Case study – Serbia: Regulated and market based power system production capacity planning

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Abstract **—This study presents a possible process of simulation of power plant generation planning. The process combines expected overall industry costs, associated cost uncertainty, and expected CO2 emissions for different generation, variation of future fossil-fuel costs, carbon prices, plant investment costs, and demand, including price elasticity impacts. Uncertainty in the decision stems from the elasticity of prices of fuel and electricity. The aim of this paper is to apply fuzzy numbers to the power generation planning and use Monte Carlo method for check. Simulations are demonstrated through a case study of an electricity industry with coal and lignite, CCGT and ST facing future uncertainties. The same simulation was used in planning the generation of electricity from wind energy (WG). Comparing the results, decisions were made about the profitability of investments in renewable energy.**

Keywords- Generation planning, price elasticity, Monte Carlo, fuzzy logic

I. INTRODUCTION

An adequate supply of electricity is a prerequisite for economic development and social well-being of a country. Tendency of increase consumption calls for good strategic planning of electric power system, with emphasis on the construction of new generating capacity. Generation investment represents, among others, the most critical and challenging decisions undertaken within an electricity industry [1]. Generation investments are, however, generally irreversible, lumpy and long-lived. Investments are also necessarily undertaken in the context of projections of future electricity demand. An analysis of long-term plans in the past has shown that none were fully realized, and the differences in the expected results were sometimes bigger, sometimes smaller, but always present In planning generation plants, uncertainty arises whenever a decision can lead to more than one possible consequence. If a longer planning period, the uncertainty of plans is greater as a result of risk due to the assumptions that the real designer. Electric utilities, given their capital intensity concerning maintenance of reliability, have always required a relatively long-term planning horizon. Fundamental risks encountered in making electric utility resource decisions include technological changes, fuel costs, load growth, economic trends and environmental concerns [2]. In a market environment, the objective of a market participant is to align the company's portfolio with the risk preferences of the company. The development of a wind farm is a complex task involving a wide range of engineering and scientific skills [3]. In Serbia has not built even one power plant with renewable energy that would be competitive with the existing thermal power plants. For this reason, in this paper we apply two methods to assess the economic risks of investing in renewable energy sources. This paper presents the portfolios of investment and discusses how to plan investments to mitigate risk. How many consumers demand commodities, how much prices increase or decrease, how much the interest rate will be and many questions like these are the ones that economic decision-makers always encounter. Replying to these questions is not easy for decision-makers, because the future is not clear and obvious to them.

In electric power industry, as a result of inflation and other factors, each new generation unit is costing many times more than the average unit built previously. The reason for unprofitable power plants is electricity price variation that depends on the demand for electricity. Producers of electricity must also consider the supply and demand sides. Load management has been developed in order to improve operational and economic efficiencies in the supply of electric energy. Demand for electricity can be controlled at peak times by employing either indirect or direct control techniques. Indirect load controls strategies involve controlling demand by the use of multi-block time-of-day tariffs, spot pricing and special off-peak rates [4].

The idea of this paper is to describe the planning of production capacity in the regulated electricity system and market environment, and the challenges posed to the process and the changes in methodology in restructuring the power sector. Monte Carlo methods and fuzzy logic (FL) were applied to the planning process. Stochastic analysis based on Monte Carlo simulation (MCS) is widely recognized as one of the most comprehensive and flexible methods for analyzing problems that involve many, and potentially interacting uncertainties. Many strategies have been used extensively; they could not flexibly and effectively deal with the uncertainties caused by fuzziness. Therefore, another strategy of planning is using fuzzy numbers (FN) in calculations [5]. Applying fuzzy numbers allows more variation in the input parameters. The price of electricity varies through both methods contained, depending on the load. The paper defines blocks of work of power plant that are correlated with the pricing tariffs. The simulations are intended to facilitate electricity industry participants, particularly policy makers and planners, to gain high-level insights into issues that may be key drivers for future industry performance such as future fuel prices, carbon price policy, demand, and plant construction costs, as well as the role of different generation technologies.

