The Unit Commitment model for the Smart grid

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Abstract: - This mathematical model allows calculation of Unit Commitment (hereinafter - UC), providing for compliance with all technical limitations in the equipment state and electricity regime parameters to ensure the minimization of the total cost of electric power generation, as determined on the basis of notifications wholesale market participants on the composition and parameters of the generating equipment and filed with the participants of market price bids UC including the cost of power units. Finally, a dynamic model of investment for the smart grid is formulated, using UC technology.

Key-Words: - Electricity market, price, reactive power, unit commitment, prosumer, investment

1 Introduction

Unit commitment (UC) technology allows competitive bidding to choose the composition of the generating equipment, and has fundamentally changed the approach to the selection of power plant capacity. Previously, the procedure for choosing the composition of the generating equipment (UC) was switched on, didn't have a market algorithm and was solved by collecting data on all generating units and then applying mathematical programming methods. This problem can be solved by the market, by encouraging suppliers who must voluntarily provide objective data [1-8].

All organizations in the market (infrastructure organizations and members of the wholesale market) are involved in UC concrete blocks or part of its generating equipment (and not against the whole power station). The existing UC technology some principles of hydro power plants: first, the system operator manages the hydroelectric directly, as the main instrument for regulating the regime in real time, and secondly, the cost of commissioning a hydro is minimal. Also excluded from the UC procedures are nuclear power plant (start/stop nuclear power plants, mainly associated with their repair and not very often because of their low mobility) and some (small) thermal power plant (mode/regime of the generators and boilers of thermal power station is mainly determined by their heat load).

The paper is organized as follows. In Section II, the formulation of the UC model is explained. Section III describes the selection of applications and planning regimes, while Section IV describes the business process of UC technology. Finally, in Section V dynamic model of investment for the smart grid, using UC technology, is formulated and in Section VI conclusions are shown.

2 The mathematical model of UC technology

The objective function represents the ***amount of the cost of produced electrical energy***, taking into account physical limitations.

Physical constraints related to physically realizable electrical regimes.

$$\sum_d \sum_t^T \sum_g \left(\sum_{b \in B} \left(c_b^2 \underline{P_b} \delta_{bt} + \Delta_b \overline{P_b} \left(\delta_{bt} - \delta_{b(t-1)} \right)^+ \right) + \sum_b \sum_l^L c_b^l P_{bt}^l \right) \quad (1)$$

where,

B, L, T – number of power blocks, number of price levels, and time horizon, respectively;

c_b^l – price of electricity;

$\underline{P_b}$, $\overline{P_b}$ – technical min and max active capacity of block b;

Δ_b – start-up cost of block b by 1 MW to $\overline{P_b}$

d – days of UC;

δ_{bt} – Boolean variables (1-committed, 0-decommitted) of the status production of block b by the end of t;

$(\cdot)^+ = \max\{0, \cdot\}$ – positive part;

r_{bt}^+, r_{bt}^- – value of reserves for loading/unloading to the end of the period t (in MW);

P_{bt}^l – power output variables, denotes the loads of block b with price level l to the end of period t.

If the balance sheet constraints, constraints on reactive power, the rate reset/set the load and capacity-controlled sections of the limitations of competitive selection electricity market (bilateral and balancing market) variables

$$P_{gt} = \sum_b \sum_l^L P_{bt}^l \quad (2)$$

$$\sum_i p_{ij}^t + \sum_g P_{gt} = \sum_c P_{ct}$$

for all t each node j, where sum is over all generators g and consumers c, related to the node j, and for all nodes i in the network, adjacent to the node j;

