Proceedings of the Seventh IASTED International Conference
POWER AND ENERGY SYSTEMS
August 29–31, 2007, Palma de Mallorca, Spain
ISBN Hardcopy: 978-0-88986-689-8 / CD: 978-0-88986-690-4

LONG TERM IMPACT OF WIND GENERATION ON DEVELOPMENT OF CROATIAN POWER SYSTEM

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ABSTRACT
Wind power plants today represent the fastest growing renewable technology. The intermittency and variability of wind generation are its important characteristics when its integration into existing power systems is considered. This paper analyses the impact of wind generation on long-term expansion of Croatian power generation system, assuming that a feed-in tariff system for renewables is in place. Optimisation of power generation expansion is done by IAEA's (International Atomic Energy Agency) least-cost planning model WASP (Wien Automatic System Planning). Study period covers the years from 2007 to 2020. Results of several development scenarios are presented, through structure of installed generation capacity in the system, CO_2 emission, CO_2 emission reduction costs and overall system costs (total, investment, O&M and fuel costs). The analysis presented here is the first of this kind conducted for the Croatian power system.

KEY WORDS
Power System Planning, Wind Power, Security of Supply, WASP Model

1. Introduction

High and volatile fossil fuel prices, endeavours to decrease dependence on energy import and a need to reduce the emission of greenhouse gases (primarily CO_2), have resulted in increasing interest to replace fossil energy sources by renewable energy sources (RES).

In the last decade the usage of wind energy for electricity generation has achieved the highest growth rate among all RES technologies in Europe [1]. Examples of countries experiencing high growth and respectable shares of wind power in their energy mix include Germany, Spain, Denmark and Ireland [2, 3]. There are multiple reasons for such an increase of wind generation capacity: opening of electricity market, favourable feed-in tariffs for wind energy producers, rapid development of wind technology that led to a decrease of investment costs to 1000 EUR/kW, short construction period (1 year), low operation and maintenance costs, no fuel costs, relatively simple preparatory works and location assessment and low environmental impact.

The main disadvantages of wind power are intermittency and generation variability caused by the variable nature of wind. Although the variability of wind can be largely predicted, it still affects the operation of the power system [5].

Long-term variations in available wind energy (monthly, seasonal or annual) are important for the long-term system development planning and operations of companies in the market. Wind power generation can affect spot and forward market prices, as well as the power system development [6].

In this paper we analyse the long-term impact of wind power on operation and development of power generation capacities until the year 2020. Its effects on operation and development of distribution and transmission networks are not being considered here. Long-term impacts on generation expansion planning will be observed through investment costs, fuel and other operation and maintenance costs, security of supply and emission of carbon dioxide.

Analyses of future scenarios of electricity generation assume a perfect electricity market. Under this assumption, the problem is set up as an optimisation problem where the objective is to minimise total electricity generation costs, i.e. to find the optimal generation expansion plan, taking into consideration all relevant constraints (prices and availability of fuels, end of life of existing power plants, hydrology conditions, etc.).

2. Wind Power in Croatian Power System

Croatian electric power system in year 2005 had a total installed capacity of 3983 MW. Hydro power plants represent 52 per cent of total capacity, while the thermal power share is 40 per cent. Joint Slovenian-Croatian nuclear power plant Krško, with half of its capacity belonging to Croatia, represents 8 per cent of the total generation capacity. Hydro generation accounts for 30 to 45 per cent of total generated electricity, while the share of wind power was only 0.1 per cent in 2006.

