Planning of an optimum regime of a power system with accounting for repair switching-off

Ali Farhan Muhsen

Yarmouk University, Hijjawi,
Faculty of Applied Engeneering,
51533 Irbid, Jordan.
E-mail: AliFarhan@yahoo.com

Oleg Igorevich Alexandrov

Belarussian National Technical University,
p/b 130, 220136, Belarus.
E-mail: sanoleg@mail.ru

The task statement and the description of the algorithm of optimal planning of active powers of the electro power plants (PP) of the power system (PS) in the period of repair campaign are discussed. In the stated task, the dynamics of different main PS equipment states in the transfer from the given time interval to the other with the corresponding variation of the functional aggregate structures is taken into account.

The task solution algorithm is composed imposing the corresponding limitations on the allowable fuel usage at the particular power plants. In the algorithm, a combination of the functional, time and spatial decomposition is applied.

Key words: optimal planning, repair, power plant, algorithm

1. INTRODUCTION

The development of effective methods to increase the economy of the current regimes of PS acquires actuality because of the developing power saving policy. Special importance in it belongs to the optimization calculations of the PS condition definition in the period of the main equipment repair switching off.

The optimization is performed by a well-known method of the branches and borders [1], where the process of determining the optimum active capacity value itself is defined on the every functional and condition hierarchy level. Taking into account the predictable values of the active and reactive loadings of the consumption units as well as the specified meanings of the extreme admitted power overflows in the intersystem connections solves the problem. The formulated problem is solved on two hierarchy levels: on the level of the PP and PS. For a more effective solution of the optimization complex problem, the method of spatial decomposition is applied, which allows decreasing the task dimension and gives the acceptable answer under condition of the insufficiently defined initial information.

The method gives the possibility to execute the correction of the optimal PS condition when initiating the limitations, also at fuel deficiency at separate PP. In this case the procedure of transfer from strict to mild restrictions is provided [2].

The optimization criterion is total fuel consumption at the PP including launching expenses. The objective function minimizes in a closed area defined by a condition-technical system of the restrictions that correspond to different demands. Various states of the aggregates of the PP and PS are characterized by a great number of corteges with logical variables (0.1 and 2) that define the scheduled moments of switching on, off and deactivating the equipment for repair. Conditions of possible transfers of each PP are described in a form of a graph, the vertex of which is the essence of the equipment composition and the branches indicate the presence of the transfers themselves.

2. FUNCTIONAL DECOMPOSITION OF THE TASK AND RECONCILIATION OF THE DECISIONS OF THE SUBTASKS OF THE ADJACENT LEVELS OF THE FUNCTIONAL HIERARCHY

In functional aspect in the given task two subtasks are allocated:

– selection of an optimum structure of the units involved at power stations (bottom level of hierarchy) and definition of the optimum daily diagrams of active loadings of stations (top level).

Let $\theta^{(0)}$, $\theta^{(1)}$, …, $\theta^{(r)}$ be the moments of time of a planned day appropriate to single out a discrete condition of the power system (PS), which are caused accepting the sampling of the daily diagrams of loadings in units of the basic network and given by a dispatching service of the PS (DS PS) of the diagrams of change of the intersystem overflow of active capacity, and also terms of the beginning and completion of repair of the generating and basic power network equipment caused accepted decisions on the earlier permitted operative requests. Then the task of a choice of optimal structures of the generating equipment is expedient to formulate as follows [3]:

$$\sum_{j=1}^{n}\sum_{t=1}^{T}\left[B_j\left(i_j(t), P_j(t)\right)+D_j\left(s_j(t-1), i_j(t)\right)\right]\to \min; \tag{1}$$

$$S(0)=\left\{s_j(0)\mid j=\overline{1,n}\right\}; \tag{2}$$

$$\left(i_j(t-1), i_j(t)\right)=(\nu,\mu),\ \nu\in X_j,\ (\nu,\mu)\in\Gamma_j^{(\nu)}, \tag{3}$$

$$y_{\nu\mu}\left(s_j(t-1), t\right)=1,\ j=\overline{1,n},\ t=\overline{1,T};$$

$$\sum_{j=1}^{n}P_j(t)-P(t)-\pi(t)=0,\ t=\overline{1,T}; \tag{4}$$

$$P_j^{\min}\left(i_j(t)\right)\le P_j(t)\le P_j^{\max}\left(i_j(t)\right),\ j=\overline{1,n},\ t=\overline{1,T}; \tag{5}$$

$$\sum_{j=1}^{n}P_j^{\min}\left(i_j(t)\right)\le(1-r_-)\left(P(t)+\pi(t)\right),\ t=\overline{1,T}; \tag{6}$$

$$\sum_{j=1}^{n}P_j^{\max}\left(i_j(t)\right)\ge(1+r_+)\left(P(t)+\pi(t)\right),\ t=\overline{1,T}. \tag{7}$$

