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Identification the Model of Electric Power Generation by Small Hydroelectric Power Station Based on Artificial Bee Colony Algorithm

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***Abstract*—Solution the task of parametric identification the athematical model of electric power generation by a small ydroelectric power station based on artificial bee colony gorithm are proposed in this article.**

Keywords*—*mathematical model, bee colony algorithm BC), parametric identification, interval data, interval data alysis, small hydroelectric power station (SHEPS)

I. INTRODUCTION

The development of small hydropower is one of the areas f potential energy savings. The tasks of restoration of xisting and creation of new small hydroelectric power ations (SHEPS) are urgent given the potential of hydro sources in Ukraine. At the same time, it is advisable to evelop mathematical models for the hydroelectric power ation in order to investigate and ensure maximum fficiency of the use of hydro resources. The dependence of e amount of electric power generated on external factors e reflected by the this models [1-2].

Such models are based on inaccurate data, which should e in interval form are presented. For their build the methods f interval data analysis are used [3-7]. Examples of the plication of such methods to solve the applied problems of edicine, economics, ecology, energy are described in ticles [8-11].

In articles [12-14] are showed that methods and gorithms based on the principles of swarm intelligence to lve the tasks of structural and parametric identification are ed. There are the algorithm of ant colony optimization, gorithm, cuckoo search algorithm, artificial bee colony gorithm of particle swarm optimization and other. That gorithms to solve complex optimization tasks, such as ultidimensional optimization, discrete optimization, lticriterian optimization are used.

In view of the above, it is advisable to solve the task of rametric identification of a mathematical model of electric wer generation by a SHEPS, using, for example, an gorithm for the behavior of a bee colony. Therefore, the rpose of this article work is to build a mathematical model electric power generation at a small hydroelectric power tion based on the identification parametric method. That sed on artificial bee colony algorithms.

II. TASK STATEMENT

The dependence between the quantity of genera electric power and the external factors of influence o small hydroelectric power station in this form is present [1]:

$$y_0 = \beta_1 \cdot \varphi_1(\vec{x}) + \ldots + \beta_m \cdot \varphi_m(\vec{x}),$$

where y_0 – true unknown value of generated electric pow $\vec{x}$ - vector of input values of external factors (for examp reactive power, water level on hydropower, fall on SHEPS, and other); $\vec{\varphi}^T(\vec{x}) = (\varphi_1(\vec{x}), \ldots \varphi_m(\vec{x}))^T$ - vector known basic functions, $\vec{\beta} = (\beta_1, \ldots, \beta_m)^T$ - vector uknown parameters.

In the form of a matrix of values of the input variable and the vector of intervals of values for the output varia $[\vec{Y}]$ represent the results of observations "inputs", "output

$$X = \begin{pmatrix} x_{11} \cdots x_{1n} \\ \vdots \\ x_{i1} \cdots x_{in} \\ \vdots \\ x_{N1} \cdots x_{Nn} \end{pmatrix}; \left[\vec{Y}\right] = \begin{pmatrix} \left[y_1^-; y_1^+\right] \\ \vdots \\ \left[y_i^-; y_i^+\right] \\ \vdots \\ \left[y_N^-; y_N^+\right] \end{pmatrix}.$$

For each of the N observations, the true unknown va of the output y_0 is in the intervals:

$$y_i^- \le y_{0i} \le y_i^+, i = 1, \ldots, N.$$

On the basis of expressions (1-3), we obtain ISLAE estimate the vector of unknown parameters $\vec{\beta}$:

$$\begin{cases} y_1^- \le b_1\varphi_1(\vec{x}_1)+\ldots+b_m\varphi_m(\vec{x}_1)\le y_1^+ \\ \vdots \\ y_i^- \le b_1\varphi_1(\vec{x}_i)+\ldots+b_m\varphi_m(\vec{x}_i)\le y_i^+ \\ \vdots \\ y_N^- \le b_1\varphi_1(\vec{x}_N)+\ldots+b_m\varphi_m(\vec{x}_N)\le y_N^+ \end{cases} . \quad (4)$$

Therefore, the the task of parameters identification of the interval model (1) is the task of solving the ISLAE by expression (4).

