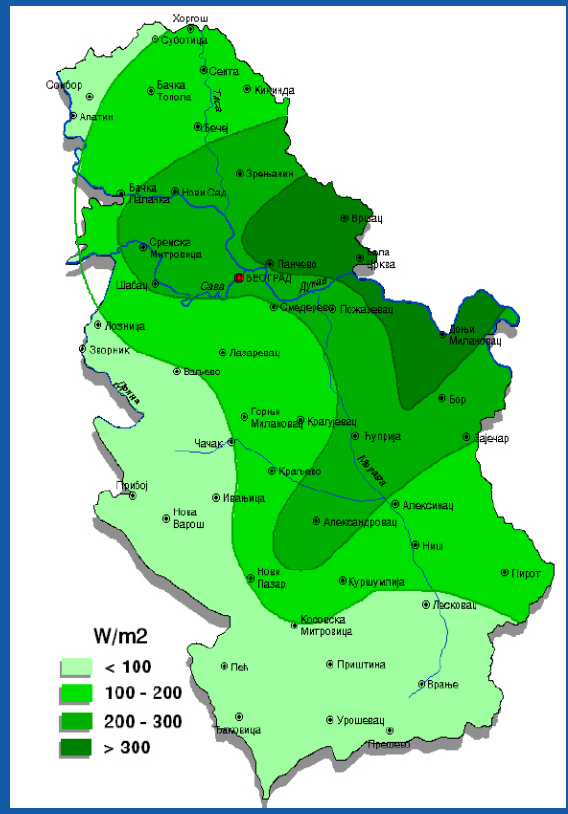
SERBIA: Power Network Analysis for Wind Power Integration

Summary of the Study

Belgrade, 5th of April 2011



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Terms of Reference

- **Part A Maximum wind power penetration in existing Serbian power system**
  - **Task 1 Review and assessment of the existing network**
  - **Task 2 Power grid technical diagnosis**
- **Part B Network reinforcement and investment requirements**
  - **Task 3 Network reinforcement and investment planning**

Task 1

Review & Assessment of existing network

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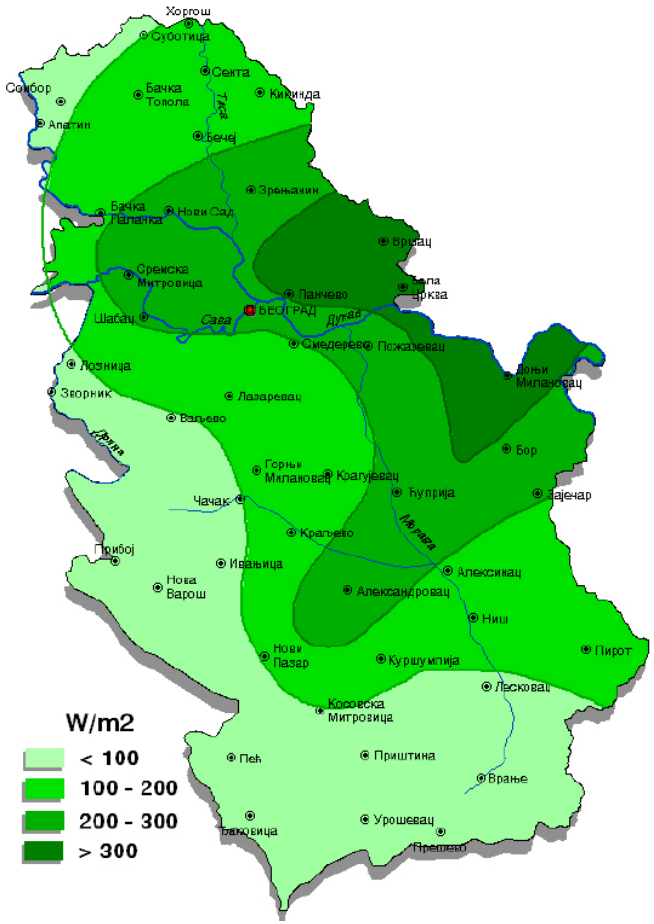
- Wind power potential and projects in Serbia
- Wind power situation in Europe
- Generation and grid structure of Serbia
- Grid situation in other European countries
- Grid operation techniques
- Wind power connection strategies
- Frame conditions for planning, construction and operation of wind power plants