(3) is the same ratio of constraint for reactive power q_{ij}^t:

$$\sum_i q_{ij}^t + \sum_g Q_{gt} = \sum_c Q_{ct} \quad (3)$$

The dependence of power flow on the branches of the network voltage is provided in the following equation:

$$p_{ij}^t = G_{ij} \left[u_i^{t2} - \frac{u_j^t u_i^t}{v_{ij}} \cos(\beta_i^t - \beta_j^t + \alpha_{ij}) \right] + Q_{ij} \left[\frac{u_j^t u_i^t}{v_{ij}} \sin(\beta_i^t - \beta_j^t + \alpha_{ij}) \right] \quad (4)$$

$$q_{ij}^t = Q_{ij} \left[u_i^{t2} - \frac{u_j^t u_i^t}{v_{ij}} \cos(\beta_i^t - \beta_j^t + \alpha_{ij}) \right] - G_{ij} \left[\frac{u_j^t u_i^t}{v_{ij}} \sin(\beta_i^t - \beta_j^t + \alpha_{ij}) \right] - u_i^{t2} C_{ij} \quad (5)$$

for all branches (i, j) and all moments t,

where, G_{ij}, Q_{ij}, C_{ij} – active, reactive and capacitive conductivity of branch;

α_{ij}, v_{ij} – coefficients of phase and transformation, if (i, j) branch is transformer, otherwise $\alpha_{ij} = 0$, $v_{ij} = 1$;

$$\sum_{i,j \in S} p_{ij}^t \leq \overline{p_s^t}, \qquad \sum_{i,j \in S} p_{ji}^t \leq \underline{p_s^t} \quad (6)$$

for all t and by dispatcher S.

And also block constraint by variables

$$P_{bt} = \sum_l^L P_{bt}^l \quad (7)$$

where technical min and max $\underline{P_b}$, $\overline{P_b}$ of block b – for all b, formally setting $\delta_{bt} = 1$ for blocks, which are included on the set (SO) regime of the inclusions.

For not involved in the optimization:

$P_{bt} = 0$, if $\delta_{bt} = 0$, and

$r_{bt}^- + \underline{P_b} \leq P_{bt} \leq \overline{P_b} - r_{bt}^+$, if $\delta_{bt} = 1$; (8)

Constraints specified the minimum SO in generation g are the following:

$$P_{gt} > \underline{P_{gt}^S} + \sum_b r_{bt}^-$$

for all g, t; (9)

Constraints by hot reserves $P_{it}^{\pm}$ for all i, t :

$$\sum_{b} r_{bt}^{\pm} > P_{it}^{\pm} \tag{10}$$

Constraints on the conditions of application - for all b, g, l, t, d :

$$0 < P_{bt}^{l} < \overline{P_{bt}^{l}} - \overline{P_{bt}^{l-1}} \tag{11}$$

if the application was no evidence,

$$0 < \sum_{t} P_{bt}^{l} < \sum_{t} \left(\overline{P_{bt}^{l}} - \overline{P_{bt}^{l-1}} \right) \tag{12}$$

formally set $\overline{P_{bt}^{0}} = 0$.

A selection of the equipment should cover the maximum load consumption electric power system (EPS), and separate regional power systems with statutory reserves of the reserves of active power to load generation equipment, as well as passing night minimum load in the presence of reserves at discharge, with possible factors: fluctuations in consumption, emergency stop generating capacity, the emergency department of any EPS parts (working in the planned mode synchronously with the EPS), as well as restrictions on the capacity of the electrical network.

In [9-13] a brief description is provided of the business process in existing UC technology, with the selection of applications and planning regimes.

Two planning phases can be identified:

1) on the day ahead, when each plant, in accordance with the electricity supply contract, receives a schedule, made up of two parts, for the next day. The first part is based on the balancing market, the second part on the wholesale market through the conclusion of bilateral agreements between the plant and the consumers.

2) real-time dispatching teams adjust the current plan for the balancing market.

In step 2, the system operator gives the command based on a simple rule: reset (discharge), the most expensive in these plants, and recovery (load increase), the cheapest (except for hydro).

To participate in UC, members register with the system operator (SO) the following parameters of the generating units:

- Technical min, max of blocks
- Time start/stop unit
- types of graphics set and load shedding,
- min-uptime (default is 2 hours)
- min-downtime (default - 36 hours)
- limitation on the number of starts per week (1 time)
- speed dial and reset the unit load in the normal control range.

The SO determines regimen generators based on the methodology.