II. BASIC CONCEPTS OF POWER PLANT GENERATION PLANNING

Methods of assessing and ranking investment projects consist of a set of procedures by which the system learns about the acceptability or unacceptability of investing. The practice is that all investment projects are subject to financial and economic analysis, which aims to provide an answer to whether the proposed investment and expenses associated with it, can be recovered through revenues over time. A financial analysis examines the profitability of the project from the standpoint of the company, i.e. investors. The purpose of the economic analysis is to determine feasibility of a certain project, with respect to the global economy of the country. Electric Power Industry, as well as power producers, need to decide on certain types of power plants projects. For this reason, special methods have been developed to compare investments, which convert all cash flows associated with a project in the equivalent values related to a specific moment in time, using a particular update rate. In this paper, the method of the Present Worth (PW) was used. PW is one of the methods of equivalent value, and consists of reducing all cash flows of a project the the present moment, using the formula update:

$$PW = C_I + \frac{R_1}{(1+i)^1} + ... + \frac{R_n}{(1+i)^n} + \frac{C_{res}}{(1+i)^n} \quad (1)$$

In (1) C_I is the present value of capital investment in the investment project, R_t is annual net cash flow (the difference between annual income and expenses), i is update rate, C_{res} is the residual value of the investment project and n is the life of the investment project. A project is cost-effective and acceptable if the:

$$PW > 0 \quad (2)$$

Fuel (c_F[€/GJ]) and electricity (c_e[€/MWh]) prices, and other prices that are entered in the budget are not fixed in the long term period. These prices must be varied to see what would happen to the profitability of the project. System load and the electricity demand is not always the same and it is shaped by the load duration curve (LDC). LDC is correlated with c_e. The connection between the load and the prices of electricity has to be defined and taken into account. It is necessary to detect the period of time when production of selected plants does not make a profit. Such periods of plant operation have been removed from the calculations. To make right decision about approving the project, we would use MCS and FL. As input data and formulas in these methods there are:

$$MC = VC_{O\&M} + HR \cdot c_F + EF_{CO2} \cdot c_{CO2} \quad (3)$$

$$EC = CF \cdot 8760h \cdot P_{\max} \cdot 10^{-6} \cdot MC + FC_{O\&M} \quad (4)$$

$$I = CF \cdot 8760h \cdot P_{\max} \cdot 10^{-6} \cdot c_e \quad (5)$$

$$P = I - EC \quad (6)$$

$$PVF = \frac{1}{(1+i)^n} \quad (7)$$

$$PWF = \frac{(1+i)^n - 1}{(1+i)^n \cdot i} \quad (8)$$

$$PW = -IC + P \cdot PWF + RV \cdot PVF \quad (9)$$

In (3) *MC[€/MWh]* is marginal costs, $VC_{O\&M}$*[€/MWh]* is variable cost of operation, *HR[GJ/MWh]* is heat rate of power plant, EF_{CO2}*[tCO2/MWh]* is emission factor of CO2 and c_{CO2}*[€/tCO2]* is price of emission CO2. In (4) *EC[millions €/year]* is the exploaitation of generation plant, P_{max}*[MW]* is maximum capacity of the power plant, *CF* is capacity factor and $FC_{O\&M}$*[€/year]* is fixed cost of operation and maintenance. In (6) *I[millions €/year]* is income earnings of plant and *P[millions €/year]* is profit of plant per year. In (7) and (8) *PVF* is present value factor and *PWF* is present worth factor. In (9) *IC[millions €]* is investment capital cost and *RV[millions €]* is rest value of plant after *n* years. Using equation (9) for any combination of inputs, for selected power plant, we get the *PW*. The advantage of renewable energy sources is that c_F and EF_{CO2} are zeros [6]. That is applied to equation (3).

III. MONTE CARLO SIMULATION

MCS can be defined as a statistical simulation method, and we use sequences of random numbers for the execution of the simulation. MCS recent decades receives a fully completed status and it is one of the numerical methods capable of solving the most complex conditions requirements. MCS was originally known as "statistical simplification". MCS computes outcomes as functions of multiple uncertain inputs, each expressed as a probability distribution. The technique involves the random selection of entries taken with variation within the given boundaries. The output sample from a simple MCS consists of independent random values from the output distribution, regardless of the number of inputs.