Here, $S(t)=\left\{s_j(t)\mid j=\overline{1,n}\right\}$, $t=\overline{0,T}$ are conditions of the EPS, *i.e.* a set of traits describing the condition of the units of stations by the t-th moment of time;

$$S_j(t)=\left(\left(Z_j^{(1)}(t),\tau^{(1)}(t)\right),\left(Z_j^{(2)}(t),\tau_j^{(2)}(t)\right),\ \ldots,\ \left(Z_j^{(nj)}(t),\tau_j^{nj}(t)\right)\right),$$
$$j=\overline{1,n},\ t=\overline{0,T}, \tag{8}$$

$Z_j^{(k)}(t)$, $k=\overline{1,n_j}$, $j=\overline{1,n}$, $t=\overline{0,T}$ are the logic variables whose meanings are determined as

$$Z_j^{k}(t)=\begin{cases}0, & \text{the } k\text{-th unit of the } j\text{-th station by the } t\text{-th moment of time switched off in repair;}\\ 1, & \text{the } k\text{-th unit of the } j\text{-th station by the } t\text{-th moment of time switched off in reserve;}\\ 2, & \text{the } k\text{-th unit of the } j\text{-th station by the } t\text{-th moment of time switched on;}\end{cases}$$

$\tau_j^{(k)}(t)$ is the planned moment $\tau_j^{(k)}\ge\theta^{(t)}$ of the completion of repair at $Z_j^{(k)}(t)=0$, or the moment of switching off in a reserve $\tau_j^{(k)}<\theta^{(t)}$ at $Z_j^{(k)}(t)=1$, or the moment of inclusion of $\tau_j^{(k)}<\theta^{(t)}$ at $Z_j^{(k)}(t)=2$;

$i_j(t)\in A=\{1,2,\ldots,m\}$, $j=\overline{1,n}$, $t=\overline{0,T}$, $m=\sum_{j=1}^{n}\left|x_j\right|$ is number of structures of the units, included in the work, at the j-th station by the t-th moment; $\left(X_j,\Gamma_j\right)$, $j=\overline{1,n}$ is the number of the columns of transitions of structures of units at the j-th station at which any unit $\nu\in X_j$, $X_j\in A$, corresponds to one of the possible structures of units, and the branch $(\nu,\mu)\in\Gamma_j$ specifies the possibility of direct transition at a fixed moment of time from structure n to structure m; $\Gamma_j^{(\nu)}\subset\Gamma_j$, $\nu\in X_j$, $j=\overline{1,n}$ is a set of branches of the column $\left(X_j,\Gamma_j\right)$ from unit ν; $y_{\nu\mu}$, $\nu\in X_j$, $\mu\in X_j$, $(\nu,\mu)\in\Gamma_j$, $j=\overline{1,n}$ is a logic variable whose meanings are defined as

$$y_{\nu\mu}\left(s_j(t-1),t\right)=\begin{cases}1, & \text{transition from composition } \nu \text{ to composition } \mu \text{ from condition } s_j(t-1) \text{ in moment } t \text{ is possible;}\\ 0, & \text{transition from composition } \nu \text{ to composition } \mu \text{ from condition } s_j(t-1) \text{ in moment } t \text{ is impossible, } t=\overline{1,T};\end{cases}$$