Wind power potential and projects in Serbia

Wind power potential and projects in Serbia



- **Basic characteristics**
  - **Meteorological data used for definition of wind power potential**
  - **Great variations all over the country**
  - **More potential in lower regions**
  - **High potential in colder periods**
  - **North east is region of special interest**

Wind power potential and projects in Serbia

- **North east region, South Banat**

- **Koshava wind blowing from south-east most time of the year**
- **Average wind speed 5 to 6 m/s**
- **Potential up to 15,600 MWh/a**
- **Wind blows relatively constant in colder periods**
- **Usage factor near 30% (higher than European average)**
- **Good conditions for shipment of wind mills**

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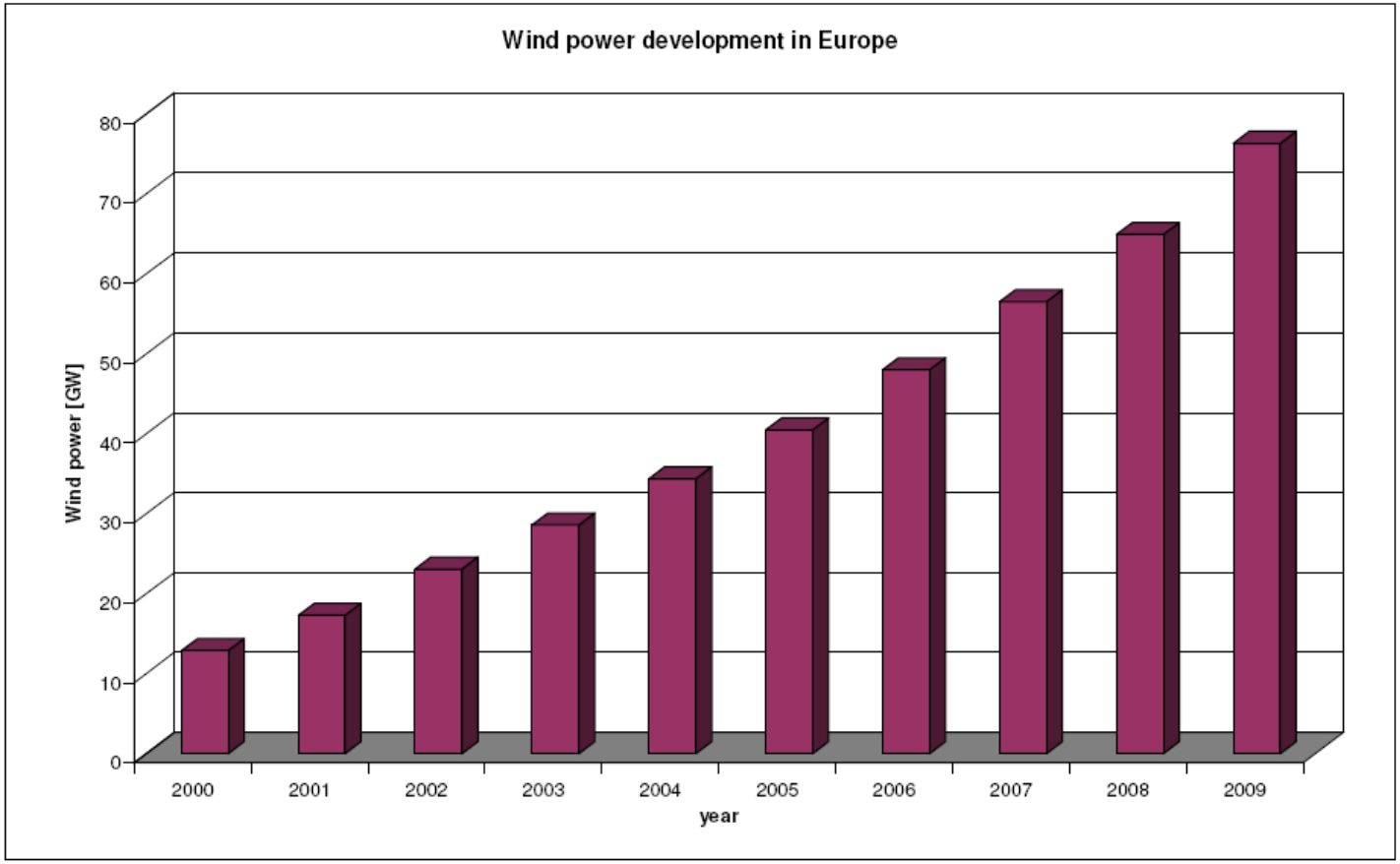
Wind power potential and projects in Serbia