Croatia is a net importer of electricity and is becoming increasingly dependent on import. The high potential of wind power could help in meeting the power needs and reducing the dependence on fossil fuels and electricity imports. Potential of wind power usage in Croatia has been assessed, and wind measurement equipment installed at several locations [7, 8, 9]. A study of wind integration potential and technical conditions for connecting wind power plant (WPP) has been made for the Croatian transmission system operator (HEP-OPS) [10]

However, due to the lack of regulation and slow market opening, development of wind power plants in Croatia has been quite modest. Electricity market opening formally commenced in 2004 by adopting the new energy legislation. The incumbent electricity utility (HEP) still holds all retail and network businesses, while the only independent generation capacities are two wind power plants. The first wind farm Ravna 1 was installed in 2004 on the island of Pag. It has the capacity of 5.95 MW and expected annual generation of 15 GWh. The wind farm Trtar Krtolin, with the total installed capacity of 11.2 MW and expected annual generation of 30 GWh, started operation in 2006.

In March 2007 the new legal framework for renewable energy sources in Croatia was enacted [11, 12, 13], and two support mechanisms introduced for promoting renewable energy and cogeneration - feed-in tariffs for producers, and quota obligations for electricity suppliers. It is expected that these measures will boost development of new wind projects.

There is already a huge interest from investors for the construction of new wind power plants. Transmission system operator (HEP-OPS) has received requests for network connection in the total amount of 1555 MW, which makes 53.6 per cent of the peak load in the country. The potential of new wind projects is much higher; 93 locations analysed in [10] have the total wind power potential of 3380 MW.

Integration of wind power in the system is constrained by the size of the power system, configuration of the network and structure of other energy sources in the system. According to the study on wind integration potential in Croatia [10], the present energy system can accept around 300-400 MW of wind power without difficulty. Integration of larger amounts of wind power requires further investments in the network and power plant equipment for generation control.

The Republic of Croatia ratified the Kyoto Protocol in 2007 and accepted the obligation to reduce its total greenhouse gas emissions by 5 per cent in the first commitment period between 2008 and 2012, compared to the base year [14]. Furthermore, the National Allocation Plan for greenhouse gas emission is scheduled for adoption in 2008 [15]. The present annual greenhouse gas emission from the power system in Croatia is above 4 million tonnes of equivalent CO_2. Wind power plants could significantly contribute to the reduction of greenhouse gas emissions.

3. Croatian Power System Development Scenarios

3.1 Model used

Long-term generation expansion planning was carried out using the IAEA's (International Atomic Energy Agency) model WASP IV [16]. Optimal generation expansion plan is evaluated in terms of minimum discounted total costs.

WASP model utilizes several mathematical techniques: *Probabilistic Estimation* of system production costs, not served energy costs and reliability; *Linear Programming* for finding the optimal dispatch of generating units, taking into account the emission constraints, fuel availability and maximum possible generation for some plants; and *Dynamic Programming* for comparing the costs of alternative system expansion policies.

Each possible sequence of power units added to the system (expansion plan, expansion policy) meeting the constraints is evaluated through a cost function (the objective function), which is composed of: Capital investment costs (I), Salvage value of investment costs (S), Fuel costs (F), Fuel inventory costs (L), Non-fuel operation and maintenance costs (M) and Cost of the energy not served (O).

The cost function can be represented by the following expression:

$$B_j = \sum_{t=1}^{T} \left(\overline{I_{j,t}} - \overline{S_{j,t}} + \overline{F_{j,t}} + \overline{L_{j,t}} + \overline{M_{j,t}} + \overline{O_{j,t}} \right)$$

where:
B_j is the objective function of the expansion plan j,
t is the time in years (1, 2, ... , T),
T is the length of the study period (total number of years).

The bar over the symbols has the meaning of discounted values to a reference date at a given discount rate i. Optimal expansion plan is defined by:

Min B_j among all j.

3.2 Scenario description

Five different system development scenarios have been considered:

- BASE – Reference scenario. All other scenarios are compared to BASE scenario. There are no wind power plants in this case. Thermal power plants expansion is fixed until 2015, with some degree of freedom for adding new units. After 2015, the construction of new TPPs is completely free. Hydro power plants expansion is fixed for the whole period;
- Other four development scenarios are divided into two groups, "reference" (REF1 and REF2) and "high" (HIGH1 and HIGH2) scenarios, with respect to the level (reference or high) of wind power plants construction (Table 3).