$P_j(t)$, $j=\overline{1,n}$, $t=\overline{1,T}$ is the capacity of the j-th station on the t-th interval of time, *i.e.* interval $\left[\theta^{(t-1)},\theta^{(t)}\right]$; $P_j^{\min}(t)$, $P_j^{\max}(t)$, $j=\overline{1,n}$, $t=\overline{1,T}$ is a technical minimum of loading and the available capacity of the j-th station at the structure of units $i_j(t)$; $P(t)$ is the total active loading of the PS with the account overflow on intersystem communications; $\pi(t)$ denotes the loss of active capacity in the basic PS network on the t-th interval; $D_j\left(s_j(t-1),\ i_j(t)\right)$, $j=\overline{1,n}$, $t=\overline{1,T}$ are the charge of fuel on transition from condition $s_j(t-1)$ to structure $i_j(t)$; $B_j\left(i_j(t),\ P_j(t)\right)$, $j=\overline{1,n}$, $t=\overline{1,T}$ are the charge of fuel on the t-th interval at structure $i_j(t)$ and loading $P_j(t)$ of the j-th stations determined on the appropriate account characterising $B_j(t_j, P_j)$ as

$$B_j(i_j(t), P_j(t)) = \left(\theta^t - \theta^{t-1}\right) B_j\left(i_j, P_j\right);$$

$r_-, r_+, 0 < r_- < 1, 0 < r_+ < 1$ are the given factors of a reserve accordingly on a technical minimum and the available capacity of EPS.

From definition (8) components $s_j(t)$ and condition $S(t)$ it follows that in the case when the structures $i_j(t-1)$, $i_j(t)$ satisfy restriction (3), the condition $S(t)$ is unequivocally determined by condition $S(t-1)$ and structure $i_j(t), j = \overline{1,n}, S(t) = f(S(t-1), I(t))$,

where

$$I(t) = \{i_1(t), i_2(t), \ldots, i_n(t)\}.$$

The structures i_j (0) and set S(0) are known from the solution of the appropriate task for previous day. The columns of transitions (X_j, Γ_j), account characteristics $B_j(i_j, P_j)$, dependence of the charges on start-up or stop of units $D_j(s_j$ (t −1), (t)), logic functions $y_{\nu\mu}$ (s_j (t − 1), t), function $P_j^{min}(i_j)$, $P_j^{max}(i_j)$ can be determined in advance at the bottom level of spatial hierarchy, *i.e.* by solving a number of optimization tasks for each station. The values $P(t)$ are defined by summation of the forecasts of active loadings in units and given by DS PS overflow of active capacity on intersystem connections. The values $\pi(t)$ at the initial solution of the tasks are defined by forecasting the appropriate temporary number, and at the coordination of the solution of the given task and the tasks of the bottom level of functional hierarchy turn out as a result of the decision by last. The factors r_+, r_- are the given constants.

The condition $s_j(t)$, structures $i_j(t)$ and capacity $P_j(t), t = \overline{1,T}$ are defined by solving the task (1)–(7) by the method of branches and borders (see Application).

The subtasks of the bottom level of functional hierarchy are formulated as follows:

$$\sum_{t=1}^{T}\sum_{j=1}^{n} B_{tj}\left(P_j^t\right) \to \min; \qquad (9)$$

$$\sum_{j=1}^{n} P_j^t - \sum_{\nu=1}^{\ell} p_\nu^t - \pi^t\left(\mathrm{P}^t, \mathrm{p}^t\right) = 0, t = \overline{1,T}; \qquad (10)$$

$$-\overset{-}{P_k^t} \le \sum_{\nu=1}^{\ell}\left(C_{Pp,k\nu}^t p_\nu^t + C_{pq,k\nu}^t q_\nu^t\right) - \sum_{j=1}^{n} C_{PQ,kj,}^t Q_j^t -$$

$$-\sum_{j=1}^{n} C_{Pp,kj}^t P_j^t \le \overset{+}{P_k^t}, k = \overline{1,m}, t = \overline{1,T}; \qquad (11)$$

$$\sum_{t=1}^{T} B_{tj}\left(P_j^t\right) - B_j^{\Sigma} = 0, j \in I; \qquad (12)$$

$$P_{j\min}^t \le P_j^t \le P_{j\max}^t, j = \overline{1,n}, t = \overline{1,t}. \qquad (13)$$

