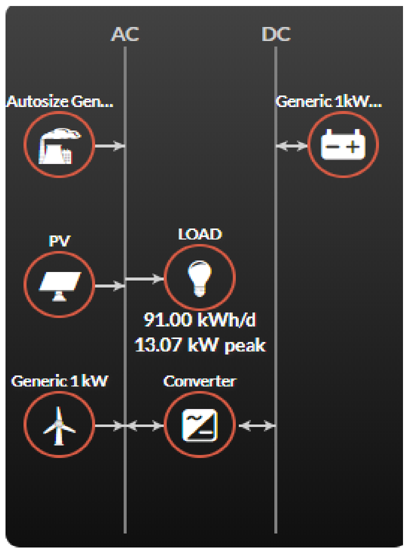


Fig. 20. Scheme of the project

IV. CONCLUSION

It is analyzed the situation with energy state of Ukraine. The necessity of hybrid energetic development is shown.

It is executed the review of several software tools for hybrid power stations design. It is shown the necessity of HOMER modernization. It is considered the examples of its application.

REFERENCES

[1] Nadeem Manhas, Gagan Deep Yadav, "A Review on Configurations, Control, and Future of Hybrid Renewable Energy Systems for Electric Power Generation," *International Research Journal of Engineering and Technology (IRJET*. Volume: 03 Issue: 06 pp. 1018–1025, June-2016

[2] Yasser Maklad, "Sizing and Costing Optimisation of a Typical Wind/PV Hybrid Electricity Generation System for a Typical Residential Building in Urban Armidale NSW, Australia" International Journal of Energy Economics and Policy, Vol. 4, No. 2, 2014, pp.163-168.

[3] Francisco Joser Contreras Cordero, Optimization of Hybrid Renewable Energy Systems. A thesis submitted in conformity with the requirements for the degree of Master of Applied Science Graduate Department of Mechanical and Industrial Engineering University of Toronto, 2015, 49 p.

[4] Binayak Bhandari, Kyung-Tae Lee, Gil-Yong Lee, Young-Man Cho, and Sung-Hoon Ahn, "Optimization of Hybrid Renewable Energy Power Systems: A Review," International Journal of Precision Engineering and Manufacturing-Green Technology, vol. 2, no. 1, pp. 99–112, January 2015.

[5] Swati Negi and Lini Mathew, "Hybrid Renewable Energy System: A Review," International Journal of Electronic and Electrical Engineering. ISSN 0974-2174, Volume 7, Number 5 (2014), pp. 535-542, © International Research Publication House http://www.irphouse.com.

[6] N. I. Pakulov, *The majority principle of building reliable nodes and devices.*: Sov. radio, 1974, 184 p. (in Russian).

Received September 19, 2019

Sineglazov Victor. orcid.org/0000-0002-3297-9060
Doctor of Engineering Science. Professor. Head of the Department.
Aviation Computer-Integrated Complexes Department, Faculty of Air Navigation Electronics and Telecommunications, National Aviation University, Kyiv, Ukraine.
Education: Kyiv Polytechnic Institute, Kyiv, Ukraine, (1973).
Research area: Air Navigation, Air Traffic Control, Identification of Complex Systems, Wind/Solar power plant.
Publications: more than 600 papers.
E-mail: svm@nau.edu.ua

Kot Ananatoliy. Post-graduate student.
Technical Cybernetic Department, National Technical University of Ukraine "Ihor Sikorsky Kyiv Polytechnic Institute," Kyiv, Ukraine.
Education: National Technical University of Ukraine "Ihor Sikorsky Kyiv Polytechnic Institute," Kyiv, Ukraine, (2017).
Research area: artificial Intelligence.
Publications: 3.
E-mail: anatoly.kot@gmail.com

В. М. Синєглазов, А. Т. Кот. Автоматизоване проектування гібридних енергетичних систем України

