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Use of Modified Cuckoo Search algorithm in the design process of integrated power systems for modern and energy self-sufficient farms

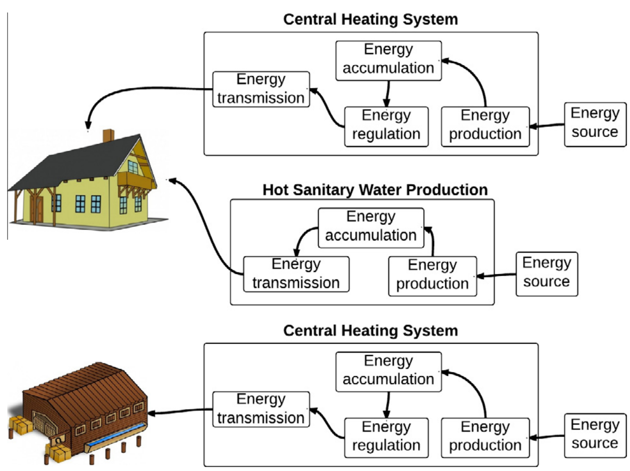
Janusz Piechocki [a], Dominik Ambroziak [b], Aleksander Palkowski [b,*], Grzegorz Redlarski [b]

[a] University of Warmia and Mazury, Department of Electrical Engineering, Power Engineering, Electronics and Control Engineering, ul. M. Oczapowskiego 11, 10-719 Olsztyn, Poland
[b] Gdansk University of Technology, Department of Mechatronics and High Voltage Engineering, ul. G. Narutowicza 11/12, 80-233 Gdansk, Poland

HIGHLIGHTS

- Optimal design of an integrated power system for farms is studied.
- A model of an agricultural holding's power system is formulated.
- A design process utilizing the Modified Cuckoo Search algorithm is developed.
- The proposed system enables to design an energy efficient and ecological farm.

GRAPHICAL ABSTRACT



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ABSTRACT

In the face of increasingly stringent pollutant emission regulations, designing an agricultural holding becomes a difficult challenge of connecting a large number of coefficients that describe an energy system of a farm in regard to its ecological and economic efficiency. One way to cope with this issue is to design an energy self-sufficient farm that integrates various technologies, including renewable energy. However, the selection of appropriate components of such a system may be difficult. Large selection of facilities for management of heating and water systems and the choice of appropriate building technology makes it difficult to solve the problem of optimizing characteristics of such a holding by using standard methods. In this paper the issue of computer-aided design of energy systems for farms is dealt with. The solution proposed use the Modified Cuckoo Search algorithm in the process of optimizing the selection of particular components that influence performance of the power system, such as energy sources, water preparation systems or structure of walls. Presented results of the optimization process with the use of different fitness functions allow to state that the system developed achieved very satisfactory results and is capable to cope with the task. Through the use of the swarm algorithm it is possible to search for solutions in a large feature space and achieve optimality in terms of energy, economy and pollutant emission simultaneously.

* Corresponding author. Tel.: +48 583471994.
E-mail address: a.palkowski@eia.pg.gda.pl (A. Palkowski).

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Nomenclature

$\eta_{H,d}$	Average seasonal efficiency of heat carrier transportation within HVAC
$\eta_{H,e}$	Average seasonal efficiency of heat storing in capacitive components of HVAC
$\eta_{H,gn}$	Efficiency coefficient of heating utilization
$\eta_{H,g}$	Average seasonal efficiency of heat production for HVAC
$\eta_{H,s}$	Average seasonal efficiency of adjustment and heat usage in HVAC
$\eta_{H,tot}$	Average seasonal efficiency of HVAC
$\eta_{W,d}$	Average seasonal efficiency of hot water transportation within a building
$\eta_{W,g}$	Average seasonal efficiency of heat production for DHW
$\eta_{W,s}$	Average seasonal efficiency of accumulation of hot water in capacitive elements of DHW
$\eta_{W,tot}$	Average seasonal efficiency of DHW
$B_{H,a}$	Annual fuel consumption for auxiliary devices
C_{HW}	Unit daily hot water consumption
CO	Coefficient of carbon dioxide emission from a selected energy source
CO_a	Annual carbon dioxide emission from auxiliary devices
E_a	Annual energy demand for power auxiliary devices
H_u	Heating value
K_A	Costs associated with purchase of facilities for HVAC and DHW
K_d	Costs related to purchase of energy-transferring devices
K_E	Costs associated with purchase of energy
K_e	Costs related to purchase of energy-controlling devices
K_g	Costs related to purchase of energy-producing devices
K_M	Costs associated with purchase of construction materials
K_s	Costs related to purchase of energy-accumulating devices
k_t	Correction multiplier for hot water temperature other than 55 °C
L_i	Number of reference units
$m_{H,a}$	Correction multiplier for auxiliary devices in HVAC
m_H	Correction multiplier for HVAC
$m_{W,a}$	Correction multiplier for auxiliary devices in DHW
m_W	Correction multiplier for DHW
P_1	Unit price of selected energy source for HVAC and DHW
P_2	Unit price of selected energy source for auxiliary devices
P_I	Unit price of insulating material
P_B	Unit price of building material
P_T	Unit price of plaster
$Q_{H,gn}$	Inner heat gains from insulation during a month
$Q_{H,ht}$	Heat losses through penetration and ventilation during a month
t_{us}	Time of use
U	Heat transfer coefficient
V_B	Volumeof demand for building material
V_I	Volume of demand for insulating material
V_T	Volume of demand for plaster
Y_B	Unitary volume of building materials
Y_I	Unitary volume of insulating materials
Y_T	Unitary volume of plaster