Here P_j^t, $j = \overline{1,n}, t = \overline{1,T}$ are the required optimum active capacities of stations, Q_j^t, $j = \overline{1,n}$, $t = \overline{1,T}$ are known (from the solution of tasks of the top level of temporary hierarchy) jet capacities of stations, $p_\nu^t, q_\nu^t, \nu = \overline{1,\ell}, t = \overline{1,T}$ are the forecasts of active and jet loadings in consumer units of the basic network (or given overflow on intersystem communications); $P^t, p^t, t = \overline{1,T}$ are a vector of active capacities of stations and consumer units, respectively; $\pi^t(P^t, p^t)$, $t = \overline{1,T}$ is a loss of active capacity in the basic PS network; $I \subset \{1, 2, \ldots, n\}$ is a set of stations for which the daily charges of fuel are B_j^{Σ}, $j \in I$; $\overset{-}{P_k^t}, \overset{+}{P_k^t}$, $k = \overline{1,m}$, $t = \overline{1,T}$ is a given extreme admitted overflow of active capacity on the k-th weak communication in negative and positive directions are given; $C_{Pp,k\nu}^t, C_{Pq,k\nu}^t, \nu = \overline{1,\ell}, C_{Pp,kj}^t$, $C_{pQ,kj}^t$, $j = \overline{1,n}$, $k = \overline{1,m}$, $t = \overline{1,T}$ are factors of distribution,

$$B_{tj}\left(P_j^t\right) = B_j\left(\bar{i}_j(t), P_j^t\right), P_{j\min}^t = P_j^{\min}\left(\bar{i}_j(t)\right),$$

$$P_{j\max}^t = P_j^{\max}\left(\bar{i}_j(t)\right), j = \overline{1,n}, t = \overline{1,T}.$$

The algorithm of the solution of task (9)–(13) turns out if to accept

$$x_j^t = P_j^t, f_{tj}(x_j^t) = -B_{tj}(P_j^t), x^t = P^t;$$

$$h^t(x^t) = \sum_{\nu=1}^{\ell} p_\nu^t - \pi^t\left(\mathrm{P}^t, \mathrm{p}^t\right), x_{j\min}^t = P_{j\min}^t;$$

$$x_{j\max}^t = P_{j\max}^t, \Psi_{k\max}^t = -\overset{-}{P_k^t}, \Psi_{k\max}^t = \overset{+}{P_k^t};$$

$$\varphi_j^t\left(x_j^t\right) = B_{tj}\left(P_j^t\right), d_j = B_j^{\Sigma}, t = \overline{1,T}, j = \overline{1,n}, k = \overline{1,m}.$$

Subtasks (1)–(7) and (9)–(13) mutually parameterize the allowable set of solutions of a subtask of an adjacent level. The subtask (1)–(7) carries out this parameterization by inserting to subtask (9)–(13) the sets of optimum structures of the units, included in work, $\bar{I}(t)=\{\bar{i}_1(t), \bar{i}_2(t),...,\bar{i}_n(t)\}$, $t=\overline{1,T}$, and subtask (9)–(13) does it by setting to subtask (1)–(7) the value of losses

$$\pi(t)=\pi^t\left(P^t, p^t\right), t=\overline{1,T}.$$

The general procedure of the coordination of the solutions of subtasks of adjacent levels of a functional hierarchy is considered in [3].

3. PROVISIONAL DECOMPOSITION OF A TASK AND COORDINATION OF THE SOLUTIONS OF TASKS OF ADJACENT LEVELS OF TEMPORARY HIERARCHY

Lowering for the sake of simplicity restriction (12) on given daily charges of fuel at power stations and restriction (11) on overflow active capacity on weak communications of the basic PS network, will copy the task of short-term planning of active capacities as

$$\sum_{t=1}^{T}\sum_{j=1}^{n} B_{tj}\left(P_j^t\right) \to \min,$$

$$\sum_{j=1}^{n} P_j^t - \sum_{\nu=1}^{\ell} p_\nu^t - \pi^t\left(P^t, p^t\right) = 0, \; t=\overline{1,T},$$

$$P_{j\,\min}^t \le P_j^t \le P_{j\,\max}^t, \; t=\overline{1,T}, \; j=\overline{1,n}.$$

The formulated task breaks up into independently soluble subtasks of the bottom level of temporary hierarchy:

$$\sum_{j=1}^{n} B_{tj}\left(P_j^t\right) \to \min, \tag{14}$$

$$\sum_{j=1}^{n} P_j^t - \sum_{\nu=1}^{\ell} p_\nu^t - \pi^t\left(P^t, p^t\right) = 0, \tag{15}$$

$$P_{j\,\min}^t \le P_j^t \le P_{j\,\max}^t, \; j=\overline{1,n}. \tag{16}$$

A similar situation takes place also at the account of the lowered restrictions (11), (12) if uncertain Lagrange multipliers are used properly.