- Wind power potential published 1,300 MW
- Currently fixed feed tariff for maximum 450 MW
- 16 wind parks in projects list with 2,600 MW capacity
- 5 projects with 1,135 MW permitted, 11 projects waiting for permission
- More than 75% of represented capacity located in Vojvodina
- Biggest single wind park capacity of 400 MW
- Short distance between preferred region and main load centre Belgrade

Wind power situation in Europe

Wind power situation in Europe

- **Strong development after 2000 every year from 10 to 80GW**



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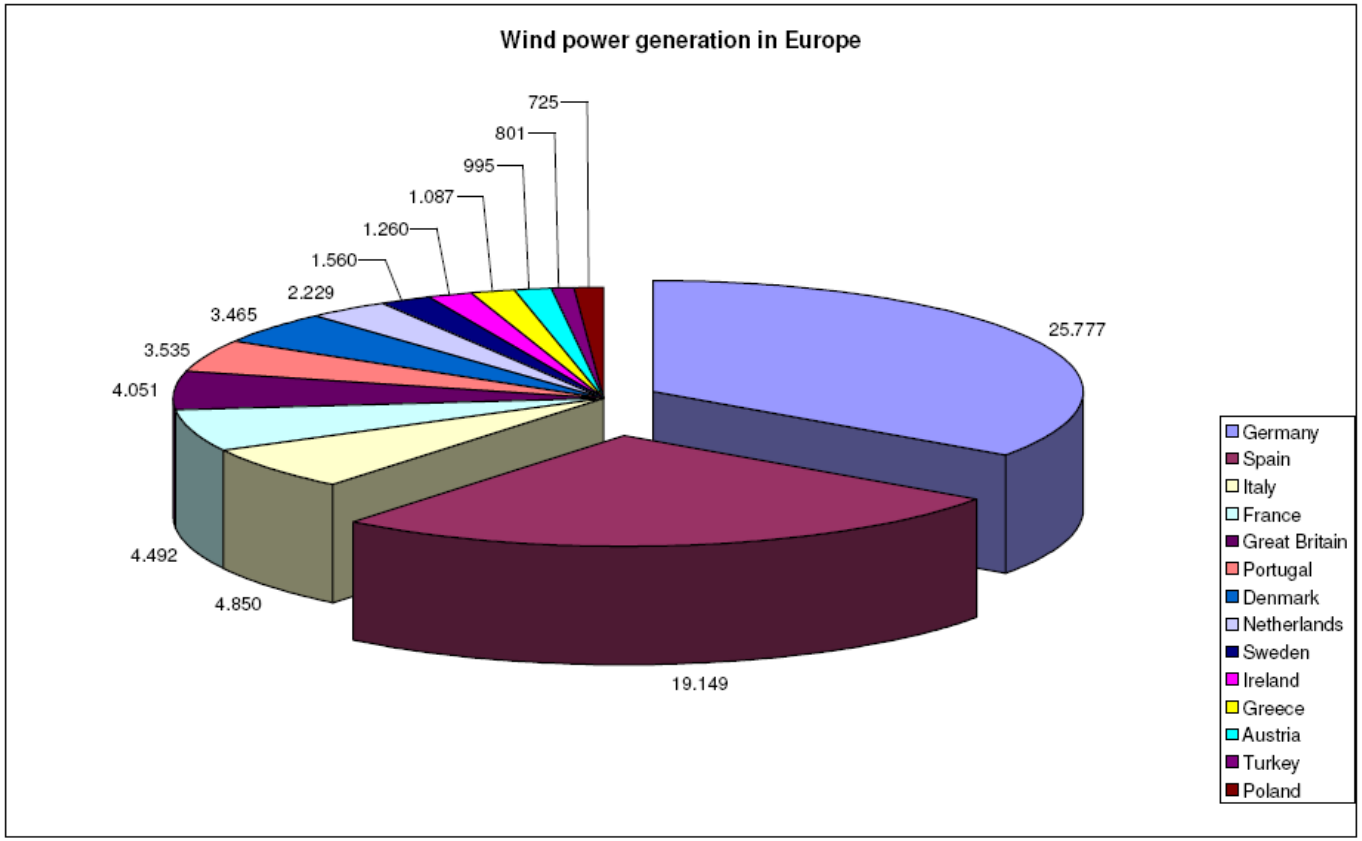
Wind power situation in Europe



