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OPTIMIZATION OF WIND POWER STATIONS STRUCTURE BY THE DYNAMIC PROGRAMMING METHOD

The article offers the wind power stations optimization model. For the solution of the optimization problem the method of dynamic programming is applied and the results of the research are presented.

Keywords: *partial criteria; weight coefficient of importance; integral evaluation; dynamic programming; Bellman's optimality; computer simulation; statistical analysis.*

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ОПТИМІЗАЦІЯ СКЛАДУ ВІТРОВИХ ЕЛЕКТРОСТАНЦІЙ З ВИКОРИСТАННЯМ МЕТОДУ ДИНАМІЧНОГО ПРОГРАМУВАННЯ*

У статті розроблено модель оптимізації множини діючих вітрових електростанцій. Для розв'язання оптимізаційної задачі використано метод динамічного програмування та наведено результати дослідження.

Ключові слова: *часткові критерії; вагові коефіцієнти важливості; інтегральне оцінювання; динамічне програмування; оптимальність Белмана; імітаційне моделювання; статистичний аналіз.*

Форм. 4. Табл. 2. Рис. 3. Літ. 23.

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ОПТИМИЗАЦИЯ СОСТАВА ВЕТРОВЫХ ЭЛЕКТРОСТАНЦИЙ С ИСПОЛЬЗОВАНИЕМ МЕТОДА ДИНАМИЧЕСКОГО ПРОГРАММИРОВАНИЯ

В статье разработана модель оптимизации множества используемых ветровых электростанций. Для решения оптимизационной задачи использован метод динамического программирования и приведены результаты исследования.

Ключевые слова: *частичные критерии; весовые коэффициенты важности; интегральное оценивание; динамическое программирование; оптимальность Беллмана; имитационное моделирование; статистический анализ.*

Problem setting. Operations of the contemporary wind power stations (WPS) involve producing a specified amount and type of electrical energy under the conditions of variable power potential of wind. In this case, the dispatcher's task of the automated control system of the energy dynamic process is to determine the necessary efficient set of a variety of available electrical wind installations for its enclosure. The dispatcher faces the task of operational appraisal of facilities and their effectiveness characterized by heterogeneous parameters. Often a dispatcher makes this assessment intuitively and thus his/her decision is not always well-grounded. Therefore, the problem of developing a method of determining the most efficient structure of wind power stations (WPS) is relevant.

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Recent research and publications analysis. The known methods for the determination of renewable sources of energy that are used for a single definition of wind power stations' effective structure, that is a long-term adjustment of the number of working electrical installations are not expected. These include Strethom and Hoal's, Colleg's, Markvart's methods (Bagul, 1996; Kellogg, 1998; Eftichios, 2006).

The known methods of the structure's determination of operating installations in traditional energetics are used for hydroelectricity, thermal power stations etc. (Rudenko, 2000; Vennikov, 1990; Urun, 1974). The essence of the problem lies in the selection of such operating units' structure, as well as starting and stop points, which provide a minimum of energy consumption for a daily or more prolonged cycle regulation. It is necessary to consider the cost of launching installations from reserve, the losses of active power in the network and the reliability conditions of a power system. In addition, it is important to explore the specific for this problem time limits standing idle before their start, the number of installations that simultaneously stop and start, the speed of power gaining etc. (Kutkovetskyi, 2004).

The methods of a single determination of wind power stations' structure (Bagul, 1996; Kellogg, 1998; Eftichios, 2006) are focused on the ability of local generation and are used for WPS projecting. Other methods used in traditional energetics are inappropriate in this case of application because they are focused on the economic criterion of fuel consumption, reduction of load on other devices and so on (Rudenko, 2000; Vennikov, 1990; Urun, 1974).

The research objective is to develop a method for determining the wind power station's dynamic structure, taking into account the instantaneous power and generalized electrical efficiency of wind.

Unresolved issues. The unresolved part of the problem is the development of the method for solving the task of determining the wind power stations' effective structure, in particular, the argumentation of the integral parameter of optimization.