Scenarios with labels 1 and 2 differ in the degree of freedom in adding new plants. REF1 and HIGH1 scenarios assume fixed addition of thermal power plants until 2015 according to HEP (Croatian electric utility) provisional business plan [17]. On the other hand, in scenarios REF2 and HIGH2 the expansion of thermal power plants is free and subject to optimisation for the whole planning period (the only constraint being the first possible year of commissioning).

The development scenarios presented here share some common assumptions:

- Electricity consumption will increase with an average annual growth rate of 2.6 per cent (from 17.9 TWh in 2007 to 24.7 TWh in 2020);
- Fuel prices are held constant during the whole planning period: Gas 25.2 EURcent/m^3, Coal 52.5 EUR/t and Fuel oil 161.7 EUR/t;
- System reserve level is limited to a minimum of 15 per cent and a maximum of 60 per cent of peak power. In simulations, commercial contracts for electricity imports are included into the system reserve.
- Price of the imported electricity is constant for the whole period, and is set to 55 EUR/MWh. Maximum imported power is limited to 500 MW;
- All costs are discounted to the year 2007 with the discount rate of 8 per cent;
- Emission allowance prices are not taken into account. Croatia does not participate in EU ETS (European Union Emission Trading Scheme) and NAP (National Allocation Plan) is not yet adopted;
- Expansion of hydro power plants is fixed in all scenarios, and follows the provisional HEP business plan.
- About 1200 MW of existing thermal power is planned for decommission by 2020.

Provisional HEP business plan assumes that about 1000 MW of new thermal power and about 300 MW of new hydro power will be constructed between 2008 and 2018 [17].

The two cases of adding new WPPs are presented in Table 1 – REF and HIGH cases.

Table 1. Reference and High Scenario for WPPs Development

Reference Scenario (REF)			
Year	**WPP Installed Power**	**Penetration (peak load)**	**Penetration (electricity consumption)**
	MW	**%**	**%**
2010	300	8.7	3.3
2015	600	15.4	5.9
2020	1200	27.8	10.6
High Scenario (HIGH)			
Year	**WPP Installed Power**	**Penetration (peak load)**	**Penetration (electricity consumption)**
	MW	%	%
2010	600	17.5	6.7
2015	1200	30.7	11.7
2020	1700	39.4	15.0

Basic technical and economic characteristics of thermal power plant expansion candidates are presented in Table 2 and Table 3. TPP candidates include one combined cycle gas power plant (G250) and two coal power plants (C330 and C480). The first coal fired TPP can be commissioned in 2015 and the first gas fired TPP in 2010.

Table 2. Candidate TPPs – Technical Data

Name	Fuel Type	Net Power [MW]	η [%]	Forced outage rate [%]	Lifetime [year]
G250	gas	250	55.1	5.0	20
C330	coal	330	41.8	8.0	30
C480	coal	480	42.0	8.0	30

Table 3. Candidate TPPs – Economic Data

Name	Investment [EUR/kW]	Fixed O&M [EUR/kW-month]	Variable O&M [EUR/MWh]	Duration of construction [months]
G250	440	2.42	1.02	24
C330	1220	3.00	4.70	48
C480	1146	3.00	4.70	48

Table 4 shows technical and economic characteristics for a generic WPP candidate.

Table 4. Data for Candidate WPP

Name	WP50
Installed power [MW]	50
Expected generation [GWh/god]	110
Forced outage rate [%]	3.0
Lifetime [year]	20
Investment [EUR/kW]	1000
Fixed O&M costs [EUR/kW-month]	0.92
Variable O&M costs [EUR/MWh]	5.0
Duration of construction [months]	12

The annual load factor for a typical WPP in Croatia is 0.25, i.e. utilization of maximum power is about 2200 hours per year. Changes in WPP generation are modelled on a monthly level, in line with other technologies considered by the WASP model. Monthly shares are calculated according to the real generation data for the WPP Ravne 1 [18]. Generation pattern is the same for the whole planning period. In other words, possible impact of WPPs geographical location on the pattern of total wind generation in the system was not modelled due to the lack of more detailed wind data.