- **Leading countries per installed capacity Germany 26 GW, Spain 19 GW; highest electricity production share of 20% in Denmark**

Generation and grid structure of Serbia

Generation and grid structure of Serbia

- Central grid in Balkan region
- Integral part of former Yugoslavian grid
- Strongly interconnected with neighboring systems
- 1,650km of 400kV lines, 2,070km of 220kV lines
- 110kV level belonging to transmission system
- Main load flow from North-east to South-west
- Designed to ensure power transfer from power plants to load centers

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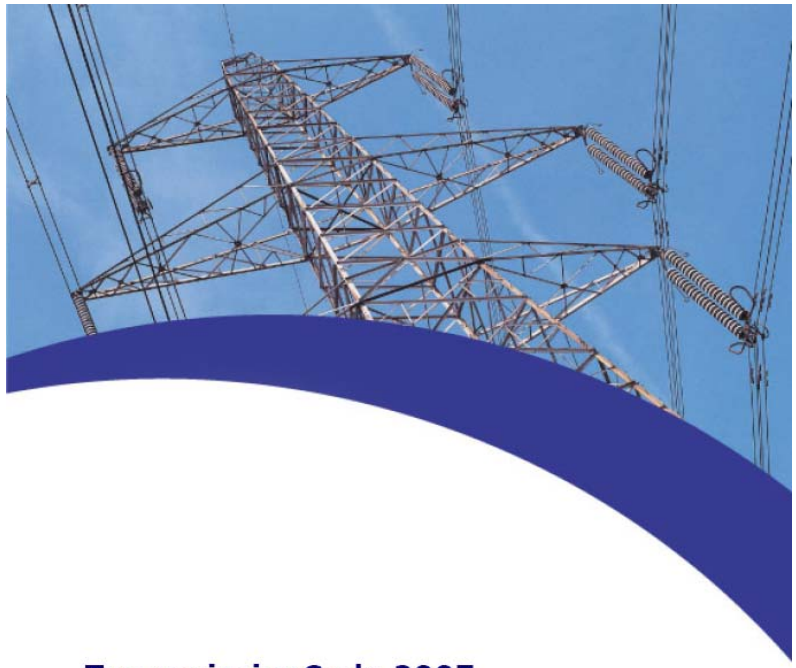
Grid operation techniques

Grid operation techniques

- **Based on ENTSO-E Operation Handbook**

- **National Grid Codes define technical requirements regarding**
  - **Synchronization**
  - **Electrical Protection**
  - **Data transfer**
  - **Frequency Control**
  - **Voltage/Reactive Power Control**
  - **Transient Stability (short circuit) Static Stability (grid oscillations)**
  - **Grid recovery (e.g. Black start)**



Wind park connection strategies

Wind park connection strategies

- **Before any detailed planning the grid operator has to work out its strategic position concerning wind park connections considering valid Serbian legislation:**

  - **Strategy 1: The system operator will lead its own grid tightly to the wind parks in order to minimise the extension of private wind park grids**
  - **Strategy 2: The system operator determines the grid connection points near to its own existing grid (next to substations and lines) in order to keep its own grid topology small**