In this paper, MCS is used to simulate the financial forecasts of the three projects and make a decision which is more profitable. For each power plant investment analysis and risk assessment for investment cases, with deviations in fuel and electricity prices in the market value of the forecasted time period, will be simulated. Score investments will be performed by the method of the present value equivalent. The final profile of the project will depend on the different scenarios regarding movement of essential inputs. The analysis conducted for this example will be deemed to have possible deviations c_F and c_e in the market in the range of 85% - 115% of the expected values considered in the baseline scenario, and the components will be modeled uniform distribution in the range set boundaries, while it is accepted that there will be other model parameters from the expected values. The essence of MCS will be performed by the probability distribution of the value of the project based on *PW,* simultaneously incorporating the probability distribution of essential inputs. Probability distribution of each of the main input to the simultaneous change of the *PW* flow into the project and make the probability distribution of the project.

Fuel prices (c_F) may be a significant factor that may increase the risk of repayment plant. It is common tohave an increase in the cost of fuel and other fuels to a growing trend. But if there is a case for a given power plant that uses a fuel and the fuel price decreases more than other fuels used by other competitive power plant in the market, then it has a more favorable position for the plant on the market.

The market price of electricity has a significant impact on the position of a power plant in the market. In periods when production costs are lower than the market price of electricity produced by these plants, there is an increased potential for production and marketing of their level of risk to become smaller. Each year of the studied period was used for block pricing for modeling c_e in the market. These pricing blocks are correlated with the consumption of blocks which can be approximated by a LDC. Some methods 'fit' the available generation options to the specific LDC to determine the mix of technologies and their respective capacity factors that minimize industry costs. In this paper we want to make a global decision on which type of power plant has bigger profit based on LDC. The market price of electricity is divided into three parts: upper block, middle block and basic block. Basic block refers to periods of time when the demand for energy is small so price for this block (c_{Be}) is lower than medium and takes value 65.57% of c_e. It is accepted that this block has 40% of the time (3504h/year), while the middle block occupies as much as peak block ,30% of time (2628h/year). Price for the middle block (c_{Me}) is 100%, while for peak block price (c_{Pe}) takes 150% of average prices, because then there is also the greatest demand for electricity. The described process of reasoning is presented in Fig. 1. The observed power is only in the moments when the electricity price in the market is higher than the marginal cost. That is the only time it makes sense to produce electricity and create potential profits. This fact is taken into account by applying the formula:

$$c_e = k_p \cdot c_{Pe} \cdot 0{,}3 + k_M \cdot c_{Me} \cdot 0{,}3 + k_B \cdot c_{Be} \cdot 0{,}4 \quad (10)$$

to the equation (6). In (10) k_P, k_M and k_B are logical coefficients which take the values 0 and 1 according to the described procedure probation.

In this way, we have taken into account the work of the power plant for exploitation period. The advantage of this concept is that it can be easily visualized, understood, and interpreted, which is important for policy makers, because they can see the project profile on the basis of only one or a few graphs. Graphic presentation can be done in many ways, and this will be displayed when using the VAR (Value at Risk) histograms and curves [7]. The histogram shows the probability that the value of a project (PW) fall in the range of values indicated by the median value of the intervals. VAR curve illustrates the cumulative probability distribution, and can be considered more informative than a histogram.

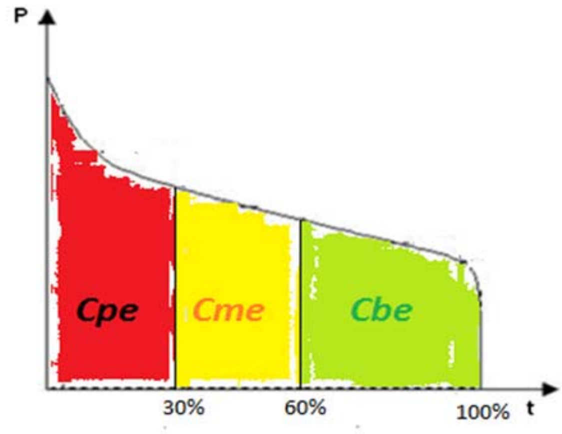

Figure 1. LDC with three pricing blocks

Curve provides information about the probability that the project will earn at least *X* units of currency (€), and the probability that it will generate a loss.

