Power Plants Feasibility Studies Supported by Stochastic Programming Software

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***Abstract* – The paper is dedicated to the power plants feasibility study, which can be considered as a first step of a long way design, construction and commissioning of power plant. This task is hundred years old, but with the market tools implementation on power systems operation and planning the feasibility study conditions change substantially. The criteria for maximizing the profit of stakeholders of power plant should be reformulated. The criteria may contain the uncertain and random variables. The task assumes stochastic programming form. The needs for additional large amount of information appear. As a result, the task becomes much more complicated which necessitates the creation of new algorithms and software tools for its solution. The paper is devoted to a description and justification of the developed software product and its application to real plant feasibility study.**

***Keywords* – Feasibility studies, optimization of power plant, planning, stochastic programming.**

I. INTRODUCTION

Aspiration of the global community towards increased power supply efficiency and reducing the influence of power generation on the environment motivated power systems restructuring process, intended for ensuring market conditions and free competition within generation and sales of energy [1]. As a result of restructuring, the monopolies that ensure power supply is replaced by a number of independent (more or less) companies striving to increase their gain and competing, in general case, with each other. New conditions predetermine significant changes for the planning of energy systems development in general and planning construction of power plants in particular.

First step in the design of new power plants should be devoted to the feasibility study. As a result of this study a place of construction, type of fuel, the connection diagram to the power grid are selected; the necessary capital expenses, the amount of produced energy, the proceeds from its sales and cost of production are estimated. Usually, power plants planning issues are formulated in the form of profit maximization problems. For this purpose, designers use a number of economical criteria, such as NPV, IRR, payback time [2, 3]. In this paper we limit ourselves using only NPV, while generality is not lost, since outlined below algorithm can be easily extended to compute and other economical criteria.

A second accepted limitation depends on the type of power plants under consideration. Cogeneration, combined heat and power (CHP), gas turbine and/or steam turbine power plants are treated (applied in this paper).

Value NPV is given by equation below [2]:

$$NPV(i,N)=\sum_{t=0}^{N}\frac{R_t}{(1+i)^t} \qquad (1)$$

where t – time of the cash flow, i – discount rate (rate of return that could be earned on an investment in financial markets with similar risk, R_t – net cash flow i.e. cash inflow and cash outflow, at time t.

Cash flow within 12 months will not be discounted for NPV purpose. Investments during the time interval from the initial design to power plant start-up are summed up with a negative cash flow.

In NPV criterion value assessment greatest difficulties arise in computing net cash flow R_t, because profits depend on chart (working diagram), construction (structure) and regime of the power plant, fuel and energy prices, ambient temperature. Several of these parameters change over time and can be described in terms of stochastic functions [4].

To avoid difficulties in estimating of power plant economic efficiency a scenario approach and replacing random variables and stochastic processes by their time average values are used [2, 3, 5].

Time average values could be chosen in different ways. There is known and applied methodology that is based on the division of the year into the seasons (winter, spring, fall, and summer) and a selection of typical days (working or holiday) for each season. In this case, the mean values of each day are used and revenues are calculated for each season based on the number of typical days.

Another methodology is based on a division of the year on the months and use of the corresponding mean values [2, 3] for cash flow calculation. The disadvantage of these methodologies is the impossibility of considering the real price (example is presented on Fig. 1.) changes in market conditions that occur every hour. Prices, temperature changes have influence on choice of day-ahead mode of power plant operation and cash flow R_t.

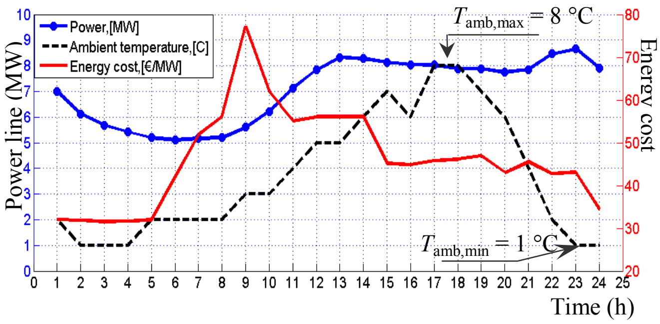

Fig. 1. Daily curve example.