We will look for the approximate solution of ISLAE (4) in the form:

$$\left[\vec{\beta}\right]=\begin{pmatrix}[b_1]\\ \vdots \\ [b_i] \\ \vdots \\ [b_N]\end{pmatrix}, \quad (5)$$

where $[b_i]=\left[b_i^-;b_i^+\right], i=1,...,N$.

To find at least one solution of ILSAE, we formulate a "quality" indicator of the current solution, which reflects the degree of closeness of that solution to a solution that transforms ISLAE (4) into a compatible system. It is obvious that the "quality" of the approximation will be the higher the closer the interval of prediction, constructed on the basis of this the parameter vector, to the experimental interval.

In case no intersection of intervals the quality of approximation will be determined by the difference between the farthest centers of the forecast and experimental interval. In case intersection of intervals the quality of such an approximation will be determined by the smallest intersection width among the predicted and experimental intervals [12-14]:

$$\Delta([\hat{\bar{b}}_l])=\max_{i=0,...,N}\left\{\left|mid([\hat{y}_i])-mid([y_i])\right|\right\}, if \quad [\hat{y}_i]\cap[y_i]=\varnothing, \exists i=0,...,N. \quad (6)$$

$$\Delta([\hat{\bar{b}}_l])=\max_{i=0,...,N}\left\{wid([\hat{y}_i])-wid([\hat{y}_i]\cap[y_i])\right\}, if \quad [\hat{y}_i]\cap[y_i]\neq\varnothing, \forall i=0,...,N, \quad (7)$$

where y_i and $\hat{y}_i$ - experimental and predicted intervals respectively, $mid(\bullet)$ та $wid(\bullet)$, - operation of definition the centre and the width of interval, respectively.

Thus, the task of parametric identification the interval model can be formulated:

$$\Delta([\hat{b}_l]\ )\xrightarrow{[b_l]}\min, [\hat{b}_{li}]\subset[b_{li}^{low};b_{li}^{up}], i=1,...,N \quad (8)$$

where $b_{li}^{low}, b_{li}^{up}$ - minimum and maximum values for each parameter of interval model.

For find the solutions of ISLAE (4) the methods localization of interval mainly are used [1,3,5-6].

However, the accuracy of these estimates is not high accordingly, the width of the prediction interval of gene electric power, depending on external factors, will be l which will mean low model accuracy.

Under these conditions, to solve this task is advosabl method of parametric identification based on artificial colony algorithm are used.

III. The Method of Parametric Identification Mathematical Model Based on Artificial Bee Colony Algorithm

Artificial Bee Colony algorithm – it is a heu algorithm based on the principles of swarm intelligence. basic principles of the Artificial Bee Colony algorithm first formulated by Caraboga D. in 2005 [15]. The main of ABK is modeling the behavior of honey bee coloni the process of finding food.

In the natural environment, scout bees initially searc valuable sources of food in a random direction. The val the food source is determined by the quantity of food the distance from the hive to it. Returning to the hive, s bees report on the food sources found and their qu Based on the information received, bees from the hive s the source of nectar to which they will fly. The bette food source, the more bees from the hive will fly to it. I food is depleted in a particular area, the bees leave it instead fly to new valuable food sources found by scouts [15-18].

In the general case, the scheme of realization sw intelligence algorithms can be formulated [15-22]:

1. Initialization an algorithm agent population (rand forming a certain number of starting points (potential solutions) in the solution search area).

2. Moving agents of the algorithm (based on a s moving rules, they move agents in the solution area o task in such a way as to get closer to the extremum o objective function).

3. Completion of the procedure (if defined the cond of stopping, otherwise the transition to the second ste made).

According to the above scheme, we form the tas parametric identification of interval model - the task solving ISLAE (4).