The problem of the coordination of the solutions of the adjacent levels of temporary hierarchy is to make the ut most use of the information saved while solving tasks (14)–(16) at the stage of short-term planning, in the cycle of operative management, when the same tasks should be solved changing some components of the initial information:

– change of loads in consumer units $p_\nu^t, \nu=\overline{1,\ell}$, in comparison with their predicted values (or overflow on intersystem communications in comparison with the given one);

– change of the account characteristics $B_{tj}\left(P_j^t\right)$, $j=\overline{1,n}$, of power stations (and accordingly of restrictions (15) owing to emergency switching-off of units);

– change of losses $\pi t(P^t, p^t)$ because of the emergency switching-off of elements of the basic power network equipment;

– occurrence of the fuel deficiency at separate power stations because of changes of their modes in comparison with those planned or because of a delayed delivery of fuel.

The basis for construction of algorithms to ensure the effective coordination of the decisions at adjacent temporary levels is:

– fast recalculation of the tables [3] by the method of dynamic programming at partial change of criterion functions and restrictions in tasks (14)–(16);

– distribution of the method of dynamic programming on a case inseparable of functions in restrictions – equality such as (15).

4. SPATIAL DECOMPOSITION OF A TASK AND COORDINATION OF THE SOLUTIONS OF SUBTASKS OF ADJACENT LEVELS OF SPATIAL HIERARCHY

The spatial decomposition of the tasks of acceptance of the decisions on the management of EPS modes can pursue the following goals:

1. To reduce the quantity of the information acting on the top level of management, reducing the loading of channels of connection and network server.

2. To lower the dimension optimization of tasks solved at the top level, thus raising the computing efficiency of the optimization algorithms.

3. To ensure guaranteed satisfactory decisions at the top level in conditions of inadvertent or conscious distortion of information from the bottom levels.

In the optimization of active capacities of power stations in the PS, an example of a subtask in which spatial decomposition is made for the first two of the mentioned purposes, is the task of optimum short-term planning of structures of the generating equipment. The initial information for the appropriate mathematical model includes a number of components, which should be determined at the bottom level, *i.e.* by solving a number of optimization tasks on power station in the PS: the account characteristics $B_j\left(i_j, P_j\right)$, $j=\overline{1,n}$, for various structures of the units involved at the j-th station; the fuel charge characteristics on transition from various condition

$s_j(t-1)$, including the operational condition of each unit of the station at the moment $t-1$, to structures $i_j(t)$ of the units involved at the moment t. The columns $\left(X_j, \Gamma_j\right)$, $j=\overline{1,n}$ of at-once possible transitions from one structure to another on the j-th station and logic functions $y_{\nu\mu}$ $(s_j(t-1), t)$ determining the conditions of realization of possible(probable) transition from structure $\nu \in X_j$ at the moment $t-1$ to structure $\mu \in X_j$ at the moment t depending on the condition at the moment $t-1$. Figure gives an illustrative example of a column of at-once possible transitions for the j-th station (in brackets are shown the numbers of units forming structures appropriate to the tops of the column) are specified. The functions $y_{\nu\mu}$ $(s_j(t-1), t)$ appropriate to the loops of the column are constants:

$$y_{11} = y_{22} = y_{33} = y_{44} = y_{55} = y_{66} = y_{77} = 1.$$

Examples of the areas of the validity of logic functions appropriate to start up or stop one unit are given below:

$$\left(Z_j^{(2)}(t-1)=1\right)\wedge\left[(\theta^{(t-1)}-\tau_j^{(2)}(t-1)\le\right.$$

$$\left.\le\bar{\theta}_j^{(2)})\vee\left(\theta^{(t-1)}-\tau_j^{(2)}(t-1)\ge\overset{+}{\theta}{}_j^{(2)}\right)\right]\to$$

$$\to y_{14}\left(S_j(t-1),t\right)=1,$$

$$\left(Z_j^{(2)}(t-1)=2\right)\wedge\left(\theta^{(t-1)}-\tau_j^{(2)}(t-1)\ge\theta_j^{(2)}\right)\to$$

$$\to y_{41}\left(S_j(t-1),t\right)=1,$$

where $\overset{-}{\theta}{}_j^{(k)}, \overset{+}{\theta}{}_j^{(k)}, \theta_j^{(k)}$ is the respective duration of k-th transition of the unit after switching off in a cold reserve, duration of its translation from the cold to hot reserve, minimally allowable duration of loading.