Показано, що проблема створення гібридних енергетичних систем дуже важлива для України. Висока якість рішення цієї проблеми може бути досягнута за допомогою систем автоматизованого проектування. Розглянуто сучасні системи автоматизованого проектування і виконано їх аналіз. Показано, що вони мають деякі недоліки. Щоб здолати їх, розроблено новий гібридний генетичний алгоритм безумовної багатокритеріальної оптимізації, який грунтується на новому підході еквівалентного перетворення задачі умовної оптимізації у безумовну з подальшим "лікуванням" парето-оптимальних точок (розв'язків), які розміщуються за межами області, сформованої обмеженнями. Розглянуто приклади автоматизованого проектування гібридних енергетичних систем для різних регіонів України.

Ключові слова: гібридна система відновлюваної енергії; автоматизоване проектування; генетичний алгоритм.

Синєглазов Віктор Михайлович. orcid.org/0000-0002-3297-9060
Доктор технічних наук. Професор. Завідувач кафедрою.
Кафедра авіаційних комп'ютерно-інтегрованих комплексів, Факультет аеронавігації електроніки і телекомунікацій, Національний авіаційний університет, Київ, Україна.
Освіта: Київський політехнічний інститут, Київ, Україна, (1973).
Напрям наукової діяльності: аеронавігація, управління повітряним рухом, ідентифікація складних систем, вітроенергетичні установки.
Кількість публікацій: більше 600 наукових робіт.
E-mail: svm@nau.edu.ua

Кот Анатолій Тарасович. Аспірант.
Кафедра технічної кібернетики, Національний технічний університет України «Київський політехнічний інститут ім. Ігоря Сікорського», Київ, Україна.
Освіта: Національний технічний університет України «Київський політехнічний інститут ім. Ігоря Сікорського», Київ, Україна, (2017).
Напрям наукової діяльності: штучний інтелект.
Кількість публікацій: 3.
E-mail: anatoly.kot@gmail.com

В. М. Синеглазов, А. Т. Кот. Автоматизированное проектирование гибридных энергетических систем Украины

Показано, что проблема создания гибридных энергетических систем очень важна для Украины. Высокое качество решения этой проблемы может быть достигнута с помощью систем автоматизированного проектирования. Рассмотрены современные системы автоматизированного проектирования и выполнен их анализ. Показано, что они имеют некоторые недостатки. Чтобы преодолеть их, разработан новый гибридный генетический алгоритм безусловной многокритериальной оптимизации, основанный на новом подходе эквивалентного преобразования задачи условной оптимизации в безусловную с последующим "лечением" Парето-оптимальных точек (решений), которые размещаются за пределами области, образованной ограничениями. Рассмотрены примеры автоматизированного проектирования гибридных энергетических систем для различных регионов Украины.
Ключевые слова: гибридная система возобновляемой энергии; автоматизированное проектирование; генетический алгоритм.

Синеглазов Виктор Михайлович. orcid.org/0000-0002-3297-9060
Доктор технических наук. Профессор. Заведующий кафедрой.
Кафедра авиационных компьютерно-интегрированных комплексов, Факультет аэронавигации электроники и телекоммуникаций, Национальный авиационный университет, Киев, Украина.
Образование: Киевский политехнический институт, Киев, Украина, (1973).
Направление научной деятельности: аэронавигация, управление воздушным движением, идентификация сложных систем, ветроэнергетические установки.
Количество публикаций: более 600 научных работ.
E-mail: svm@nau.edu.ua

Кот Анатолий Тарасович. Аспирант.
Кафедра технической кибернетики, Национальный технический университет Украины «Киевский политехнический институт им. Игоря Сикорского», Киев, Украина.
Образование: Национальный технический университет Украины «Киевский политехнический институт им. Игоря Сикорского», Киев, Украина, (2017).
Направление научной деятельности: искусственный интеллект.
Количество публикаций: 3.
E-mail: anatoly.kot@gmail.com