Influences on the Optimization of the Energy System

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Abstract: The purpose of this paper is to highlight some aspects of the production process characteristics of the energy system operation. So, in the first part it highlights the continuous nature of the production process ant the unstorable character of the finished product and their influence on the curves of the load on the types of functional power plants in the energy system. In the second part it is following the sequences that optimize the energy system, starting from the nuclear power plants, the individual producers power plants, the optimization of the hydro electric plants and finally the optimization of the thermal electric plants. Because the optimization of the energy system needs to ensure maximum efficiency in the production, transport and distribution of the electric energy, as well as safe operations during the process, this paper follows the perspective of reducing resources comsuption and implicitly of costs.

Key-Words: Production Process, Energy System, Power Plants, Hydro Electric Plants, Charge Curves, Optimum Value

1 Introduction

Based on a dramatic decrease of resources, industry seeks to ensure energy needs from domestic production and to limit the dependence on imported energy resources, Nowadays more and more governments and institutions in the field is actively involved in optimal exploitation of energy resources and the development of projects promoting the use of regenerable resources, in the implementation of long-term strategies aiming the optimization of the energy system [1]. Regardless of what point of view we have on this optimization – financially speaking, or, from the resources independence side – the most important influences are related to the complexity character of the technological process.

The main characteristic of the production process within the energetic industry is the fact that there is a close connection between the generation and the consumption of electricity, the phases of electricity generation process and those of the consumption process blend together, and this makes the use of production capacities depend on the operational command of the national energy dispatcher, and in underlying an energetic strategy it should analyse all these aspects in detail. Therefore, due to shape of the daily consumption curve and allowing for the implication of electric power plants in covering the lead chart of the energy system (figure no. 1) which has ups and downs, as well as intermediary areas, electric power plants fall into three categories [3]: basic power plants, semi-basic power plants and peak power plants. In order to obtain electricity, according to the energetic source and the used technology, the generating processes are mainly carried out in four types of electric power plants: thermal power plants using natural gas, black oil or coal; hydroelectric power plants using the forces of water; nuclear power plants using uranium as raw material; power plants based on non-conventional technologies (wind-driven, solar, bay-type power plants etc.).

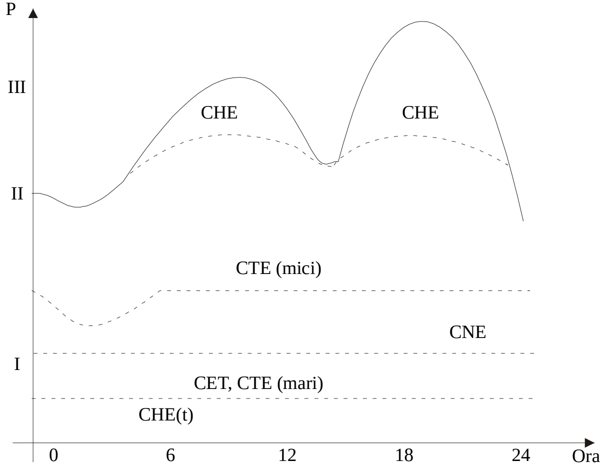

Figure.1.Covering the load chart of the energy system

Source: Potolea E., Tudose M. *Electro-energetic*

Systems, U.P.B. Publishing House., Bucharest, 1998

The coordinates of production processes within the energetic industry can be: the generation process is continuous; in dimensioning the generation capacities the peak consumption must be taken into consideration and this fact leads to a miss-usage of the existent production capacity, because part of it is needed only during the peak hours of the energetic system; in order to ensure a continuous supply of electricity to consumers it is necessary to provide a margin of energy because electricity cannot be stored; the coefficients for using fixed assets are relatively low compared to other industrial branches and they vary a lot because they are activated before electricity consumers become operational; the period of time needed to reach normal functioning parameters is uncertain [2]; the use of production capacities is closely related to the economic efficiency at system level.

2 Optimization methodology

2.1 Configuration of charge curves

Since production is continuous and the final product cannot be stored, the efficient use of electrical power plant depends on the charge curves form, on their filling or flattening. Observing the charge curves in different periods (daily, weekly, annual curves, etc) shows they deviate from the form corresponding to the optimum use of the energy production and transport installations, these deviations are due to the consumption specific regimes of the main users.