1. Introduction

Agricultural sector is currently one of the most important segments of the global economy in both political and economic terms. In the European Union alone this sector employs more than 13.7 million people [1], and budget for its implementation in 2012 reached nearly 60 billion Euros [2]. For this reason the leaders of the European Union consider striving for most efficient and sustainable development of the sector concerned as one of the top priority tasks for the coming years. In their opinion, a particularly important task is the pursuit of sustainable technological progress, whose achievement is possible through appropriate and intensive investments, particularly in relation to countries located in Eastern Europe. Implementation of such provisions was confirmed at the recent European Union summit in Brussels on 7th and 8th of February 2013, when leaders of all 27 EU Member States decided to allocate significant funds for the development of agricultural sector. In the case of Poland, for the years 2014–2020 a total amount of 108.8 billion Euros were allocated, where up to 28.5 billion Euros were assigned for agricultural development alone.

While analysing the situation of the agricultural sector in the European Union, in particular with regard to the so-called Eastern Bloc countries, it is clear that one of the major factors hindering the development are high heat and electricity prices, which additionally are constantly increasing [3,4]. This phenomenon is caused primarily by rising prices of energy sources (oil, coal and lignite, fuel oil, natural gas, etc.) and growing demand for environmental protection. For this reason, methods, which would increase energy efficiency currently form the basis of studies in various research centres worldwide [5–17].

Requirements for reduction in energy consumption are regulated by a number of international treaties and provisions, including [18–21]. Hence, one of the branches of science aimed at increasing energy efficiency imposes the necessity for thermomodernisation of such objects, e.g., by increasing efficiency of production, control, transmission and accumulation of energy, or as a result of using alternative energy sources (wind, biomass, geothermal or solar energy). Such actions seem to be especially appropriate for a number of demanding modernisation processes of agricultural holdings in the Eastern Bloc of Europe. Increasing efficiency is in relation to the amount of pollutant emission because, due to lower energy demand (i.e., greater energy efficiency), the amount of pollutants emitted into the atmosphere decreases. Main source of the pollutants are primarily heating plants, power plants and thermal power stations. During the combustion process in these facilities harmful substances are emitted in the form of carbon dioxide, sulphur dioxide, carbon monoxide, oxides of nitrogen, particulate matter and polycyclic aromatic hydrocarbons (of highly carcinogenic effects on living organisms).

The idea of an integrated and self-contained power system comprises of satisfying energy needs of an agricultural holding without necessity to connect to an external power system. Such a solution can be achieved through use of adjacent energy sources. In this paper the following energy sources are taken into consideration: fuel oil, natural gas, biomass, coal, mixed electricity production and electricity retrieved from the national power grid. With a self-sufficient power system it is possible to reduce losses associated with transmission of energy, which arise from the fact that frequently power plants, heating plants and thermal power stations distribute produced energy over long distances. Efficiency of an energy transmission system increases by reducing the transmission losses. Therefore it can be concluded that the increase in efficiency of production, control, transmission and accumulation of energy of an agricultural holding may have a significant effect on reduction of emission of the aforementioned harmful substances.

To commence a thermal modernisation of agricultural holding facilities, one should make in particular the choice of materials