IV. FUZZY LOGIC

Risk analysis is performed in the interpretation of large quantities of information, to make a proper decision. A new mathematics can consider ''inaccuracy'' and ''fuzziness'' in a logical manner [8]. The use of advanced technology allows to significantly reduce the time, and on the other hand, increases the accuracy of the analysis [9]. One such method is based on fuzzy logic, which allows to apply the input variables as fuzzy numbers.

Fuzzy logic is mathematically formalized model which can show some uncertainties in linguistics. In classical, clear set theory any particular element (*x*) either belongs or does not belong to a defined set. Fuzzy entities are sets with nonsharp boundaries in which there is a transition between elements that belong and elements that do not belong to the set. In this situation, there is no uncertainty [10]. Fuzzy set (*A*) is, in this sense, a generalization of classical set (*X*), since the membership (ie membership level) of the element to fuzzy set can be characterized as a number from the interval [0,1] [9]. In other words, the membership function ($\mu_A(x)$) of fuzzy set maps each element of the universal set of the mentioned interval of real numbers:

$$A = \left[x, \mu_A(x) \middle| x \in X\right] \quad (11)$$

Fuzzy logic provides a formal methodology for representing, managing and implementing human heuristic knowledge about how to make decisions. In recent years, fuzzy optimization, and especially fuzzy linear programing, is utilized in many economic areas, such as energy planning. In this paper we work with c_e and c_F as the two variables, which are presented as fuzzy numbers. As such, they are entered into the budget and used in equations (3) - (9). The result is *PW* in the form of a fuzzy number. Results of MCS shall be verified on the basis of such result. A similar logic is also applied to the load flow, where the power and voltage in the power grid are seen as fuzzy numbers.

The first step in the implementation of fuzzy numbers is the fuzzification. Fuzzification simply modifies the input signals, so that they can be properly interpreted. This is provided by the membership functions, which actually map the degree of truth claims. For ce and c_F the membership functions are shown in Fig. 2. The biggest probability, $\mu(c)=1$, is that the price takes the exact, 100% value prices. The probability that the price deviates 85% and 115% of the minimum. Probability that price increases and decreases is the same. So selected membership functions correspond to inputs in the MCS.

Fuzzy number can be regarded as a generalization of the concept of belonging to an interval $A^{(\alpha)}$, which is usually defined in terms of its upper and lower limits, $A^{(\alpha)}=[A_1^{(\alpha)}, A_2^{(\alpha)}], \alpha \in [0,1]$. During the implementation of the operations of addition, subtraction, multiplication and division of fuzzy numbers, obtained by fuzzy numbers whose membership functions can be expressed in equation:

$$\mu_C(z) = \mu_{A+(-,*,/)B} = \max\{\min[\mu_A(x), \mu_B(y)]\} \quad (12)$$

If $A(a_1, a_2, a_3)$ and $B(b_1, b_2, b_3)$ *are* fuzzy numbers with their intervals that determine the α-level of belonging, then the basic arithmetic operations are defined as:

$$\begin{aligned} A+B &= (a_1+b_1, a_2+b_2, a_3+b_3) \\ A-B &= (a_1-b_1, a_2-b_2, a_3-b_3) \\ A\cdot B &= (a_1\cdot b_1, a_2\cdot b_2, a_3\cdot b_3) \\ A/B &= (a_1/b_3, a_2/b_2, a_3/b_1) \end{aligned} \quad (13)$$

The result, *PW,* is in the form of fuzzy number, whose membership functions are triangular in shape. It is necessary to transform this result to a number. Defuzzification, which is the final step in the FL, transforms the interface conclusion in a signal that can be a signal representing the output.

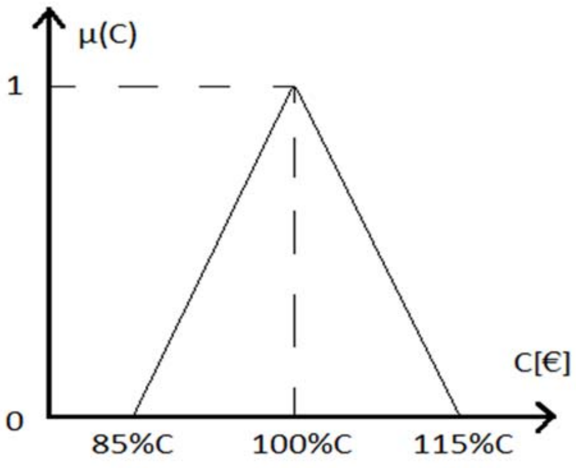

Figure **2.** The membership functions for c_e and c_F

This is in fact a process that needs to transform the result of aggregation, which is basically a surface cross-section, into the signal that the process can recognize. The output must have a unique value, usually represented by a real number. Methods commonly used for defuzzification are: center of the surface (gravity), the sum center, the center of the largest surfaces, first maximum, middle maximum and height defuzzification. The method applied is the center of gravity:

$$PW = defuzzy(\mu(PW)) = \frac{\int \mu(PW)\cdot PW \cdot dPW}{\int \mu(PW)\cdot dPW} \quad (14)$$

Based on all of this, decision about investing power can be made.

V. Case study and Results

To demonstrate use of both methods, a case study of an electricity industry with conventional pulverized coal, Combined Cycle Gas Turbine (CCGT), and with lignite with supercritical boilers (ST) generation options that faces uncertain future fuel prices, carbon prices, demand, and capital costs is presented. These technologies are the most common generation options for many electricity industries around the world. With the renewable energy sources were processed data related to wind power. They also possess different characteristics in terms of capital costs, fuel, operating costs, and carbon emissions. The study includes planning for 25 years (n = 25) with an interest rate of 9% (i = 9%), which is commonly taken in Serbia. Technical parameters and characteristics of each technology used in this study are approximated from [11], and presented in Table 1.

MATLAB® technical computing software has been used to apply MCS and FL [12]. For each of three generations, MCS determines a probability distribution of PW from 10,000 simulated future fuel prices,fuel price,demand and capital costs. These provide a basis for comparing the expected costs, associated cost uncertainties, and expected emissions of each generation. MCS results are shown in the following Fig. 3 and Fig. 4. Information for the possible values of PW for ST, CCGT and WG are displayed using a histogram (Fig. 3). Figure 4 is a comparative VAR curves. Based on the risk analysis carried out using MCS to generate scenarios of variations in fuel prices and electricity prices in the market than predicted.

TABLE I. Technological parameters

Technogy	ST	CCGT	WG
n[years]	25	25	25
IC[millions €]	450	210	393
RV[millions €]	45	21	39,3
P_{max}[MW]	270	288	280
CF[%]	84	89,2	31,1
EF_{CO2}[tCO2/MWH]	0,9	0,33	0
HR[GJ/MWh]	9,8324	6,52704	0
$VC_{O\&M}$[€/MWh]	1,7	1,3	2,666
$FC_{O\&M}$[€/year]	$12{,}5\cdot10^6$	$4\cdot10^6$	$2{,}7\cdot10^6$
C_F[€/GJ]	1,5	7,5	0
C_e[€/MWh]	60	60	60;95
C_{CO2}[€/tCO2]	6,8	6,8	0