Therefore, the best estimation of the charge curve configuration is important both from the future investments in top, basic or semi-basic plants point of view and from the electric charge optimization between power plants point of view. These charge curves represent the variation of the electric energy consumption in time, while depending on the period, their graphic representation is found within the charge graphics.

The value of the maximum charge the energy system needs to provide varies from one period to another, mainly due to the consumption variation.

The value of the maximum power varies as well, strongly connected to the electric charge, being also influenced by other factors, such as the natural background or by the permanent increase of consumption, which makes the maximum of one month to be different to the maximum of the same month from the previous year, as you can see in figure 2.

Curve 1, called static curve, reproduces the variation of the maximum charges only based on the organizing conditions, while curve 2, called dynamic curve, is more realistic, as it takes into considerations all the factors (natural background, execution of repairing graphics for the system energy equipment), while straight 3 represents the charge increase.

The frequency of the monthly maximums, as seen above, may be determined from the classed curve which allows the determination of the yearly energy and the possibility of highlighting the power plant types (NEP – nuclear electric plant, HEP – hydro electric plant, TEP – thermal electric plant) which ensure the charge necessity and the length of monthly maximum power.

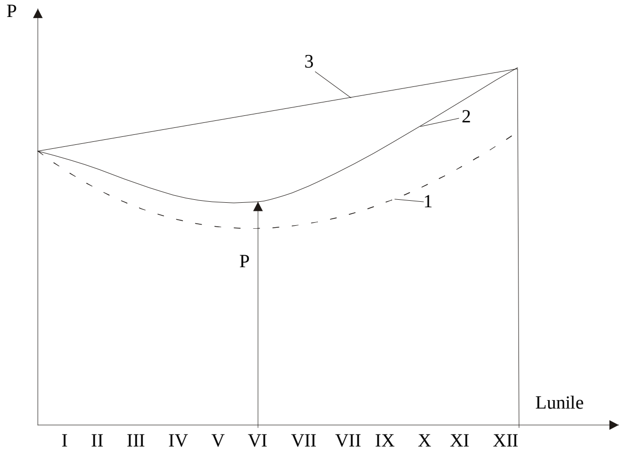

Figure 2
Charge curve evolution during one year

Knowing the yearly variation and frequency for the maximum charge, it’s needed to determine the daily charge variation which usually will have the form as seen in figure 3.

The basic values of this graphic are the minimum power $P_{\min}$, which is obtained in the point of the charge curve with the lowest ordinate, the maximum power $P_{\max}$, which is obtained in the point with the highest ordinate, and the average power P_{med}, which results from the report $E/24$.

Within the main values of the charge curve we can meet the following correlations:

$$\alpha = \frac{P_{\min}}{P_{\max}}, \qquad (1)$$

where α represents the minimum coefficient determined by the report within the minimum and maximum powers

$$\gamma = \frac{E_{24}}{24P_{\max}} = \frac{P_{med}}{P_{\max}} \qquad (2)$$

where γ is the filling coefficient and results from the report between the average power P_{med} and the maximum power $P_{\max}$.

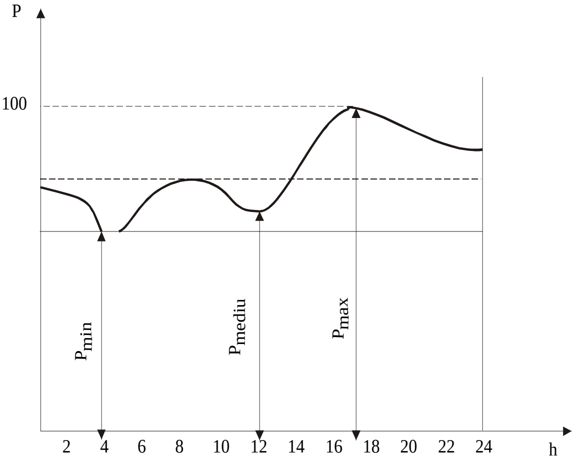

Figure 3
The daily charge curve

The index α and γ depend on the consumption type and may have large variations. Therefore α may be 0 in case there isn't any night consumption and may be 1 for continuous industries. The report between the maximum and minimum charges represents the maximum coefficient [2].