As a result, in the absence of detailed information on changing operational environment of power plant impossible to prove its mode of operation. Irregularity of the load is taken into account very roughly by introducing the concept – the number of hours of use maximum power [6].

The second problem is related to the need to deal with uncertainty by using the scenario approach.

With this approach the variables describing the scenario lose their uncertain nature. However, this simplification is achieved due to the fact that final decision making process becomes more complicated [6].

Number of scenarios, which are taken into account and the combination of uncertain parameters can be very large, what complicates the choice of suitable alternatives of power plant design and decision about choosing the best one among them. In practice, the progress of the project is accompanied by negotiations with investors, with companies – suppliers of equipment, landowners. Some of the values initially uncertain parameters become known and a necessity to recalculate the criteria appears. As a result, feasibility studies of project are performed multiple times that leads to additional time and cost.

II. Essence of New Method

The NPV definition solution issue based on calculation of the net cash flow, which can be described as:

$$R(t,\Delta t) = \varphi[x_1(t), x_2(t), \ldots x_n(t); \Delta t; \Pi], \qquad (2)$$

where $x_1(t)$, $x_2(t)$, are time depending parameters which influence cash flow, namely plant electrical and thermal power, energy and fuel prices, ambient temperature. Δt – time interval under consideration; Π – includes parameters which are time independent (investment and maintenance cost, investors and stakeholders interest rate).

Analyzing (2), it can be claimed that powers, energy price and temperature are random, time dependent parameters which are correlated to each other [5]. Correspondingly, also R_t is a random time function. Multidimensional random process can be transformed by discretization of the function R(t) to a number of time periods [5]:

$$\begin{matrix} t_1, t_2, \ldots, t_n < t_{PL} \\ t_1, t_2, \ldots, t_K \end{matrix}, \qquad (3)$$

where T_{PL} is length of planning period.

Multidimensional probability distribution function Φ can be assigned for each random value $x_i(t_i)$ and for each time period t_i. These distribution functions can be described as [5]:

$$\Phi(x,t) = \Phi[x_1(t_1); x_2(t_2); .. x_n(t_1); .. x_1(t_k); .. x_n(t_k)) = \Phi[x(t_i)] \qquad (4)$$

Having the probability distribution functions the average cash flow can be calculated as:

$$M[R(x(t_i))] = \Delta t \int_{-\infty}^{+\infty} \ldots \int_{-\infty}^{+\infty} R(x(t_i)) d\Phi(x(t_i)) \qquad (5)$$

Analyzing equation (5) one can easily state that probabilistic approach has led us to formulation of extremely complicated target function for given problem. In order to estimate the NPV value according to (1) the multidimensional integral should be calculated. It should be added that for the considered task the dimension of the integral can be huge, since the planning period for the power plants is normally 25–40 years. At the same time the electricity prices, temperature, thermal load can vary considerably on hourly bases. This means that the number of discrete time periods leading to the dimension of the integral can become hundreds of thousands. Moreover, in specified task it is necessary to operate with at least three correlated processes. In this case autocorrelation and correlation functions should be taken into account [5]. It can be confirmed, that in order to avoid labor-intensive calculations it is necessary to limit the number of sampling time moment, because each moment should be described by the distribution function. For this purpose, as was mentioned above, it is possible to use detachment of year into few specific days. The distribution functions of the parameters for each of such days can be approximated for example by Pearson charts [6]. However, this kind of analysis is still demanding a lot of efforts. This paper presents the new approach to solve the problem.

The algorithm for estimation of the power plant net cash flow, described below (see Fig. 3), is based on the following assumptions:

1) Cost of energy, temperature, power and heat loads are the random time dependent function;

2) Considerable amount of data from the past is available (databases formed by supervisory control and data acquisition (SCADA) system);

3) The records from the past can be projected into the future processes;

4) Projection of the records from the „past" x_{past} into the „future" processes x_{fut} can be performed by using one of the stochastic processes forecasting parametric or artificial intelligence based methods [7, 8].