4. Results of Simulations

Following results of simulations are presented:

- Commissioning schedule and installed power of new thermal power plants
- Value of the objective function
- System reserve
- Total CO_2 emission reduction and CO_2 emission reduction cost
- Costs

Table 5 presents the commissioning schedule of new thermal power plants, with total installed power and value of objective function for all scenarios.

Table 5. Commissioning Schedule of new TPPs and Value of Objective Function

Year	BASE	REF1	REF2	HIGH1	HIGH2
2007					
2008	G103	G103	G103	G103	G103
2009					
2010	**G250**	**G250**		**G250**	
2011					
2012	G250	G250	G250	G250	
2013					G250
2014			G250		
2015	**C480**	**C480**	**C480**	**C480**	**C480**
2016	C480				
2017					
2018		C480	C480	C480	C480
2019	C330				
2020					
Total cap. of new TPP [MW]	**1893**	**1563**	**1563**	**1563**	**1313**
Objective function [mil EUR]	**5681**	**5684**	**5638**	**5725**	**5611**

As expected, the largest new thermal capacity is added in the BASE scenario (without WPPs).

For three scenarios (REF1, REF2 and HIGH1) the total installed power of new TPPs is the same (about 1500 MW). Two of these scenarios, REF1 and HIGH1 have the same construction schedule. In REF2 case (decision on new TPPs fully subject to optimisation), commissioning of new G250 plants is postponed for two years compared to BASE and REF1 scenarios.

Increased development of WPPs, combined with the fixed expansion plan for TPPs until 2015 (HIGH1), has no effect on the development of new TPPs after 2015. The impact of an increased construction of wind power in this scenario is reflected in the load factor of TPPs. Wind generation substitutes some of thermal generation. Consequently, TPPs load factor gradually decreases towards the end of planning period, i.e. TPPs lose their market share. In case the expansion of TPPs is free (HIGH2), the optimal solution has one G250 unit less.

Objective function values are close for all scenarios, ranging from 5.6 to 5.7 billion EUR.

System reserve is presented in Figure 1. The reserve shown does not take into account energy import contracts, i.e. interconnection capacity with neighbouring systems (in the model these contracts were calculated into the reserve margin). Only domestic power plants are considered in terms of system reserve in Figure 1.

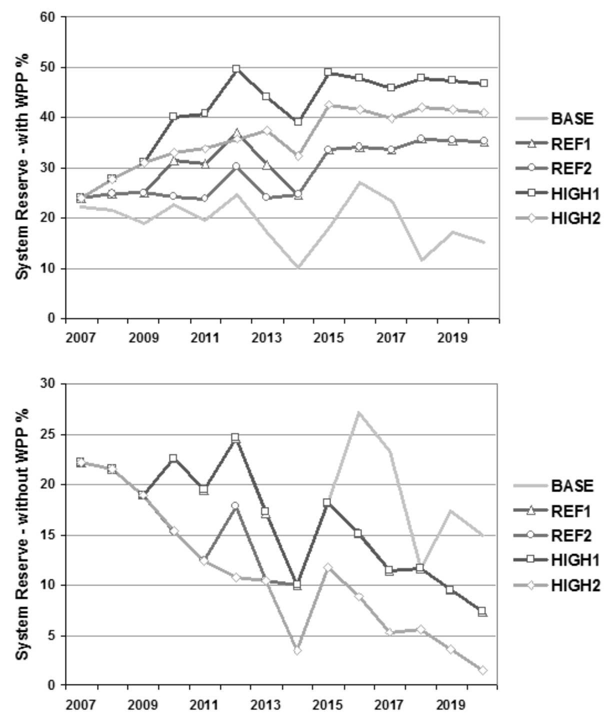

Figure 1. System Reserve – with and without WPPs

If total installed power of new WPPs is included in the system reserve (i.e. capacity credit [4] for WPP is 100 per cent), the system reserve is acceptable. Figure 1 shows the system reserve for capacity credits of 100 and 0 per cent. (Realistic capacity credit for WPP is far below 100 per cent, but also above 0 per cent.) In some scenarios the system reserve is very low. In other words, if it is not possible to ensure the reserve from adjacent systems, maintaining an adequate level of security of electricity supply becomes questionable. For a better valuation of

WPPs contribution to the system security, it is necessary to perform additional analyses.