Key research findings.

The optimization problem formulation. For the determination of the wind power station's structure, for some wind electrical installations identified by their own integral assessment and by the value of power, Boolean programming can be used (Medykovskyy, 2010). This is one of the combinatorial optimization tasks. It is sometimes called the task of packing a backpack, the task of loading a vehicle (carriage, car, ship, aircraft) and it refers to Boolean programming (Kutkovetskyi, 2004). It received its name from the maximization task of packing as many items as it is necessary in a backpack, given that the total volume (or weight) of all objects is limited. Similar tasks often arise in economics, applied mathematics, cryptography, logistics, genetics. In general, the task can be formulated as follows: with an unlimited number of objects that have their own cost and weight, a number of items should be selected in such a manner so as to get the maximum total value and to keep at the same time restrictions on its total weight (Valeeva, 2006; Zaozerskaya, 2011).

The task of packing a backpack can be formalized by means of mathematical tools: a finite set of objects is given as $Q = \{q_1, q_2, \ldots, q_m\}$, for each $q_j \in Q$ is the known value (efficiency) C_j and fixed capacity P_j, and the backpack with P capacity is given. A backpack should be packed in a way so that the total value of packed items is the largest, and their total capacity does not exceed P. It is traditionally considered that C_j, P_j, P are negative integers.

Let us introduce the following binary variables $b_1, b_2, ..., b_m$, we will assume that b_j = 1, if the subject q_j ¸Q and is chosen for packaging and b_j = 0 in the other case.

Then, the task of packing a backpack is reduced to the task of integer linear programming with Boolean variables, where it is necessary to find such values of variables $b_1, b_2, ..., b_m$, at which the maximum sum can be reached (Bellman, 1965; Finkelshtejn, 1976):

$$C = \sum_{j=1}^{m} C_j b_j \qquad (1)$$

and the limitation is executed

$$\sum_{j=1}^{m} P_j b_j \le P. \qquad (2)$$

Solving the problem (1–2) should be found among 2^m binary vectors of length m, where m is the number of items. Sorting this exponential number, the problem (1–2) will be solved.

Features of determining weight coefficients, the importance of criteria. It is known that each wind power station is characterized by several criteria that distinguish it from all the rest. For easier comparison of objects that have different partial criteria quantitative estimates are used (Podinovskyi, 1979). A certain score is assigned for each qualitative estimate of the criterion. Then, objects can be evaluated by means of numerical methods. If an object is characterized by a large number of partial criteria, quite often generalized (integrated, global, complex, aggregated, synthetic) estimates are used.

Typically, instead of the integrated assessment, arithmetic sum of partial estimates criteria is used (Podinovskyi, 2007):

$$C_{‡"} = K_1 + K_2 + ... + K_n, \qquad (3)$$

where C_Σ is an integral estimate of the object; K_i is an estimate of the i-th criterion.

But in the process of the objects' integrated assessment it is also necessary to take into account the unequal importance of partial criteria. Typically, this problem is solved by introducing the weights coefficients of the criteria's importance, whose purpose is a numerical estimate of a certain criterion contribution to the final result. To calculate the weight importance coefficients different approaches are used, within the scope of which several methods are developed. Found by different methods vectors of weight coefficients do not always coincide with their meanings, that is why the error estimation problem of weight importance coefficients are relevant; the introduction of the permissible values scale at the time of their determination and others. In detail the effectiveness of the research of the weight coefficients importance can be found in the work (Medykovskyy, 2011), and the obtained weight coefficients' values for the electrical installations are given in Table 1.

Special features of the dynamic programming method application. Thus, with the sets C_j and P_j that characterize each wind power station, the task of packing a backpack can be solved (Virt, 1989; Fridman, 1973).