In this paper the following two procedures are used (see Fig. 2): Using the linear algebraic expressions that describe changes in the characteristics of the random process in time (for example average value and standard deviation of plant power changes in the future);

Summing up the records of the past processes with anticipated changes. In this case, the planned load can be added to the historical load records;

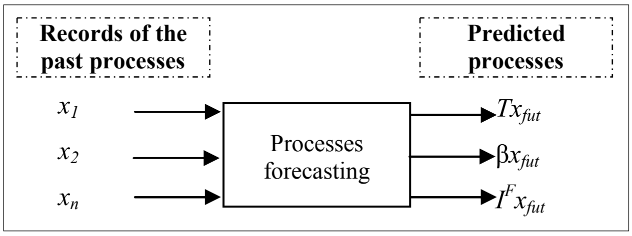

Fig. 2. Processes prediction scheme structure.

The random process of parameters x_{fut} variations is egrodic (the term is used to describe a dynamical system, which, broadly speaking, has the same behavior averaged over time as averaged over the space of all the system's states). In this case:

$$M[R(x(t_i))] = \sum_{i=1}^{k} R(x(t_i + \Delta t \cdot i)), \quad (6)$$

where: k=8760 is the number of hours in year, $R[x(t_i)]$ – profit in hour i.

The adoption (6) instead of (5) allows us to calculate the average value of the annual expenditure on the basis of multidimensional casual process with x_1, x_2…

The new method is based on the following assumptions and requirements:

1. Forecasting of influencing parameters of designed power plant should be used. The prediction should cover the entire planning period (20–30 years) up to every hour.
2. Results of the feasibility study have to be represented in the form of software, providing the ability to change the conditions (scenario) of the operation of power plant.
3. Mode of operation of the plant and accordingly, the cash flow should be defined for each hour, depending on the specific conditions of the planed day.
4. Feed of huge volume of input data should be provided using Internet and smart greed technologies and special methods of processes forecasting.

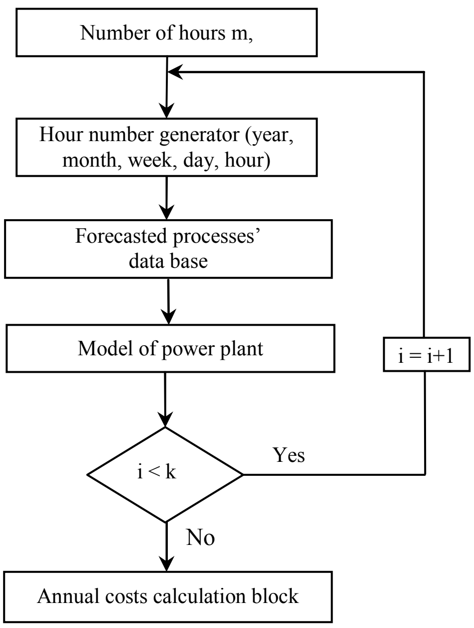

Fig. 3. The algorithm structure.

III. Model of Power Plant

To facilitate the design of power plants special software, such as *Thermoflow* [9], are used. These programs contain the knowledge base, which generalizes experience of designing similar facilities, and provides a rational choice of several, the most efficient structures and equipment for implementation of power plant under design. Named software provides ability to calculate the profit of power plant in given mode of operation and prices. Mentioned calculations can be used to create models of plants that can be implemented in programs that are independent of *Thermoflow*. For this purpose, it is necessary to use a called program to carry out calculations of fuel consumption (*Sfi*) for different modes of power plant operation:

$$Sfi = M(Q_{ti}, P_{ei}, T_i), \quad (7)$$

where i is number of modes of operation, Q_{ti} is heat consumption, P_{ei} electrical power and T_i ambient temperature. M is a procedure, generated by the *Thermoflow* program, which provides calculation of fuel consumption for a given operation mode i. To overcome the issue of the calculations accuracy can take the opportunity of approximating the M via polynomials where coefficients may be selected using, for instance, the method of least squares.