3 The selection of applications and planning regimes

The UC is a typical (ordinary) week (hereafter: the UC week), which starts on the Saturday of the current week and ends on the Friday of the following week. In the existing technology, UC makes two optimization calculations. The first calculation is prevalent, and its result determines the choice of generating equipment for the entire week UC (all 7 days). The second calculation is adjusted in relation to the former, according to the results clarified the choice of generating equipment at the end of the current UC week (Wednesday-Friday).

A calculation adjustment is required in order to take into account the data of the actual start / stop for the Friday – Monday segment of the UC week (as indicated, the data may be different from the start/stop schedule, which was planned according to basic calculation, for example, due to either system failures or to a unit not running according to the UC plan and therefore signalled for replacement or include other block, which was to be turned off). In addition, at the end of the UC week consumption forecasts appear more accurate, due to refinement of weather forecast and other forecasts (hydro restrictions, thermal load graphics and other forced modes of generators, etc.). With the development of UC technology, there may be several corrective calculations (clarification of the basic UC calculation prior to settlement of day-ahead market will also be conducted on a formal - the optimization procedure). What is the benefit for providers involved in UC?

First, their UC price bids affect the system operator's decision whether to include, or not to include, the generating equipment supplier in the start/stop schedule - a low price of a start-up application is more likely to lead to the selection of its equipment, and vice versa.

Secondly, the specified provider receives a fee for its start-up generation equipment based on the results of the UC optimization calculation. The current UC technology also is not supposed to be paid in case of shutdown.

Price on application UC members serving commercial operators, who in terms of routine transfers them to the system operator for the optimization calculation UC. Price filed an application once before the UC week and operate throughout the UC week, and these requests for production of electricity act like that is indicative defining indicators - upper bounds for applications filed per day.

The administration trader collects and transmits to the SO an indicative pricing proposal (on electricity) suppliers with respect to all blocks and preferences (regime-generating units) irrespective of participation in UC. Price on application UC party includes:

• The price of production of electric energy on the block. The rates specified in that application are then used as the upper limit prices for the bids of the party in the market the day ahead. If the participant subsequently indicates in day-ahead applications market prices above the price of electrical energy production in the UC application, then they will automatically "cut" a commercial operator to price in the UC application. This requirement is logical, because when the block was included as a result of the UC procedure, it was assumed that the electrical energy produced at such a unit will cost no more than the price specified in the UC application;

• The start-up cost of the block. When the unit is started, it takes some time to reach a set of Pmin values and to synchronize operation with the central power system. During this time the station fuel consumption, and the value of which indicates participant in the application (in addition to the cost of the start-up unit, it may include other costs decided by the party);

• The shut-down cost of the block. Each of these parameters is taken into account when planning the boot schedule of the blocks in the week ahead.

4 Business process in existing UC technology

A short business process in existing UC technology consists of the following steps.

Let the day Z be Saturday this week (the first day of the UC week). On the day Z-2 (Thursday, two days before the start of the UC week) the system operator:

- establishes a UC week preliminary topology of electrical networks with network constraints, the light received from the network companies confirmation of readiness for the repair of network equipment in accordance with the planned schedule;
- makes a preliminary decision on the planned during the UC week for repair of generating equipment.

On the morning of Z-2 (Thursday, 2 days before the beginning of the UC week):

- vendors will claim to the system operator on the actual day and advanced to next week UC data on the readiness of the generating equipment according to agreed schedules repairs;
- providers will transmit commercial operator pricing UC application for all their blocks;
- commercial operators will send these requests to the system operator.

On the same evening, Z-2, the system operator for the UC week:

- specifies the consumption outlook and reserve requirements and other parameters affecting the solution of the UC problem (for example, the system operator specifies a list of secure units, that is, those units that must be incorporated into the work under the terms of reliability, regardless of their bids. Start for such units not yet paid, although in future it may be introduced as a payment system for generators);

- generates an updated computational model on the Z-day and a set of planned/predictive computational models for a UC week;

- solves the problem of optimizing UC with the initial day Z-1 (prepared on the day Z-2 on the basis of all previous UC calculations) and a forecast for the week, then reports the results to participants and commercial operators. The decision determines the equipment choice for any day with the Z on Z +3 (for bidding on PC B) and equipment pre-selection for the last remaining days of the week UC - Z +4, Z +5, and Z +6.