For example, the spatial decomposition of the task of optimization of active capacities of power station in the PS allows to receive the satisfactory solution at a doubtful initial information. It occurs in case of unforeseen deficiency of fuel at separate stations.

Analysis of deviations of the actual PS modes from the planned daily mode and delayed delivery of fuel to separate power stations revealed that at these stations deficiency of fuel took place. Then, on correcting the mode on the nearest interval of the bottom temporary level in dispatcher service (DS), PS should be received by an expert way or from the decisions of the appropriate tasks of the bottom level of spatial hierarchy of an estimation of the allowable charges of fuel at scarce stations during the specified interval. The task of the top level in such conditions is expedient to formulate as a task of multi-purpose optimization:

$$\sum_{j=1}^{n} B_j\left(P_j\right)\to\min,$$

$$B_j\left(P_j\right)\to\min,\ j=\overline{1,k},$$

$$\sum_{j=1}^{n} P_j-\sum_{\nu=1}^{l} p_\nu-\pi\left(\tilde{P}\right)=0,$$

$$P_{j\min}\le P_j\le P_{j\max},\ j=\overline{1,n},$$

$$B_j\left(P_j\right)\le B_{j\max},\ j=\overline{k+1,n},$$

where $B_j\left(P_j\right)$, $j=\overline{1,n}$ are the account characteristics of the power stations; $P=\left(P_j\right)$, $j=\overline{1,n}$, $p=$ $=\left(p_\nu\right)$, $\nu=\overline{1,\ell}$ are the respective vectors of active capacities of the stations and loadings in units of the basic network of the power system; $P_{j\min}$,

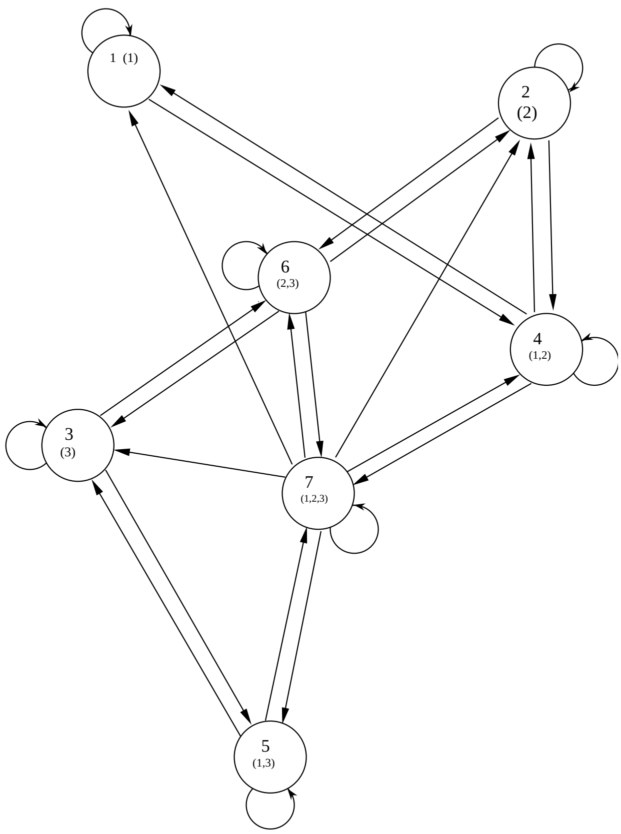

Figure. Example of a column of at-once possible transitions for the j-th station (the numbers in brackets show the units that form structures corresponding to the tops of the column)

$P_{j\max}$, $j=\overline{1,n}$ are the respective technical minima of loading and the available capacities of the power stations; $B_{j\max}$, $j=\overline{k+1,n}$ are the allowable charges of fuel at stations not scarce on fuel; $\pi(\tilde{P})$ is a loss of active capacity in the basic network (jet capacities in the generating and consuming units of the basic network as well as the factors of transformation in parts of this network are assumed as given).