Figure 4 shows an example of the power plant structure, which was generated by the *Thermoflow* program. Figures 5, 6 displays results of plant characteristics approximation.

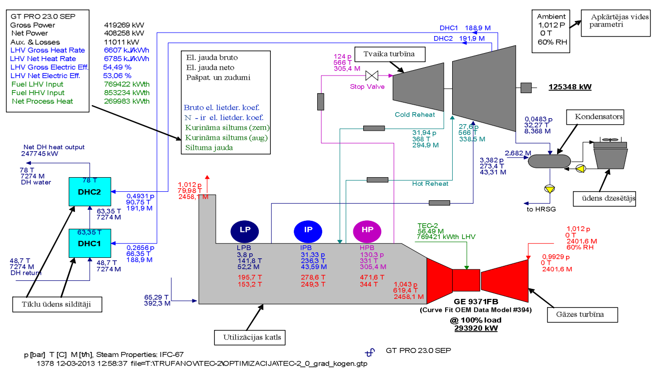

Fig. 4. Example of power plant structure.

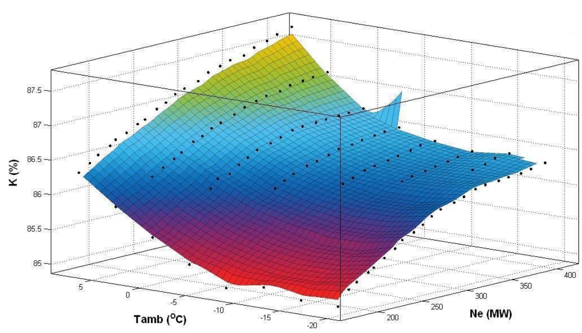

Fig. 5. The example of power plant characteristic approximation.

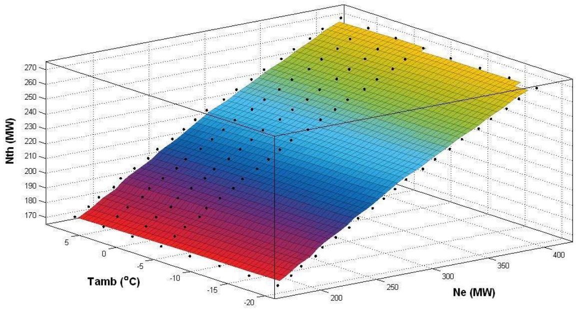

Fig. 6. The example of power plant characteristic approximation.

IV. THE POWER PLANT OPERATION MODE

In real life operating mode of cogeneration plants have to be selected based on solution of optimization problems and short-term forecasting of loads and working conditions. To avoid the need to solve complex optimization problems in this paper is accepted:

None modes at which it becomes profitable to stop work station;

The best in specific conditions of each hour may be one of three modes:

1. Shortage of heat load Q for ensuring minimal load of equipment in cogeneration regime Q_{min}. In this case depending on ratio of current prices, is selected one of two feasible, partly condensing power plant working regimes:

1.1. Minimal power regime

$$Q_T = Q_{\min} \,. \tag{8}$$

In this case *part of heat* comes into cooling tower power – losses appear:

$$\Delta Q = Q_{\min} - Q \,. \tag{9}$$

1.2. Nominal power regime:

$$Q_T = Q_{\max} \,. \tag{10}$$

the losses are:

$$\Delta Q = Q_{\max} - Q \,. \tag{11}$$

2. Heat load exceeds $Q_{\min}$, but is less than maximum Q value ($Q_{\max}$):

$$Q_{\min} < Q < Q_{\max} \,. \tag{12}$$

In this case, like in previous, is selected one of two extreme modes:

$$Q_T = Q \,. \tag{13}$$

or

$$Q_T = Q_{\max} \,. \tag{14}$$

In first mode (13) ensured full cogeneration mode, but in second mode (14) ensured partial cogeneration mode.

3. Heat load equal to maximum Q value ($Q_{\max}$):

$$Q = Q_{\max} \,. \tag{15}$$

Full cogeneration mode ensured in this case.