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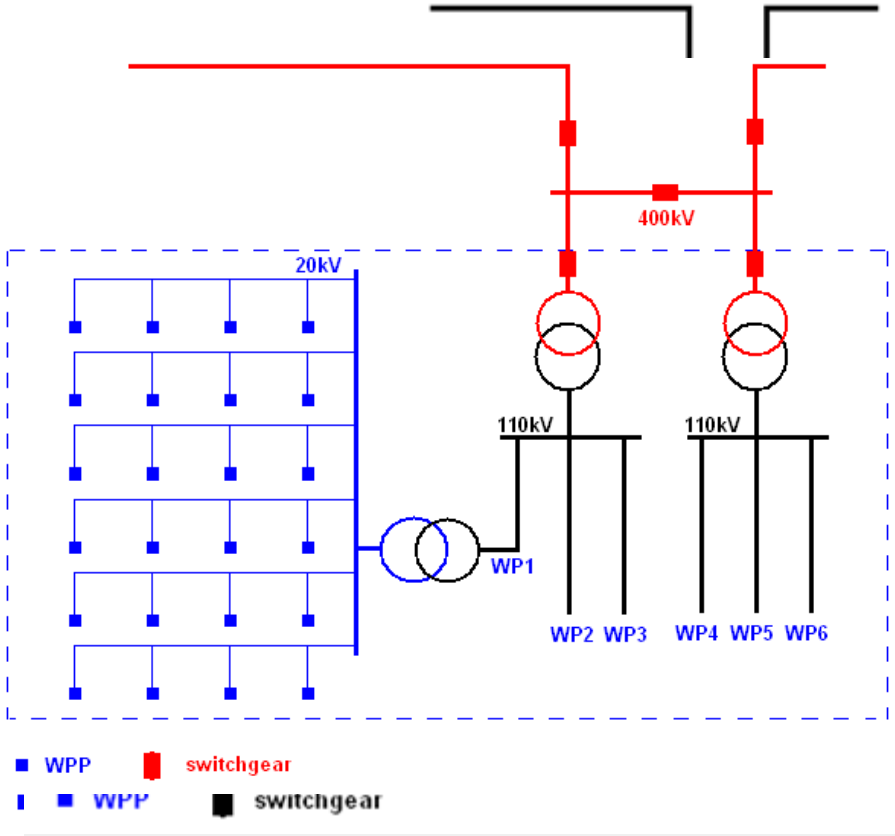
Wind park connection strategies

- Another design criterion is (n-1)-principle
- In Serbia generation units are connected to the grid following the (n-1)-principle, which is very reliable but also costly solution
- In Germany and other countries of the EU branch grid connections of power plants are usual
- Especially for grid connections of wind parks a branch solution could be even possible in Serbia in order to minimize costs, since the risk of non-availability due to wind conditions is much higher than the outage a branch line



400kV-branch connection line

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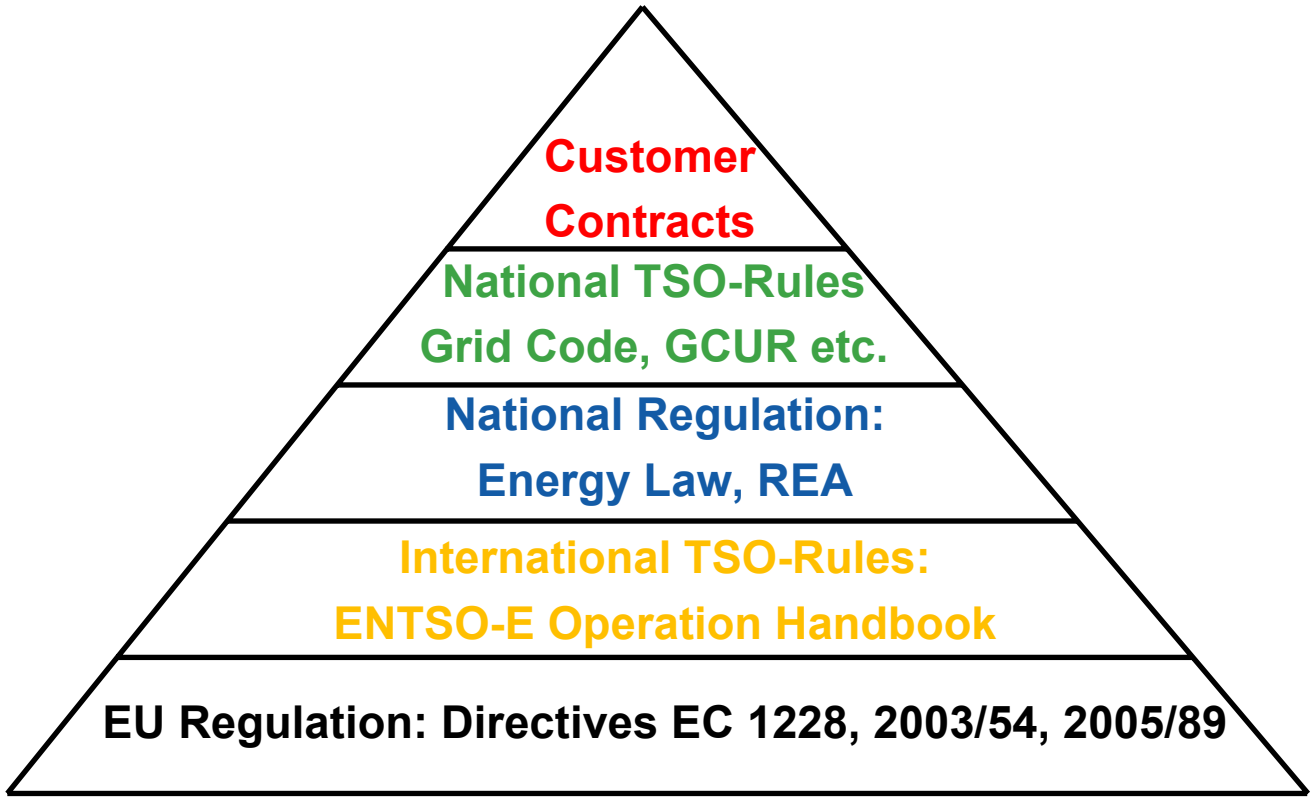
Frame conditions for planning, construction and operation of wind power plants