The algorithm of the decision of this task is given in [3]. If the result of solving the task shows that the loading of the power system cannot be covered at the actual fuel resources at these stations, it is necessary to impose rigid restrictions on the allowable charges of fuel at scarce stations and to ensure the possibility of an output of the actual charges of fuel at not-scarce stations for the earlier given limits. For this purpose it is necessary to proceed from rigid restrictions under the allowable charges of fuel at not-scarce stations to blurred restrictions. Then at an appropriate choice of the functions of an accessory of blurred sets it is possible with a guarantee to receive the acceptable solution of a task.

5. CONCLUSIONS

Presumptive methods of the decomposition of the task of the optimal day scheduling of the aggregate structure on the PS carry out transition from the formulated task of optimization to individual, independently soluble subtasks, allowing to reduce the total operating time of the whole algorithm.

Combination of methods of functional, temporary and spatial decomposition allows to create a system of off-schedule artificial restrictions and thus to construct the floppy computing circuit in view of a various degree of reliability of information blocks.

The method of dynamic programming allows to receive the solution of a formulated task of optimization irrespectively of the characteristics of PS equipment.

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THE APPLICATION

Calculation of an integrated bottom rating and vector of dot bottom ratings for the initial task of optimization

With the purpose of calculation of the bottom rating for task (1)–(7), the following subtask is considered:

$$\sum_{j=1}^{n}\sum_{t=1}^{T} B_j(i_j(t), P_j(t)) \to \min; \quad \text{(a.1)}$$

$$i_j(t)\in X_j,\ j=\overline{1,n},\ t=\overline{1,T}, \quad \text{(a.2)}$$

$$\sum_{j=1}^{n} P_j(t) - P(t) - \pi(t) = 0,\ t=\overline{1,T} \quad \text{(a.3)}$$

$$P_j^{\min}(i_j(t)) \le P_j(t) \le P_j^{\max}(i_j(t)),\ j=\overline{1,n},\ t=\overline{1,T}; \quad \text{(a.4)}$$

$$\sum_{j=1}^{n} P_j^{\min}(i_j(t)) \le (1-r\_)(P(t)+\pi(t)),$$

$$j=\overline{1,n},\ t=\overline{1,T}; \quad \text{(a.5)}$$

$$\sum_{j=1}^{n} P_j^{\max}(i_j(t)) \ge (1+r_+)(P(t)+\pi(t)),$$

$$j=\overline{1,\text{n}},\ t=\overline{1,T}. \quad \text{(a.6)}$$

This subtask breaks up into independently soluble subtasks:

$\sum_{j=1}^{n} B_j(i_j(t), P_j(t)) \to \min$ (a.7) at restrictions (a.2) – (a.6) with fixed *t*. Each of them can be solved by the method of dynamic programming (MDP). For our purposes, it is enough to define the optimum values of

$F_{\min}(t), t=1,T$ of resanation functions (a.7).

Direct course of MDP. Functions are defined and their values are memorized:

$$F(y,1)=\min B_1(i_1,y),$$
$$i_1\in X_1$$

where

$$\min P_1^{\min}(i_1)\le y\le \max P_1^{\max}(i_1),$$
$$i_1\in X_1,\quad i_1\in X_1$$

and also function, $\bar{i}_1(y)$ where $\bar{i}_1(y)$ satisfies the condition

$$B_1(\bar{i}_1(y),y)=F(y,1)$$

and function

$$\bar{P}_1(y) = y .$$

At $\tau = \overline{2, n}$ for the values of y from an interval

$$\sum_{j=1}^{\tau} \min_{i \in X_j} P_j^{\min}(i_j) \le y \le \sum_{j=1}^{\tau} \min_{i \in X_j} P_j^{\min}(i_j) \quad \text{(a.8)}$$

the following task of optimization of two variables, i_τ and P_τ, is solved:

$$B_\tau(i_\tau, P_\tau) + F(y - P_\tau, \tau - 1) \to \min , \quad \text{(a.9)}$$

$$i_\tau \in X_\tau ; \quad \text{(a.10)}$$

$$\max(P_\tau^{\min}(i_\tau), y - \sum_{j=1}^{\tau-1} P_j^{\max}(\bar{i}_j(y_j))) \le P_\tau \le$$

$$\le \min(P_\tau^{\max}(i_\tau), y - \sum_{j=1}^{\tau-1} P_j^{\min}(\bar{i}_j(y_j))) ; \quad \text{(a.11)}$$