Table 1. **Weights coefficients of the importance of wind electrical installations,** *calculated by the authors*

Method	ω_1	ω_2	ω_3	ω_4	ω_5	ω_6
Saaty complete	0.128091	0.029424	0.39225	0.276713	0.09055	0.082958
Saaty simplified	0.0986	0.014	0.4931	0.2958	0.0493	0.0493
Wei	0.1944	0.0277	0.3055	0.25	0.1388	0.0833
Cogger and Yu	0.13758	0.03	0.41662	0.28001	0.08621	0.0431
Fishber's	0.1904	0.04761	0.2857	0.238	0.1428	0.0952
The principle of indistinct majority	0.190475	0.047626	0.2857	0.238116	0.142855	0.095234

The dynamic programming method is based on the principle of optimality, which was formulated in 1957 by an American mathematician R. Bellman: "the optimal behavior has the property that whatever the initial state and solution of the problem at the initial time are, the following solutions must form the optimal behavior regarding the state that is obtained as a result of the first solution" (Virt, 1989).

The complexity of the problem of packing a backpack is equal to $O(m \times P)$, where m – the number of objects; P – the given power.

In this paper, the problem of packing a backpack is solved by means of tabular method, according to which the two-dimensional array is formed, the columns of which correspond to the capacity of a backpack and the rows correspond to the number of the wind electrical installations (Table 2). The power of wind electrical installations remains in an array $p[1]...p[m]$, and their effectiveness – in $c[1]...c[m]$. The function $A(s,n)$ is the electrical efficiency maximum of wind electrical installations that can be fitted in a backpack that has got a capacity maximum n, if you can use only the first s items out of the given m. The value of the function $A(s,n)$, where $0 \le s \le m$, $0 \le n \le P$ is saved in the array $A[m+1][P+1]$.

Table 2. **The tabular method of solving the problem of packing a backpack,** *calculated by the authors*

	0	1	...	P
s = 0	0	0	...	0
s = 1	0	$0 \Vert C_1$	...	$0 \Vert C_1$
s = 2	0	$0 \Vert C_1 \Vert C_2 \Vert C_1 + C_2$	...	$0 \Vert C_1 \Vert C_2 \Vert C_1 + C_2$
...	...	...	...	...
s = m	0	$0 \Vert C_1 \Vert ... \Vert C_m \Vert C_1 + C_m$	...	$0 \Vert C_1 \Vert ... \Vert C_m \Vert C_1 + C_m$

The following table is filled in using an algorithm the structure of which is shown in Figure 1.

The features of the software's implementation of the method for solving the problem lie in the following.

```
int A[m+1][P+1];
for(n=0;n<=P;++n)      // filling null row
   A[0][n]=0;
for(s=1;s<=m;++s)      // s – the maximum number of the object,
{                  // that can be used
   for(n=0;n<=W;++n)  // P – the capacity of a backpack
   {
      A[s][n]=A[s-1][n];
      if ( n>=p[s] && ( A[s-1][n-p[s]]+c[s] > A[s][n]) )
         A[s][n] = A[s-1][n-p[s]]+c[s];
   }
}
```