$$\alpha_M = \frac{P_{\max}}{P_{\min}} \qquad (3)$$

For the top area (limited by the paralels with x-axis from the minimum point of the curve), the filling coefficient γ_V has the expression:

$$\gamma_V = \frac{E_v}{24(P - P_{\min})} \qquad (4)$$

2.2. The optimization of the hydro energetic systems

In the next stage, from the charge curve we subtract in the first place the power given by the self-production power plants -m- and the nuclear electric power plants –n- (apart from the reparing periods), afterwards the aim is the optimization of the hydro energetic systems.

The optimization of the hydro energetic systems aims to determine an exploitation way which to ensure „high water value" through using the same water quantity in turbines in different time periods. This value allows taking an immediate decision, so if the future utility of the water is higher, the decision is to store the water for future use, while if the water utility is currently higher, the decision is to immediately fill the turbines with water.

So, picking the right decision aims to maximize the profit from the production of electric energy considering that water, although a non-valuable fuel, may be associated to the fictional cost of producing one KWh of electric energy which to meet the economic value which may be obtained in the future by using the stored water in turbines.

Mathematically, on short term, for the optimization of this system types it is used the linear programming, while for the optimization on medium and long term it is used the dynamic stochastic programming which allows a calculation method for the variable coefficients which are associated to the water stock from the seasonal storage.

These coefficients are represented as follows:

- T the time period between the initial moment t_i and the final moment $t_f : T = t_f - t_i$

- $VS(S,t)$ the economic value of the stock *(S)* at the moment *t*;

- $v(S,t_f) = \delta VS(S,t_f)/\delta S$ which determines the transition between the stock S_i at the initial moment t_i and the stock S_f at the final moment *t* with the result *X* of the random factors

If φ_f is the S_f coefficient in the objective function of the *P* problem, this can be written as follows:

MAX (capitalized production $+\varphi_f \cdot S_f$), (5)

or

MIN(production costs $+\varphi_f \cdot S_f$) (6)

The main restrictions taken into consideration are:

the superior and inferior limits imposed to the debits, powers and volumes;

the hydraulic results of the accumulations for every step and node of the hydraulic system.

The hydraulic result restriction in the initial moment t_i is written:

S_f + evacuated volume = S_i + afluent volume

Let δ_1 the immediate value of one m^3 of water from the stock S_i.

By solving the linear problem $P(t_i, t_f, S_i, S_f, x)$ we get the values S_f for data $S_i \varphi_f$ and *x*. Applying the dynamic programming principle leads to the iterative determination of the value $\varphi^* f(x) = v(S_f, t_f)$ which obtains the equality between the value $\varphi^* f$ postulated in *P* as being assigned to the marginal cubic meter from the stock S_f and the effective value $v(S_f, t_f)$ assigned to the same cubic meter through recurrent calculation of dynamic programming. This solution is given the dual value δ_i^*.

It is considered $v(S_i, t_f, x) = \delta_i^*$.

Thus, it is calculated the function $v(S_i, t_f, x)$ for which one can study the *x* probability law.

Thus, it was calculated a value $v(S_i, t_i)$ of the initial stock in the moment *i*, starting from the value of the stock after period *T*.

The dynamic programming in calculating the optimum value for using water is characterized by the correlation of the occurrence probability of various random factors which may influence the electric energy production in different time periods. In case there are present probability elements grouped in a prediction vector *Y* (which gives the possibility of highlighting the correlations between the water stocks, drought periods and heavy precipitation periods), the dependency of the value $v(S_f, t_f, x)$, may be written as follows:

$$v(S_f, t_f, y) = \text{expectation} \qquad x / y(S_f, t_f, x) \tag{6}$$

On short term, the optimization of the hydro electric plants is done in safety conditions and uses linear programming.

In this case, the objective function may be represented by the economic value produced by the accumulated water management during the analyzed problem, adding the stock value, case where this function is maximized – or represented by the production cost during the same period, subtracting the stock variation, case where the objective function is minimized [5].