$$P_\tau^{\min}(i_\tau) + \sum_{j=1}^{\tau-1} P_j^{\min}(\bar{i}_j(y_j)) \le (1 - r\_) y ; \quad \text{(a.12)}$$

$$P_\tau^{\max}(i_\tau) + \sum_{j=1}^{\tau-1} P_j^{\max}(\bar{i}_j(y_j)) \ge (1 + r_+) y ; \quad \text{(a.13)}$$

where

$$y_j = y_{j+1} - \bar{P}_{j+1}(y_{j+1}) , \; j = \overline{1, \tau - 2} ; ,$$

$$y_{\tau-1} = y - P_\tau . \quad \text{(a.14)}$$

As a result of the solution of a family of tasks (a.9)–(a.13), (a.8), the functions are defined: $F(y, \tau)$, $\bar{i}(y)$, $\bar{P}_\tau(y)$, where $\bar{i}(y)$, $\bar{P}_\tau(y)$ are components of the solution of task (a.9)–(a.13), $F(y, \tau)$ is the respective value of criterion function (a.9).

One can see that the given description results of the unitary executed direct course are valid for all subtasks (a.14), (a.2)–(a.6). Besides, at everyone $\tau = \overline{2, n}$ there is no necessity to remember the value of function $F(y, j)$ for all $j = \overline{1, \tau - 1}$; it is enough to keep only $F(y, \tau - 1)$.

Return course of MDP. For the given subtask (a.7), (a.2)–(a.6) at fixed t the value is defined:

$$F_{\min}(t) = F(P(t) + \pi(t), n) .$$

For subtask (i.1)–(i.6), which we shall designate as R_0, the following information is memorized:

1) Vector of dot bottom ratings

$$F_0 = (F_0(1), F_0(2), \ldots, F_0(T)),$$

where

$$F_0(t) = F_{\min}(t) , \; t = \overline{1, T} .$$

2) Integrated bottom rating

$$f_0 = \sum_{t=1}^{T} F_0(t) .$$

3) The moment T_0 appropriate to the last finally known state for the given subtask

$$T_0 = 0.$$

4) A sequence of finally known statuses for the given subtask consisting of a sole state

$$S_0(T_0) = S(0).$$

Ali Farhan Muhsen, Olegas Igorevičius Aleksandrovas

ELEKTROS ENERGETINĖS SISTEMOS OPTIMALAUS REŽIMO PLANAVIMAS ĮVERTINANT REMONTO ATJUNGIMUS

S a n t r a u k a

Straipsnyje pateikta uždavinio formuluotė ir elektrinės aktyviųjų galių darbo algoritmas elektros energetinėje sistemoje (EES) remonto kampanijos metu. Sprendžiant uždavinį įvertinama EES pagrindinių įrenginių darbo dinamika pereinant nuo vieno laiko intervalo į kitą, keičiant dirbančius agregatus. Uždavinio sprendimo algoritmas aprėpia leistiną kuro suvartojimą atskirose elektrinėse. Algoritme panaudotas funkcinis, laiko ir erdvės dekompozicijos derinys.

Raktažodžiai: planavimas, optimalus režimas, elektrinės, remontas, skaičiavimo algoritmas

Али Фарган Мухсен, Олег Игоревич Александров

ПЛАНИРОВАНИЕ ОПТИМАЛЬНОГО РЕЖИМА ЭЛЕКТРОЭНЕРГЕТИЧЕСКОЙ СИСТЕМЫ С УЧЁТОМ РЕМОНТНЫХ ОТКЛЮЧЕНИЙ

Р е з ю м е

В статье приводятся постановка задачи и описание алгоритма оптимального планирования активных мощностей электростанций (ЭС) электроэнергетической системы (ЭЭС) в период проведения ремонтной кампании. В сформулированной задаче учитывается динамика различных состояний основного оборудования ЭЭС при переходе от одного временного интервала к другому с соответствующим изменением состава работающих агрегатов. Алгоритм решения задачи составлен с учетом соответствующих ограничений на допустимые расходы топлива на отдельных электростанциях. В алгоритме применено сочетание функциональной, временной и пространственной декомпозиции.

Ключевые слова: планирование, оптимальные режимы, алгоритм расчета, ремонты, электростанции