- on the day Z +2 (Monday, third day in the UC week), the system operator specifies the consumption outlook, reserve requirements, and other parameters of the problem and UC:

- generates an update computational model for the day Z +3 and a set of planned/predictive models for the days Z +4, Z +5, and Z +6 (based on the actual start/stop data for days Z, Z +1 and Z +2);

- solves the problem of optimizing UC with the initial data for the day Z +2 and a forecast for the UC weekend. His decision determines the choice of equipment for days (Z +4) - (Z +6) for bidding on the day ahead market.

In addition to the results UC (selection included generating equipment for a week UC / weekend UC) have the following procedure, also affecting the choice of the generating equipment for the day-X:

- vendors claim the actual state of the system operator (confirm availability) generating equipment for a day X and the rest of the week before the day UC Z;
- for the deterioration of the parameters of the generating equipment readiness decreases the amount of payment for the power received by the supplier.

In an ideal picture of the equipment choice for day X, as close to real time as possible, should coincide with the equipment choice, made in the course of solving the UC optimization problem. However, in real conditions, due to such reasons as:

- consumption was higher / lower than had been taken into account in solving the UC problem;
- one of the vendors was not ready to run the required system operator blocks;
- the networking company launched an unscheduled repair of their facilities, which influenced the choice of generating equipment;
- the choice of equipments on the day X for some blocks may differ from the results of solving the UC problem.

If, for whatever reason, the UC problem was not solved (the optimal solution was not found or the optimization process is not limited, or there is a malfunction in the software, etc.) or solved incorrectly, for example, are not provided with capacity reserves for unloading or loading, the system the operator selects the composition included generating equipment based on old technology, which operated until the introduction of formal UC technology. However, in this case, none of the participants receives a fee for launches.

At the end of each month, the system operator transmits to a commercial operator the list of blocks, which ran this month work based on the procedures UC. For each of these blocks, on the day ahead market an additional requirement arises, the amount of which is the product of the value of the starting block at its installed capacity.

The funds that providers should get for their UC launches for the billing period are collected from all wholesale customers by adjusting their prior commitments and requirements. The value of gross adjustments for each wholesale buyer is calculated as directly proportional to the difference between its maximum and minimum planned hourly consumption for that month. This difference characterizes the unevenness of consumption, and it is logical that the costs of start-up units were covered in proportion to this index.

Everything that was described earlier in this section relates to a UC technology working as planned, in advance of selecting the work units and thereby defining a timetable for their downloads. Meanwhile, start-up units occasionally have to exercise in real time (in the balancing market [12, 16-18]). Such launches, for example, occur when there is an emergency, and (or) consumption suddenly goes up dramatically; in these cases, in order to balance generation and consumption, the system operator has to give commands to turn the blocks in real time. The fee for real-time launches is always - regardless of whether the block is involved in UC or not - based on the price value of launches in the balancing market, which is reported separately when applying for the day ahead market.

We can apply the following dynamic model of investment for the smart grid [12-15], where UC technology is used.

5 Dynamic investment model

A development of the electricity market requires innovation and investments on devices for smart grid technology, that increases efficiency thanks to the use of power generation facilities and the delivery of uninterruptible, high quality consumer-centered power services [19-22].

The establishment of the smart grid [15] will not only solve future energy problems and improve the quality of life, but also bring other benefits, such as creating new jobs, reducing greenhouse gas emissions, lowering dependence on energy imports, increasing exports, creating domestic consumption, and avoiding the need to build new power plants.

The Smart Grid Establishment and Usage was enacted to promote the development and usage of a stable, systematic smart grid, to actively cope with global climate change by establishing the legislative or regulatory grounds for fostering the related industries, and to contribute to the innovation of the energy usage environment and development of the national economy, by establishing a green, low-carbon, growth-oriented future industrial base.

At limited opportunities for investment development the following should be taken into account:

- establishment of regulatory basis for the smart grid, and utilization and protection of energy information and securing reliability, stability, and interoperability of information;
- development of financial support for the establishment of smart grid infrastructure, and its systematic designation;

- promotion of smart grid international cooperation, PR, business support and export;
- management of comprehensively power IT and smart grid R&D project;
- technology development;
- power industry structure;
- demand management, billing system;
- metropolitan investment financing mechanisms, including reinvestment (domestic and foreign investment capital, implementation, timing, and financial sharing etc.)