Frame conditions

- Legal framework
- Technical framework
- Organizational framework
- Economical framework

Frame conditions

- **Framework and rules for operation and security by the TSO**



Task 2

Power grid technical diagnosis

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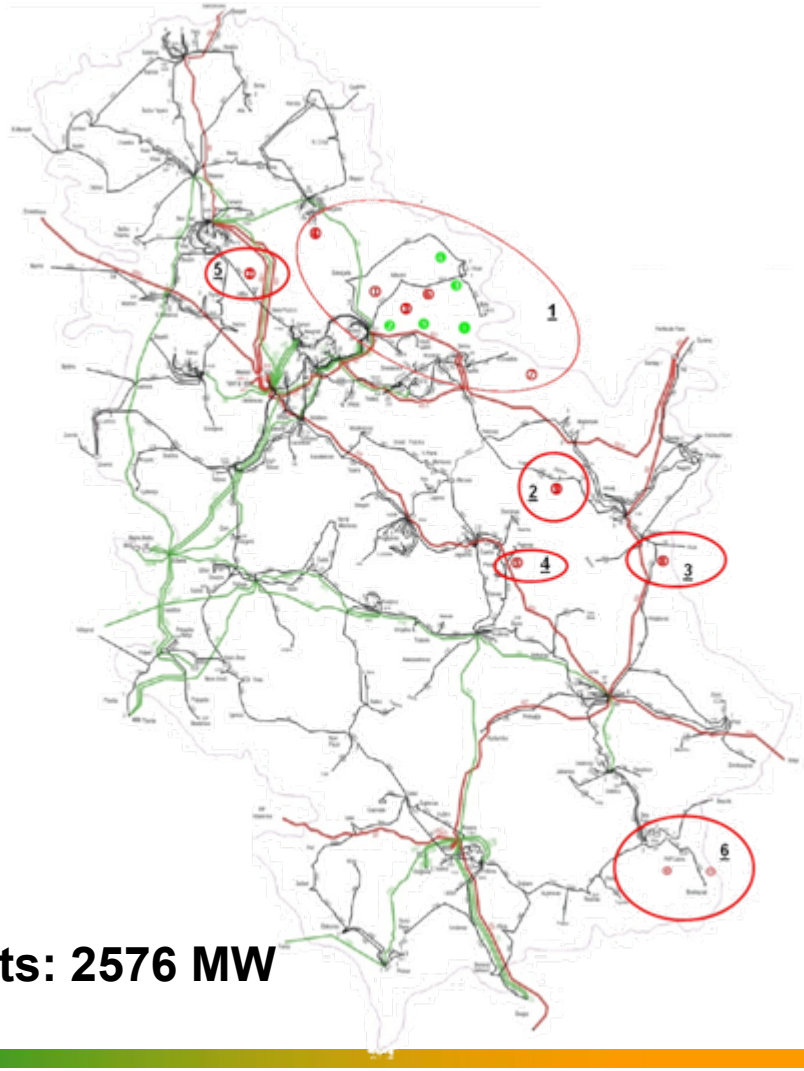
- **Transmission network analysis**
  - Analyzed wind power plants
  - Scenarios – exchange, season, topology
  - Network analysis summary
  - Connection points
  - Network reinforcements
- **System reserve analysis**
- **Economical effects of wind power in-feed**

Transmission network analysis

Transmission network analysis

- **Analyzed wind power plants:**

WPP	P (MW) per phase
Bela Anta	120
Belo Blato	10.5 + 10.5
Bela Crkva	37.5 + 150
Bavanistansko polje	188
Čibuk	50 + 250
Dolovo	150 + 200
Golubac - Krivača	112.8
Košava	50 + 67
Šušara	60
Vršac	100 + 300
Žagubica	63
Vrška čuka	189
Čestobrodica	50 + 230
Inđija	20
Milevska	66
Vardenik	102