Using the results of forecasting the heat load of the power plant, one of the three mentioned modes can be chosen. Using the forecasted temperature and costs of energy and fuel, it is possible to choose the most advantageous mode, which is adopted for the calculation of NPV.

V. SOFTWARE STRUCTURE

Software development is based on the following assumptions and requirements:

1. Software should be developed for windows environment;

2. To simplify the task of software development, it is desirable to use the *MATLAB* opportunities [10, 11];

For purpose to build applications and software components program *MATLAB Compiler* were used. This product lets as share *MATLAB* programs as applications for integration with common programming languages, which enables deployment for users who do not have *MATLAB*. Use of the titled product led to need to select the *C++* language and *Microsoft Visual C++* integrated software development environment. Thereby, we compose Graphical User Interface in *C++* using *Visual Studio 2013* and *MATLAB* computing capabilities by connecting modules compiled in the form of libraries or exe modules. Data exchange between external programs and modules is provided through .CSV data file [12]. Software structure is shown on Fig. 7.

Figures 8 and 9 show the examples of displaying the results of NVP calculations. The described software offers the possibility of changing the scenarios and source data. To do this, even a novice user should spend only a few minutes.

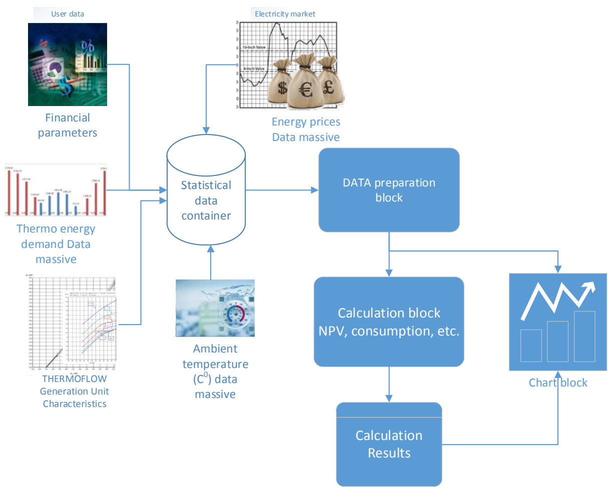

Fig. 7. Software structure.

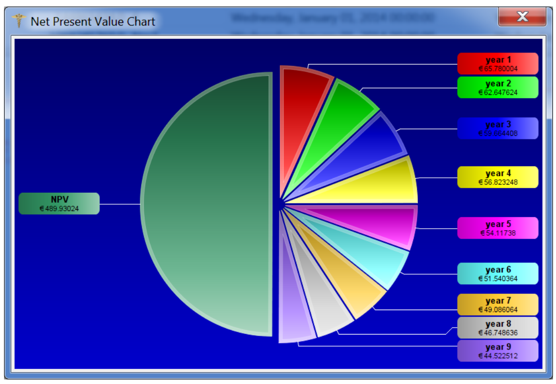

Fig. 8 Example of NPV calculation results.

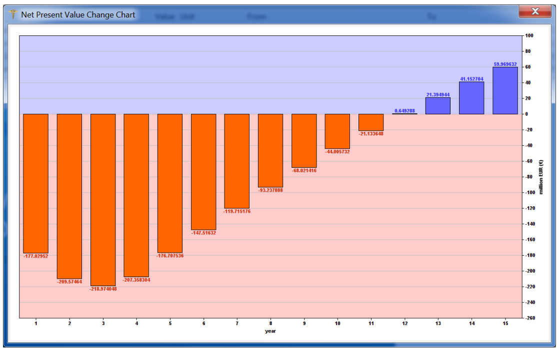

Fig. 9 Example of cash flow calculation results.

VI. Conclusions

With the market conditions and tools implementation on power system operation and planning the feasibility study tasks conditions change substantially. Necessity to take into account stochastic nature of variables appears.

The stochastic approach to the power plants feasibility study requires a large amount of input information. The difficulties of collecting input data can be overcome by using the opportunities of the Internet and smart grid technologies. The software accompanying the description of the feasibility studies provides wide opportunities to consider additional scenarios and take into account new information.

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