In market conditions, the optimal criteria for energy development are purely economic criteria: maximization of profit, return on investment, etc. Given the limited availability of investment funds from external sources, as well as the possibility of equity accumulation in the form of reinvested profits. Dynamic investment performance criteria should include a reasonable discounting procedure.

Socio-economic assessment options for developing the smart grid system are given over a period of time with the reflection of the formation of these estimates over time. An important role is played by the procedure of comparing and aligning costs and benefits occurring at different times to a single point in time. In this dynamic optimization it is necessary to consider energy development and to evaluate current costs and investment in new construction and renovation of its operation for the period of power development and output optimum mode of operation.

Let's consider the following dynamic model. N sectors of electricity market can be divided into segments or objects, which are subdivided into M new construction objects or modernization (reconstruction) objects.

Let's enter the following notations:

W – total amount of investment attracted on developing the electricity market;

x_i – share of W aimed at the development of sector i $(i = \overline{1,N})$;

$W_i = W x_i$ - volume of investment in sector i;

W_i^τ – investment into new/reconstructed objects in sector i in the period τ;

G_{ij}^τ – power setpoint of new/reconstruction object j in sectors i in the period τ;

c_{ij}^τ – cost of new/reconstruction object j in sector i in the period τ;

G_{0j}^τ – power setpoint in sectors i, realization existing at the beginning of the period τ;

$\bar{G}_{ij}^\tau$ – maximum power setpoint of new/reconstruction object j in sectors i;

W_l^τ – total investments from allocation source l in the period τ;

m_l – price of investment from allocation source l (credit percent);

$\overline{W_l^\tau}$ – maximum receipt of funds on investments from l allocation source in the period of τ;

ΔW_i^τ – balance of investments of new/reconstruction objects in sector i at the end of period τ (therefore, $\Delta W_i^0 = 0$);

V_k^τ – demand of electricity generation/power from producer k in the period of τ;

u_k^τ – power price/profit of generator/producer k during τ;

r_{ik} – normative load in sectors i of producer k that corresponds to the offered standard determined by indexes (ik);

α_τ – reduction coefficient of expenses/profit sum in period τ by realization beginning time: $\alpha_\tau = 1/(1+r)^{s^\tau}$, $\tau = \overline{1,T}$ where s^τ – time horizon, which has passed since the beginning of realization until the end of the period τ;

T – number of the periods into which realization term is divided;

r – interest rate;

β – normative coefficient of payback on investment profit in the electricity market $\beta = 1/t_a$: where t_a – average payback period in the electricity market on investment profit;

s_τ – time horizon in period τ;

A_{re}^τ – assignments from profit on reinvestment in period τ;

A – tax assignments in shares from balance profit;

L – set of investments sources;

l_c – set of investment sources from own accumulation.

The dynamic optimization model is formulated as:

$$\sum_{\tau=1}^{T}\sum_{k=1}^{K}\alpha_\tau s_\tau u_k^\tau V_k^\tau - \sum_{\tau=1}^{T}\beta\alpha_\tau\sum_{i=1}^{N}W_i^\tau - \\ -\sum_{\tau=1}^{T}\sum_{\substack{l=1\\ l\neq l_c}}^{L}\alpha_\tau W_l^\tau m_l \rightarrow max \qquad (13)$$

Balance of power by sectors:

$$\sum_{k=1}^{K} r_{ik}V_k^\tau - \sum_{t=1}^{\tau}\sum_{j=1}^{M}G_{ij}^t \leq G_{0i}^\tau$$

$$i = \overline{1,N}, \quad \tau = \overline{1,T} \qquad (14)$$

Balance of investment by power reconstruction:

$$\sum_{j=1}^{M} c_{ij}^{\tau} G_{ij}^{\tau} \leq W_i^{\tau}$$

$$i = \overline{1,N}, \quad \tau = \overline{1,T} \quad (15)$$

Restrictions on the amount of new/reconstruction work of existing facilities:

$$\sum_{t=1}^{\tau} G_{ij}^{t} \leq \bar{G}_{ij}^{\tau}$$

$$i = \overline{1,N}, \quad j = \overline{1,M}, \quad \tau = \overline{1,T} \quad (16)$$