- **Total installed power of analyzed projects: 2576 MW**

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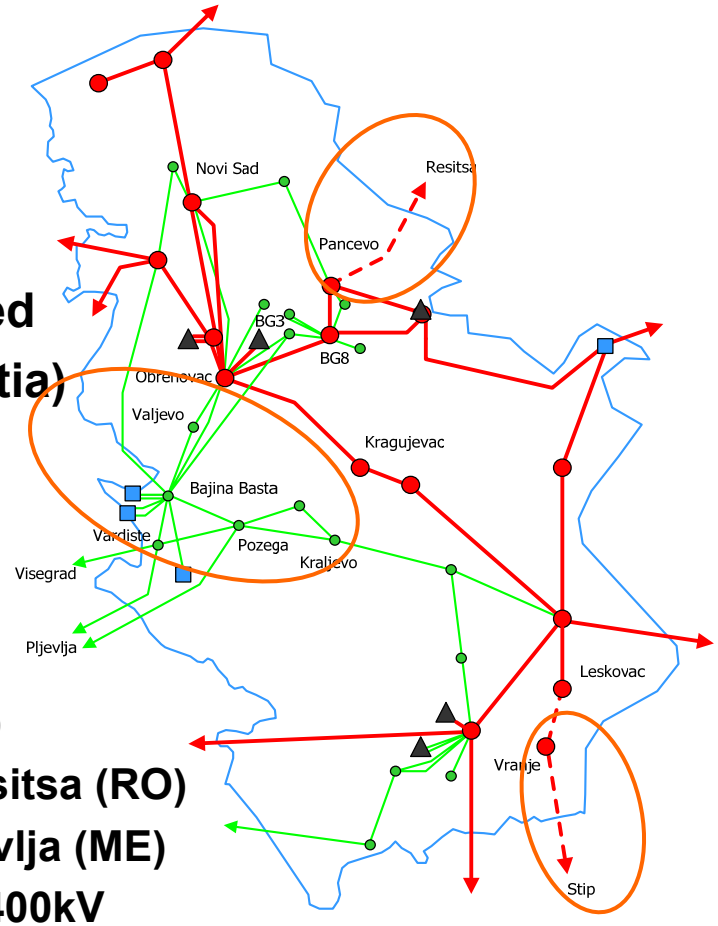
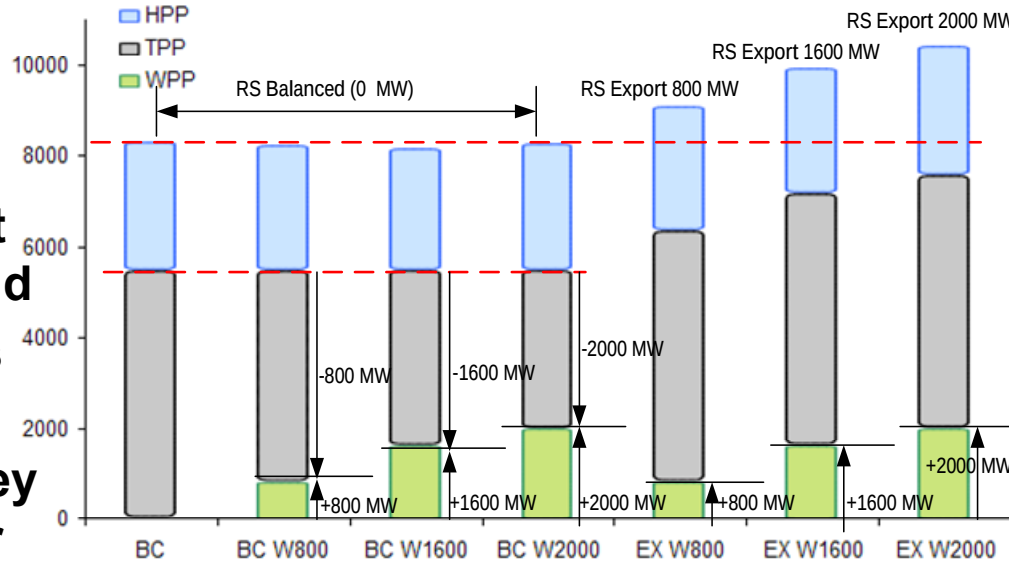
Transmission network analysis