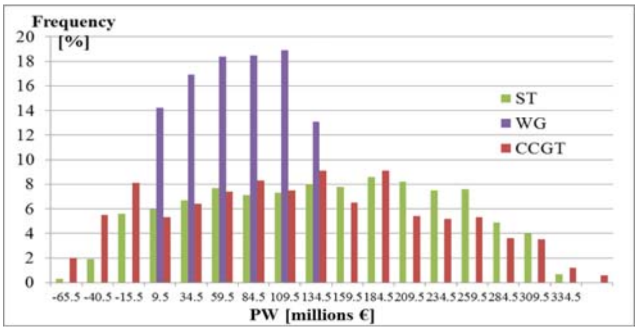

Figure **3.** Comparative histogram of PW for ST and CCGT

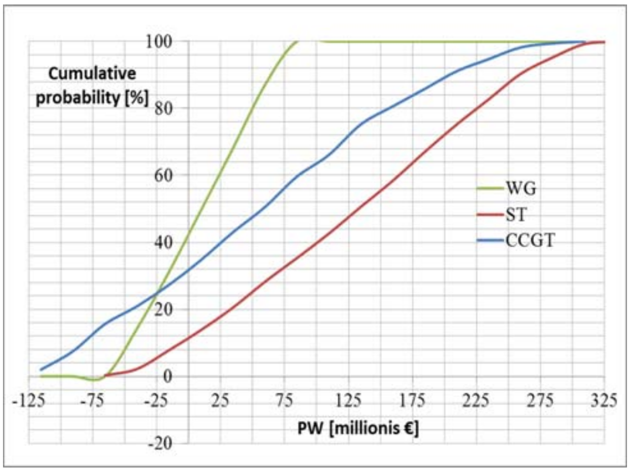

Figure **4.** Comparative VAR curves of PW for ST and CCGT

It was found to investments in ST is a risk of negative 8.3% of the project value, and therefore is less risky than investment in CCGT, which has the probability of negative 28.7% of the project value, and the bigest risk is 31,2% for WG . It is observed that the risk of CCGT is approximate to WG and WG is certainly competitive in the energy market.

As explained in chapter 3 for the prices, c_e and c_F, the assigned membership functions are shown in Fig. 5 and Fig. 6. After performing calculation with those prices, the results obtained in the form of *PW* fuzzy numbers are as shown in Fig. 7. After defuzzification value *PW* for ST is 36,5917 milions €, for CCGT is 4,8333 millions €, for WG is 5,5314 millions €. FL confirms the results of MCS, and as MCS it gives similar values of *PW* for WG and ST. But taking into account the set of membership functions is seen that the membership functions of WG narrower and this shows that they are less posibility to have a lower PW value than defuzzification value of PW. In previous calculations did not take into account the feed in tariff or renewable energy payments, and WG is already competitive.

If the price of electricity from WG pay 9,5c€/ kWh to feed in tariffs, then the MCS results are like on Fig. 8, 9. New price for wind energy is regulated by the Ministry of Energy of Serbia. New results of FL are presented in Fig. 10.