Balances on the formation and use of investment areas:

$$\sum_{i=1}^{N} W_i^{\tau} \leq \sum_{l=1}^{L} W_l^{\tau} + \sum_{i=1}^{N} \Delta W_i^{\tau-1}$$

$$\tau = \overline{1,T} \quad (17)$$

Investment sources:

a) By fund investments generated from their own savings in previous periods:

$$\sum_{t=1}^{\tau} W_{l_c}^{t} \leq \sum_{t=1}^{\tau-1} \sum_{k=1}^{K} s_{\tau} u_k^t V_k^t A_{re}^t (1-A)$$

$$\tau = \overline{1,T} \quad (18)$$

b) According to other investment sources (from the state budget, local budget, foreign investments, etc.):

$$W_l^{\tau} \leq \overline{W_l^{\tau}}, \quad l = \overline{1,L} \quad l \neq l_c$$

$$\tau = \overline{1,T} \quad (19)$$

c) On receipt of the investment balance (unused funds at the end of the period) after the period τ :

$$\sum_{i=1}^{N} \Delta W_i^{\tau} = \sum_{i=1}^{N} \left(W_i^{\tau} - \sum_{j=1}^{M} c_{ij}^{\tau} G_{ij}^{\tau} \right)$$

$$\tau = \overline{1,T} \quad (20)$$

Variables:

$$G_{ij}^{\tau}, W_i^{\tau}, V_k^{\tau}, W_l^{\tau} \geq 0,$$

$$i = \overline{1,N}, \quad j = \overline{1,M}, \quad \tau = \overline{1,T}, \quad k = \overline{1,K} \quad (21)$$

The proposed model of investment attractiveness, based on the balance of demand, existing and new capacity, can be used to determine the volume of necessary investments and their temporal structure by sector and facilities, the funding development in stages and source of funds, as well as the optimal structure and dynamics of directions.

Solution series of the problem in the previous stage are calculated power input objects resulting from new construction and reconstruction of facilities:

$$\sum_{j=1}^{M} G_{ij}^{\tau-1} \quad (22)$$

In (14) these additional facilities are added to the stage τ to the initial power (phase $\tau-1$) objects of this sector:

$$G_{0i}^{\tau-1} + \sum_{j=1}^{M} G_{ij}^{\tau-1} \to G_{0i}^{\tau}$$

$$. \quad i = \overline{1,N} \quad (23)$$

In (16) keep in mind that reserve power is reduced by objects already spent and reconstruction in the previous phase:

$$\bar{G}_{ij}^{\tau} - G_{ij}^{\tau-1} \to \bar{G}_{ij}^{\tau}$$

$$i = \overline{1,N}, \quad j = \overline{1,M} \quad (24)$$

We can decompose the model as a system of interrelated models in stages to the following terms and obtain a model for an arbitrary phase τ, given the results of (23)-(24) for the system development for the preceding stages $\tau-1$.

$$\sum_{k=1}^{K} \alpha'_{\tau} s_{\tau} u_k^{\tau} V_k^{\tau} - \beta \alpha'_{\tau} \sum_{i=1}^{N} W_i^{\tau} - \\ - \sum_{\substack{l=1 \\ l \neq l_c}}^{L} \alpha'_{\tau} W_l^{\tau} m_l \to max \quad (25)$$

In model $\alpha'_{\tau} = (1+r)^{-\frac{s_{\tau}}{2}}$ where s_{τ} – time horizon in period τ, as income and costs are reduced to the initial year of each period, and their income is uniformly distributed within the period. The discount factors are meaningful reduction coefficients: they cite the effects obtained for the time horizon s_{τ} (assuming they even produce income for the time horizon s_{τ} to the start time of each period τ). As a fixed common factor α'_{τ} in the objective function, it does not affect the choice of optimal development and functioning of market on stage τ. However, the resolution of any problems with the above calculation for T periods plays an important weighting effect at each stage.