A. Initialization phase

The vectors that determine the coordinates of sou with characteristic food content are denoted by $[\hat{\bar{b}}_l]$. T we initialize a rectangular area in the search area for sources. Therefore, these are the vectors of interval mo parameters in the context of solving the task (4). vector of coordinates the source of foods responde to l-th bee that researches it. Denote the number of the population by S. All population vectors $l=1,...,S$ by scouts are initialized. Each vector of parameters inclu variables $[b_{li}], i=1,...,m$ that need to be optimized minimize the objective function.

To initialize randomly the initial sources of food, we the following expression:

$$[b]_{li}=[b_{li}^{low};b_{li}^{low}+\Delta b_i], i=1,...,m$$

where $\Delta b_i = 0,1 \cdot (b_i^{up} - b_i^{low})$.

Thus, after initialization, we get the such of rectangular sections in the search area. These rectangular sections must be constant.

It should be noted that in this phase we also configure all the parameters of the algorithm. There are *mcn = 0* - the current iteration number and *MCN* - the total number of iterations, *LIMIT* - the number that determines the exhaustiveness of the source and its current value *limit = 0*. *limit*=0.

B. Employed bees phase

Employed bees are looking for new sources that contain more food. In the context of optimization task (8), this means finding new solutions with smaller values of the function (6) or (7). Employed bees search for surrounding food sources and evaluate their "quality". Such formulas to calculate the neighborhoods of food sources are used:

$$[b_{li}]^{mcn} = [b_{li}] + \Phi_{li} \cdot (b_{li}^{-} - b_{pi}^{-}), \qquad (10)$$

if $i = 1,...,m; p \neq l = 1,...,S$, where $[b_{li}]^{mcn}$ - the coordinate of the food source at the current iteration, $[\vec{b}_p]$ - randomly selected vector of food source from $p \neq l = 1,...,S$; $i = 1,...,m$ - randomly selected index of parameter; Φ_{li} - the random value from the interval [-1;1].

After calculating the surrounding of coordinates for new sources of food $[\vec{b}_l\ ]^{mcn}$, a pair selection between existing and current ones using the objective function (6) or (7) is performed:

$$[\hat{\bar{b}}_l] = \left\{[\hat{\bar{b}}_l],\ \text{if } \Delta([\hat{\bar{b}}_l]) \leq \Delta\left([\hat{\bar{b}}_l\ ]^{mcn}\right)\right\} \ or$$
$$[\hat{\bar{b}}_l] = \left\{[\hat{\bar{b}}\ \ ]^{mcn}{}_l,\ \ \text{if } \Delta([\hat{\bar{b}}_l]) > \Delta\left([\hat{\bar{b}}_l\ ]^{mcn}\right)\right\}. \qquad (11)$$

C. Onlooker bees phase

In this phase, the employed bees arrive at the hive and share their information about the sources of food with the scout bees who are waiting for them in the hive. The latter are likely to select food sources, depending on the information obtained. For this purpose, for each current source of food, we calculate the probability P_l of its choice by scout bees:

$$P_l = \frac{1 - \Delta([\hat{\bar{b}}_l])}{\sum_{l=1}^{S} (1 - \Delta([\hat{\bar{b}}_l]))}. \qquad (12)$$

Note that expression (12) is applied after the previous normalizing the values of the objective function $\Delta([\hat{\bar{b}}_l])$ to the interval [0, 1].

Based on calculated probabilities, the scout bees choose surrounding of certain sources of food $[\hat{\bar{b}}_l]$ consisting of points z_l whose coordinates are calculated by expression (12). In this case, the number of surrounding points for each source is calculated such as:

$$z_l = P_l \cdot S.$$

Next, for each generated food source, we calculate the objective function (6) or (7) and again make group selection between existing and current food sources based on the expression (11).

D. Scout bees phase

This is the phase of bees that randomly select new sources of food. Employed bees that produce new solutions to the optimization task become bees scouts if those solutions do not improve over many iterations. In the context of the task's conditions, this means the depletion of current sources of food when the *limit* counter exceeds its limit value *LIMIT*.