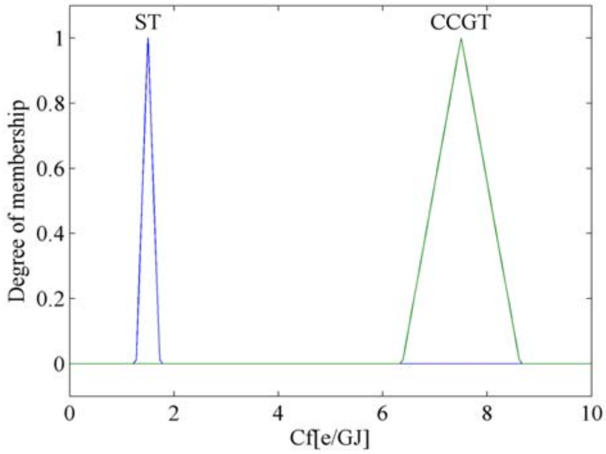

Figure 5. Membership functions for c_F

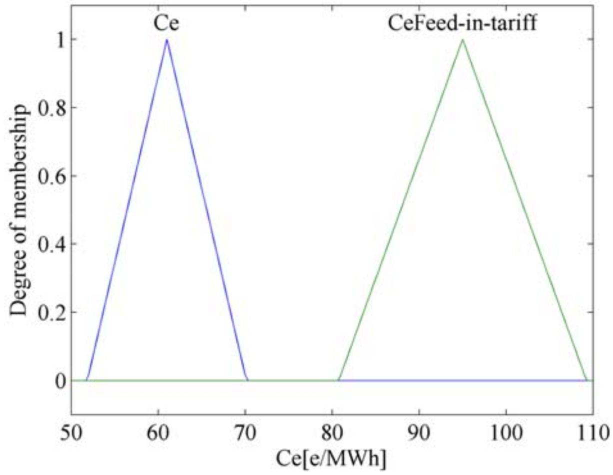

Figure 6. Membership functions for c_e

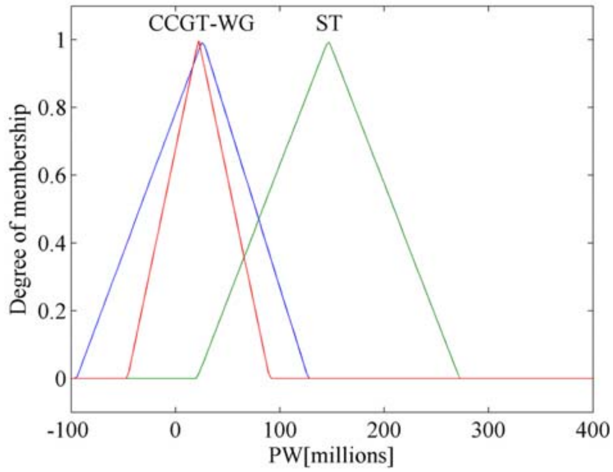

Figure 7. Membership functions for output *PW*

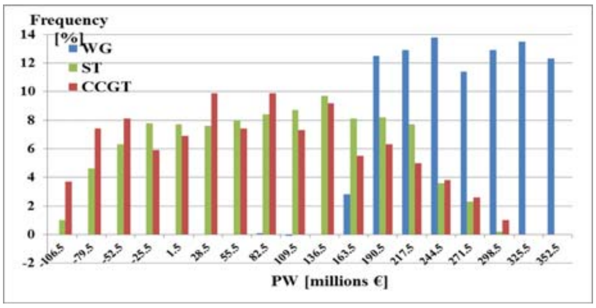

Figure 8. Comparative histogram of *PW* for ST, CCGT and WG with including feed in tariff

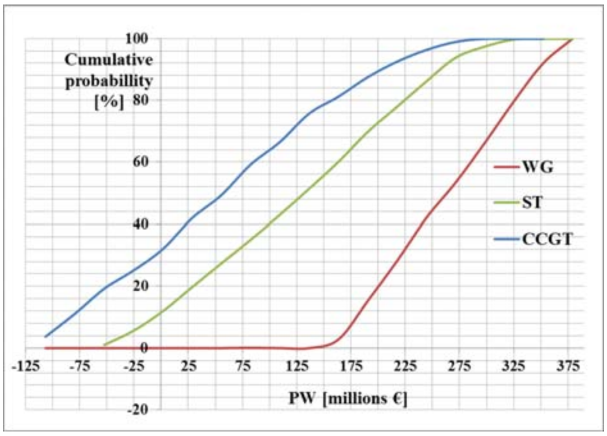

Figure 9. Comparative VAR curves of *PW* for ST and CCGT with including feed in tariff

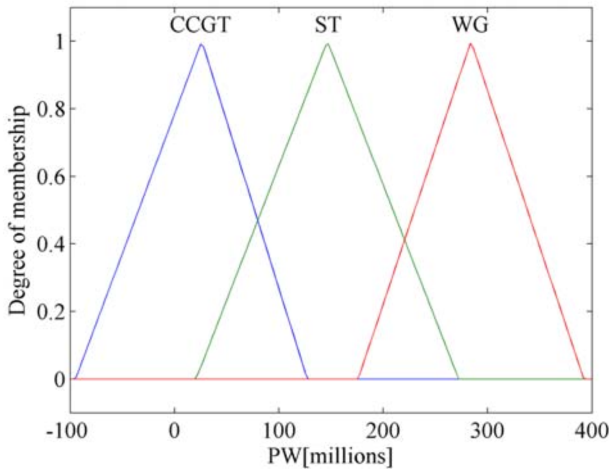

Figure 10. Membership functions for output *PW* with including feed in tariff

We can see that the project is likely to turn a profit (for the considered value of any profits) is higher in ST than CCGT (ie the probability that the project will generate a profit of 100 million or more for (ST) power 60%, and (CCGT) power 36%). With histigrama and VAR curve shows that now there is no negative risk WG. It can be seen that the *PW* takes a value greater than 200 millions € with a probability of 80%. Now the value of *PW* for WG by FL is 71,1876 millions €. Based on all the above, in this study, the conclusion is that it is more cost effective and less risky investments in building WG, and it is recommended company, investors, interested in investing, the best choice as a candidate for the construction of plants. Such decisions as the final result comes from both methods. So use MCS and FL is justified and gives the same conclusions.

VI. Conclusion

This study presents a novel generation investment decision to help assess future electricity generation under uncertain future fuel prices, carbon prices, plant investment costs, and electricity demand, including price elasticity impacts. The experiment included two relatively new methods in planning, MCS and fuzzy logic. The presented methods and the results confirm the validity of applying fuzzy logic in making appropriate decisions about the investments planning. The study is important in stimulating building wind farms in Serbia, and provides insight into economic profit.

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