The use of their own savings as a source of investment requires, as early as possible, to make full use of the funding for profit development and return on investment at the previous stages. This forms the basis for own savings while separately maximizing the return on investment at each stage.

Restrictions on fund investments generated from their own savings consider the reinvestment funds from profits generated in the previous period. Therefore, by solving the phase $\tau - 1$ for the formation of the task steps τ value is calculated:

$$\sum_{k=1}^{K} s_{\tau-1} u_k^{\tau-1} V_k^{\tau-1} A_{re}^{\tau-1} (1 - A) \tag{26}$$

Deductions from the balance profits to pay loan interest are determined on the basis of data on investment from the previous years. Factor $s_{\tau-1}$ means that the maximum average profit obtained in step $\tau - 1$ should be multiplied by the time horizon in the period. It is up to the sum of profits and deductions are taken to increase production in the subsequent period.

Investments for new/reconstruction projects should not exceed the amount of external sources of the period and accumulated by the time funds.

The proposed model, decomposed into subtasks to be solved sequentially on temporary stages, basically solves the dimensionality problem. The dimensions of the programming problems at each stage are reduced in T time.

As a result, the solution series of T tasks

$$\sum_{\tau=1}^{T} s_\tau$$

The carrying amount of the reduced earnings for the entire period T is determined by the formula:

$$\sum_{\tau=1}^{T} \alpha_\tau \left[\sum_{k=1}^{K} \alpha'_\tau s_\tau u_k^\tau V_k^\tau \right] \tag{27}$$

The numbers in square brackets are the sum of the balance sheet profit derived from the values of the objective function in an optimal solution for each stage τ, excluding interest payments on loans and reduced amounts of investment.

The reduced amount of net income for the period T can be calculated taking into account the interest payments on loans and tax deductions:

$$\sum_{\tau=1}^{T} \alpha_\tau \left[\sum_{k=1}^{K} \alpha'_\tau s_\tau u_k^\tau V_k^\tau (1 - A) - \sum_{\substack{l=1 \\ l \neq l_c}}^{L} \alpha'_\tau W_l^\tau m_l \right] \tag{28}$$

If the period T has duration of not less than the standard term of return on investment, the cost-effectiveness of development can be identified by the reduced value of the net increase in assets for the period T:

$$\sum_{\tau=1}^{T} \alpha_\tau \left[\sum_{k=1}^{K} \alpha'_\tau s_\tau u_k^\tau V_k^\tau (1 - A) - \sum_{i=1}^{N} \sum_{j=1}^{M} \alpha'_\tau W_{ij}^\tau - \sum_{\substack{l=1 \\ l \neq l_c}}^{L} \alpha'_\tau W_l^\tau m_l \right] \tag{29}$$

Optimal values V_k^τ indicate the optimal structure and dynamics of power different directions. It's on standard, which can be implemented in stages of the period, based on the types and proportions. Optimal values W_l^τ determine the allocation of investment sources by stages.

Values $c_{ij}^\tau G_{ij}^\tau$ define the detailed investment program: the direction of funds for new and reconstruction objects in each sector, as well - the temporal structure of the investment program (index τ). Optimal values G_{ij}^τ show the necessary sequence (index τ) of new and reconstruction objects in each sector.

Substituting the optimal values of the above variables in the constraint, we obtain the corresponding balances on capacities and resources justifying the optimum realization of its development $(0, T)$.

Addressing global challenges requires a large-scale influx of mid-term investment and the creation of an effective mechanism to attract them and use both at the state. The need for organizations to invest in the energy sector causes great practical need for research investment process (e.g. in Mongolia) and the theoretical justification for choosing the directions of investment activity.

6 Conclusion

As a result of solving an optimization problem, a UC model was used to determine the optimal composition of the generating equipment. The optimal mix ensures a minimum price of electricity supply and helps to reduce electricity prices. UC ensures openness and transparency in the functioning of the electricity market, and the use of indicative bids more understandable to consumers and producers.

UC technology can be used in the electricity market in Mongolia, especially in view of the central PES of Mongolia.

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