The objective function for the hydro electric facilities is expressed below:

$$MAX\left(\sum_{t,c} i_c \cdot D_{t,c} \cdot d_t + \sum v_f \cdot \Delta S\right) \tag{7}$$

where:

i - the capitalization coefficient of one transited cubic meter;

D - the debit of the control unit;

d - the established value of time (hours);

v_f - the water value at the end of the analyzed period;

ΔS - the algebric difference of water stock variation during the analyzed period;

t - the basic time period index (hours);

c - the debit control unit index;

f - the seasonal accumulation index.

Short term optimization of a mixed hydro-thermal energetic system assumes the building of an objective function which has as variables both the power of the thermal electric plants and the production cost of one KWh electric energy in this kind of plants, therefore it is expressed as:

$$MIN\left(\sum_{t,s} C_s \cdot P_{t,s} \cdot d_t + \sum v_f \cdot \Delta S\right) \tag{8}$$

where:

C - the proportional cost of the thermal electric plant;

P - the thermal electric plant power;

Δ - the thermal electric plant index.

c). In the third stage, after drawing the charging graphics of the hydro electric plants and of the imposed power plants (self-production and nuclear power plants) the charge difference needs to be covered by the thermal electric plants.

Short term optimization (daily and hourly) of the thermal electric plants starts from the daily charge graphic of the system which includes also the estimated network losses, the technic-economic characteristics of the plants and the available power at plant terminals. For the hourly optimization it starts from the minimization o the hourly conventional fuel consumption in the thermal electric plants.

$$C = \sum_{i=1}^{n} C_i(P_i) \tag{9}$$

$$i = 1,2,...,n$$

where:

C_i - hourly conventional fuel consumption of the plant *i*;

P_i - active power produced by the plant *i*;

n - the number of thermal electric plants in the system.

For optimizing the fuel consumption in thermal electric plants there are considered the energetic characteristics of the energy groups with different forms depending on the turbine type (energy groups with or without outlets) and on he regulation method for the steam input (counter-pressure groups and turbine steam capture outlets) [4,5]. Regarding the cover for an electric and thermal charge in a moment or for a period it may be calculated the optimal allocation using the linear or non-linear, stationary or dynamic mathematic models, for an established period. Since the electric and thermal charges vary, both for 24 hours interval and for longer periods, meeting the demand may be done through a constant or variable number of groups. The optimization of the electric plant functions is done by solving the deterministic and probabilistic models with discrete and continuous structure, starting mainly from the Euler integral written as [2]:

$$F_E = \int_{t_1}^{t_2} F(P_i, P_i')dt = minimum \quad (10)$$

where:

P_i – demanded power ;

P_i' – power derivative P_i ;

F_E – Euler functional.

If there is considered a variation ΔF_E of F_E , the minimum condition is met if $\Delta F_E = 0$

$$\Delta F_E = \int_{t_1}^{t_2} \left[\frac{\partial F}{\partial P} \cdot \partial P(t) - \frac{\partial F}{\partial P'} \cdot \partial P'(t) \right] dt$$
$$\Delta F_E = \int_{t_1}^{t_2} \left[\frac{\partial F}{\partial P} - \frac{d}{dt}\left(\frac{\partial F}{\partial P'} \right) \right] dt = 0 \quad (11)$$

From the variation calculus theory we observe that the minimum extreme of this functional is obtained if the storing expenses $\frac{\partial F}{\partial P}$ are equal to the marginal expenses $\frac{d}{dt}\left(\frac{\partial F}{\partial P'} \right)$. In case the storing expenses are lower than the marginal expenses, the production volume needs to vary with the demand, otherwise, it is more advantageous to store the current stock. Since the electric energy is not a storable product, and the power plants work connected to the national energy system, the distribution of the electric charges is done both for every plant and for the entire energy system, with and without taking into consideration the energy losses of the connection networks. In both cases the aim is to minimize the expenses during the production.

At power plant level, if the energy groups have linear characteristics then their charge is done in ascending order of the additional specific consumption while for the non-linear characteristics, the groups functioning together accomplish the optimum condition if their additional specific consumption are equal.