Figure 2 shows total emission of carbon dioxide from all TPPs in the power system. The largest CO_2 emission is in the BASE case (without WPPs). At the end of study period CO_2 emission reaches 8.5 million tons per year. In all other scenarios CO_2 emission stabilizes after 2015 at about 6 million tons per year. All scenarios show sharp increase of CO_2 emission in 2015, after commissioning a coal fired TPP.

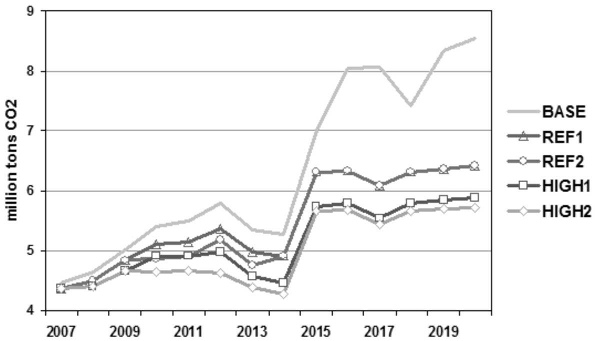

Figure 2. CO_2 Emission from the power sector

Cost of CO_2 emission reduction and total CO_2 emission reduction are calculated with respect to the BASE scenario, and are shown in Figure 4. The largest reduction in CO_2 emission, about 18.9 million tons for the whole period, is achieved in scenario HIGH2. Scenario HIGH2 also has the least cost of CO_2 emission reduction of -3.7 EUR/kt CO_2. Scenarios HIGH2 and REF2 have lower values of objective function and lower emissions in comparison to the BASE scenario. Therefore, CO_2 emission reduction costs for these two scenarios are negative. In other words, those scenarios are advantageous from the aspect of CO_2 emission reduction costs because they provide a win-win situation – lower emission at lower total cost. If prices for emission for TPPs would be included, CO_2 emission reduction costs would be even more favourable.

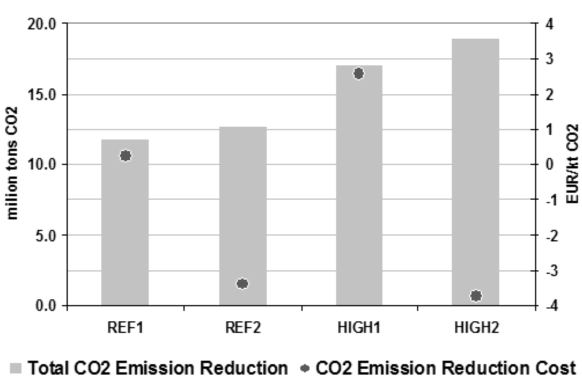

Figure 3. Total CO_2 Emission Reduction and CO_2 Emission Reduction Costs

All scenarios have approximately the same dynamics of investment cost. As expected, the highest fuel cost is for the BASE scenario (without WPPs), and lowest for HIGH2 (high level of WPPs and the lowest installed power of TPPs).
Scenarios with fixed addition of TPPs until 2015 (REF1 and HIGH1) have larger fuel cost compared to scenarios with free decision on new TPPs (REF2 and HIGH2).

Annual share of fuel cost in total cost is 40 to 50 per cent for scenarios REF1, REF2 and HIGH1. In the BASE scenario this annual share is above 50 per cent, while in HIGH2 it is below 40 per cent.