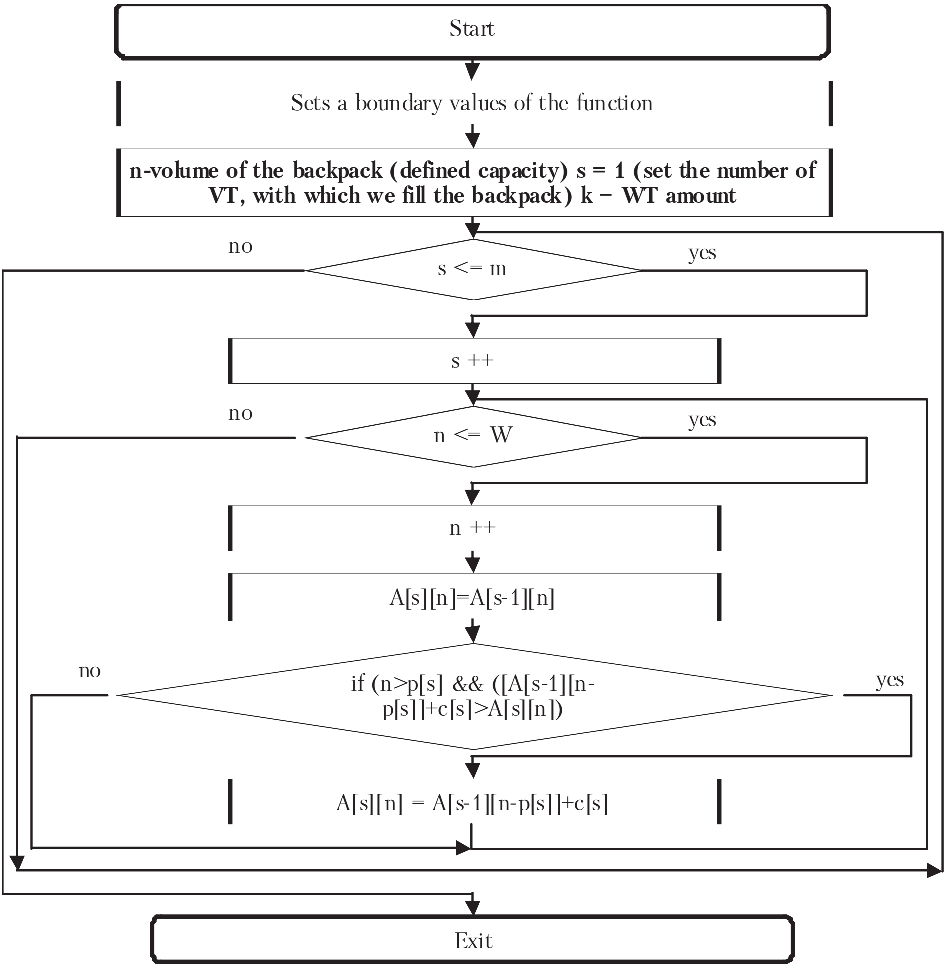

Figure 1. **Algorithm's structure for solving the problem,** *developed by the authors*

In the above code, the function $A(s,n)$ has boundary values:

- If $s = 0$, then $A(0,n) = 0$ for all n (no object can be taken, that is why the maximum efficiency is equal to zero);
- If $n= 0$, then $A(s,0) = 0$ for all s (any of the first objects can be taken, but the backpack's capacity, herewith, is equal to zero).

The statistical analysis of the obtained results. To evaluate the effectiveness of the results of the system's work the elements of the probability theory and mathematical statistics are used (Gmurman, 2003; Babaitsev, 2002).

The effectiveness of the elaborated method was studied with the use of computer simulation. The researched system behavior is reproduced in time by means of discrete-event simulation, the result of which as the determination of the optimized structure of wind power stations was specified in a certain number of times and the results of each experiment were written down in the data set, after this the evaluation of all the experiments was carried out.

The following input data were selected for the simulation: the given WPS power – P = 80000 kW; the number of wind electrical installations – m = 100; the power of each WPS P_j is randomly generated from the interval [100, 8000] kW; the efficiency of each installation C_j is randomly determined on the interval [100, 200].

The results of the computer simulation are shown in Figures 2 and 3.