The optimum charge of the groups functioning together is done by solving the following equation systems:

$$\begin{cases} \frac{dBh_1}{dQh_1} = \frac{dBh_2}{dQh_2} \\ Qh_1 + Qh_2 = Qh \end{cases} \qquad \begin{cases} \frac{dQh_1}{dP_1} = \frac{dQh_2}{dP_2} \\ P_1 + P_2 = P \end{cases} \quad (12)$$

where :

Bh_1, Bh_2 – fuel quantities ;

Qh_1, Qh_2 – steam quantities ;

P_1, P_2 – the powers of the two groups ;

Qh – the steam quantity needed for obtaining the power P ;

P – the imposed power by the consumer.

The characteristics of the boilers and turbines are determined for stable conditions. For the plants with automated processes, the additional losses in transit conditions are not significant, therefore thus calculated characteristics are used also for the charge variation situations. The consumption characteristics of the turbines and boilers include the internal services with two components: the constant component of ≈ 40 % ; the variable component (≈ 60 %) which varies proportionally with the charge and is part of the consumption characteristic of the affected aggregate.

Another important energetic characteristic for the optimization of the thermal electric plants is the fuel consumptions recorded at the start of the aggregates, reason why this charging and starting period is considered part of the normal exploitation process [4].

The fuel consumption at boiler start is used for the warm-up and for covering the charge losses in that period, depending on the usage interruption times and the technic state of the boiler. Regarding turbines, for the warm-up period and for important charge variations which appear during the activity, there are no additional energy losses.

The starting period of the turbo-aggregate represents at most 5% of the total working hours in one year while the average heat consumption at start is quite equal with the idle consumption (10-15 % of the heat consumption for nominal charge). For optimizing the repartition of the charges to plants, the total fuel consumption is determined by adding the consumers on time sub-intervals whose delimitation is done in case of fixed aggregates combination and an unique consumption characteristic. The starting consumptions are compared to the total fuel consumption established for the next sub-interval where the plant works with the same aggregate combination and if the duration of the second sub-interval is too long, the starting consumptions may be neglected.

In the final stage of the algorithm, after determining the structure and the number of quantum energy produced in the hydro electric plants, within the working thermo electric groups there is generated a structure, depending on their efficiency. Therefore, for every analysed structure, it is taken a decision, and among all there are eliminated the ones who do not allow the consumption of the entire quantity of hydro electric energy. Through filtering the remaining decisions, it is picked the one which ensures the production of electric energy with the lowest expenses.

3 Conclusions

From analyzing the optimization method of the power plant activities for covering the system's charge electric curve we get the following conclusions: the hydro electric plants cover the basic charge curve area, with the electric energy corresponding to the minimum power, the remaining energy participating exclusively to covering the variable area of the charge curve. This plant type have an important participation to the charge curve during weekdays because [6]: of the reduction of the electric charge and curve flattening in weekends; the hydro electric plants have a different share within the yearly energy production proportionally with the evolution of the hydro factors; the marginal cost of the system is higher during summer compared to winter, because the participation of the hydro electric energy is lower, while a series of thermal and nuclear electric plants are stopped during summer because of the missing thermal heating charge. Because the optimization of the energetic system works needs to ensure maximum efficiency in the production, transport and distribution of the electric energy but also the work safety, lately, the research institutes and specialists from the energetic industry were busy developing various software to ensure an efficient economic management of the energetic resources.

References:

[1] Dura, C., *Management strategic*, Universitas Publishing House, Petrosani, 2007

[2] Carabulea A., *Industrial systems management*, Polytechnic University Litography, Bucharest, 1994

[3] Potolea E., Tudose M. *Electro-energetic Systems*, U.P.B. Publishing House, Bucharest, 1990

[4] Vaida V. *Energy market management*, Perfect Publishing House, Bucharest, 2011

[5] Vaida V. *The operating modes of power systems management*, Mirton Publishing House, Timisoara, 1998

[6] Vlădescu A. and others. – „*The covering method of the charge curve by the electric plans from the national electric energy system – basic process for developing the selling / buying contracts in the electric energy market*", Energetica no. 10/2001