Electricity import decreases in all scenarios, dropping to the level between 4 and 8 per cent of total electricity consumption at the end of planning period.

Figure 4 shows total annual costs for all scenarios, indicating very similar evolution of costs across scenarios. This similarity is reflected in the final result, through close values of the objective function, as shown in Table 5.

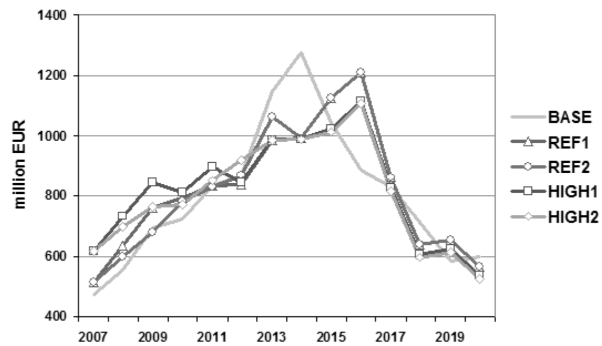

Figure 4. Total Annual Costs

5. Conclusion

This paper was motivated by the large interest expressed for building new wind power plants in Croatia (>1500 MW). The approach used in the paper assumed a gradual development of wind capacities until 2020, analysing the impact of wind generation on development of other generation technologies.

According to the results presented, large installed capacities of WPPs reduce fuel consumption. Furthermore, the load factor of TPPs is decreased. To some extent, the need to construct new TPPs can also be reduced. At the same time planners must take full care of the issues of security of supply and system reserve margin. It is also important to determine realistically achievable contribution of WPPs to system security, and the possibility of satisfying peak demand.

Objective function values are rather close across all considered scenarios. WPPs can play significant role from the aspect of carbon dioxide emission reduction, especially considering that some scenarios with high level of WPPs in system have a lower value of objective function compared to the reference case (without WPPs). At the same time, the prices for emission allowances for TPPs were not taken into account.

The main advantage of the analysis presented is the usage of relatively simple, reliable and widely accepted model (WASP). This model requires relatively simple input data, which can be easily acquired, particularly considering WPPs. Although initially designed as a model for centralised planning of generation expansion, WASP proved to be a useful tool for conducting market analyses. Least-cost optimisation used by WASP is equivalent to simulating a perfect market, and can be used as a reference plan for any power system and/or electricity market. Results of long-term analyses obtained by modelling wind generation with monthly resolution are satisfactory. Using this type of analysis is deemed reasonable only for longer study periods (>10 years).

For detailed simulations of short-term impact of WPPs on power system, it would be necessary to have more detailed wind data (which can be a problem since private investors are unwilling to disclose wind data). Detailed data would also be needed for evaluating the capacity credit for WPPs.

The topic addressed in this paper is important from several aspects:

- Opportunity for generation companies to invest in wind development projects (environmental protection, reduction of pollutant emissions, portfolio diversification and risk management [19]);
- In evaluation of generation expansion investments it is important to examine WPPs impact on engagement of existing and new plants, considering the privileged market position of WPPs. As a consequence of using WPPs, the existing fossil fuel plants lose a part of their market share;
- From the standpoint of generators, WPPs can significantly influence unit commitment and associated costs (e.g. reduction of fuel costs, increased number of start-up/shut down, etc.).
- From the standpoint of TSO, with respect to secure operation of transmission system, it is necessary to consider the impact of WPPs and their contribution to the security and adequacy of generation capacities (in terms of power and energy);

Future work in this area will be focused on several aspects: the scope of the analysis can be extended beyond 2020; there is a possibility to model impact of a number of installed WPPs on monthly variations in generation (assumed constant here); seasonal changes of wind could be modelled and related to changes in hydro conditions (one of the main characteristic of Croatian system being the large share of hydro energy): finally, short-term analyses (yearly with 10 minute resolution) could be done to find technical an economical impact of WPPs on system operation.

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