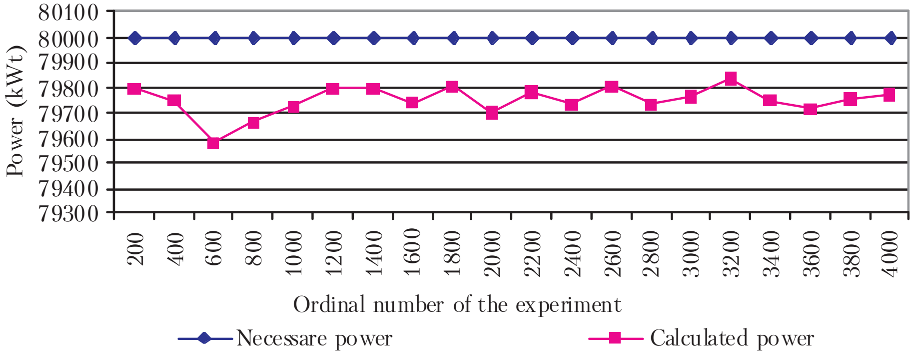

Figure 2. **The gained power of WPS in the course of computer simulation**

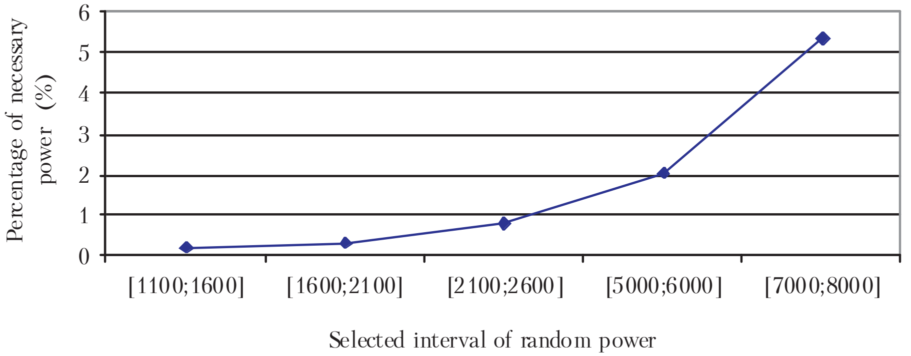

Figure 3. **Interest's dependence of not fullfilling a backpack from the interval of random power**

The solutions' domain of the problem Z $(Z \le P)$ has dispersed within the scope of R variation.

The mathematical expectancy of a discrete distribution is defined by the following expression:

$$M[Z] = \sum_{i=1}^{\infty} v_i p_i , \qquad (4)$$

where v_i – the solution to the problem of i-th experiment; p_i – the probability of the value v_i, where $\sum_{i=0}^{\infty} p_i = 1$.

Thus, as a result of solving the problem, the mathematical expectancy that is equal to $M[Z]$ = 79945.78 kW is gained. The difference between the desired power value and the discovered value of mathematical expectancy makes 0.068%. Therefore, by increasing the value of the input condition for 0,068% we will raise the distribution of random variables solutions and thereby draw nearer the scattering of solutions within the given power value.

The scope of variation is from R = 419 kW, the average linear deviation l = 36 kW, the variance of aggregate values $\sigma^2 = 2349$, the standard quadratic deviation σ = 48.46 kW, the linear coefficient of variation V = 0.045% and the quadratic coefficient of variation V = 0.06%.

Conclusion. On the basis of theoretical and experimental studies. The article offers the elaboration of the optimization method of wind power station with the use of integral evaluation of objects and the method of dynamic programming.

The analysis of the computer modelling results allows making the following conclusions to ensure the stability of the system, that is, to obtain more precise results for solving the problem, the value of the input conditions should be increased (that is the ordered power) to 0.52–5.33% (the percentage of the increase depends on the installed capacities of WPS — Figures 1 and 2).

Also it has been established that the solution to the problem of determining the optimal structure of the WPS with the help of dynamic programming can be implemented in real time.

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КНИЖКОВИЙ СВІТ

СУЧАСНА ЕКОНОМІЧНА ТА ЮРИДИЧНА ОСВІТА
ПРЕСТИЖНИЙ ВИЩИЙ НАВЧАЛЬНИЙ ЗАКЛАД

НАЦІОНАЛЬНА АКАДЕМІЯ УПРАВЛІННЯ

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Дипломатичний і міжнародний діловий протокол та етикет: Навчальний посібник. — К.: Національна академія управління, 2011. — 164 с. Ціна без доставки — 25 грн.

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У навчальному посібнику викладено основи дипломатичного і міжнародного ділового протоколу і етикету, з історією становлення української протокольної практики і протокольної служби.

Призначений для студентів, що вивчають спецкурс "Дипломатичний і міжнародний діловий протокол та етикет", а також для широкого кола осіб, яким за родом діяльності доводиться контактувати з іноземними установами, організаціями та громадянами.