It should be noted again that, unlike in the classical case where solutions of the optimization problem (8) based on artificial bee colony algorithm are sought as a point's value. In our case, the solution will be a area in the form of the vector $[\vec{b}_l\ ]$, which in the initialization phase as the form (9).

As we can see, the width of the interval is determined $\Delta[\vec{b}_{il}]$. Thus, as a result of applying the above algorithm there may be a situation where the solution $[\vec{b}_l\ ]$ in the form of a rectangular area does not exist. In this case, after a given number of MCN iterations, we propose to initialize the solution area by the formula (9), having previously reduced in this way:

$$(\Delta b_i)_{d+1} = \frac{(\Delta b_i)_d}{2}.$$

IV. Identification the Mathematical Model of Generated Electric Power by Small Hydroelectric Power Station

In the paper [1] described example of build a model of generated electric power by SHEPS. The dependence between the quantity of generated electricity and the external factors of influence (water level on hydropost, fall in SHEPS, and reactive power) is described by the expression:

$$y(\vec{x}) = b_1 \cdot x_1 + b_2 \cdot x_1 x_3 + b_3 \cdot \sin(x_3) + b_4 \cdot x_1 \cdot x_2^{\ 2},$$

where $y(\vec{x})$ - generated electric power, x_1 - reactive power, x_2 - fall on SHEPS, x_3 - water level on hydropost.

Experimental data for the task obtained at the SHEPS built on the river Strypa in Ternopil region (Table 1).

Within the limits of the errors in the experimental d… we obtain the following ISLAE:

$$\left\{ y_i^- \leq b_1 \cdot x_{i1} + b_2 \cdot x_{i1} x_{i3} + b_3 \cdot \sin(x_{i3}) + b_4 \cdot x_{i1} \cdot x_{i2}^{\ 2} \leq y_i^+,\ i = 1,...,30 \right. \qquad (16)$$

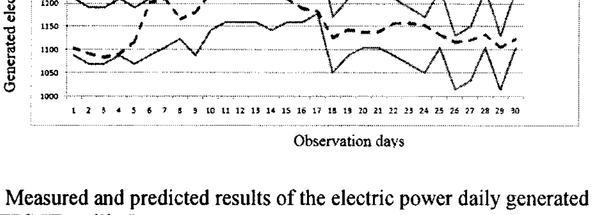
'ABLE I. SUMMARIZED DATA QUANTITY OF ELECTRIC POWER AND INFLUENCE FACTORS FOR ITS GENERATION BY POWER STATION

No	Reactive power	Fall on SHEPS	Water level on hydropost	Generated electric power
1	182,5	4,6	6,5	[1087,2; 1211,28]
2	182,7	4,7	5,5	[1069,08; 1191,092]
..	...	...	...	...
29	189,4	4,8	4,11	[1014,72; 1130,528]
30	189,5	4,75	5,01	[1105,32; 1231,468]

The results of computer simulation to identification the athematical model of generated electric power on ydroelectric power station based on artificial bee colony gorithm are given below.

The interval model of electric power daily generated by HEPS was built:

$$y(\vec{x}) = (5,5996;5,6001)\cdot x_1 + (0,0937;0,0941)\cdot x_1x_3 + +(-5,7855;-5,7851)\cdot \sin(x_3) + (-0,0077;-0,0073)\cdot x_1x_2^2, \quad (17)$$



g. 1. Measured and predicted results of the electric power daily generated SHEPS "Topol'ky"

In Figure 1 also showed measured results. As we can see this figure the resulting model predicts daily amount of nerated electric power within the measured amount that is nfirming its adequacy.

V. CONCLUSIONS

The solution of task parametric identification of athematical model of electric power generation by a small ydroelectric power station based on artificial bee colony gorithm are proposed in this article.

The result is a mathematical model that has a guaranteed edictive properties, that is, the predicted interval values the antity of generated electric power belong to the intervals the measured values of this characteristic.

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