- **Seasonal scenarios:**
  - **Winter 19h30 2015, "*Winter peak*"**
  - **Summer 10h30 2015, "*Summer max*"**
  - **Summer 03h30 2015, "*Summer min*"**
- **Exchange:**
  - **No exchange, wind power output balanced**
  - **Export (Italy *(via DC cable)*, Greece, Croatia)**
  - **Outage of the largest TPP unit**
- **Topology:**
  - **Present, topology 2010 & demand 2015**
  - **Expected, topology & demand 2015**
    - **400 kV OHL SS Vranje (RS) – SS Stip (MK)**
    - **2 x 400 kV OHL SS Pancevo (RS) – SS Resitsa (RO)**
    - **2 x 400 kV OHL SS B.Basta (RS) – SS Pljevlja (ME)**
    - **Upgrade of network in western Serbia to 400kV**



Transmission network analysis

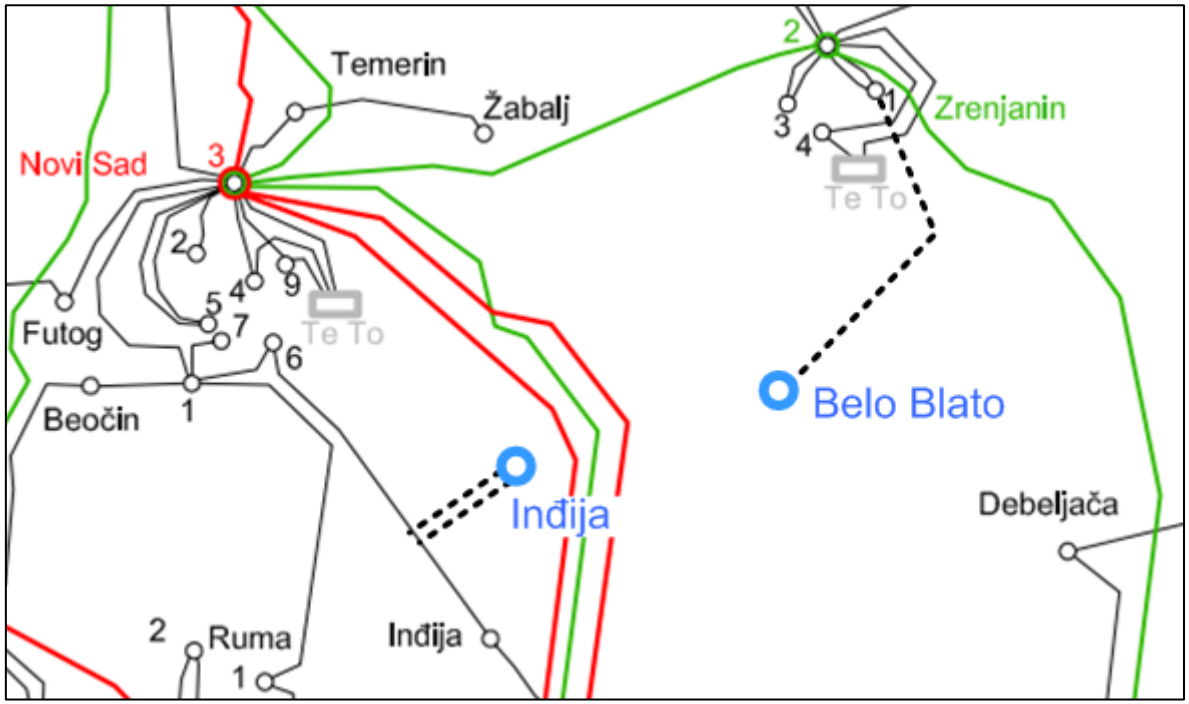
- **Initial analysis to identify limitations in the transmission network:**
  - **WPPs separately per geographical region**
  - **all WPPs altogether**
- **Present topology cannot support the level of "*Winter peak*" demand even without integration of WPPs**
- **Outage of one unit in TENT B causes network limitation but they resolved by topology changes or generation redispatch**



- **Proposal of connection points by maximization of wind power in-feed avoidance of network limitations and minimization of network reinforcements**

Transmission network analysis

- **Belo Blato (10,5MW + 10,5MW) – 110kV line to SS Zrenjanin 1**
- **Inđija (20MW) – in/out connection to 110kV line Novi Sad 6 - Inđija**



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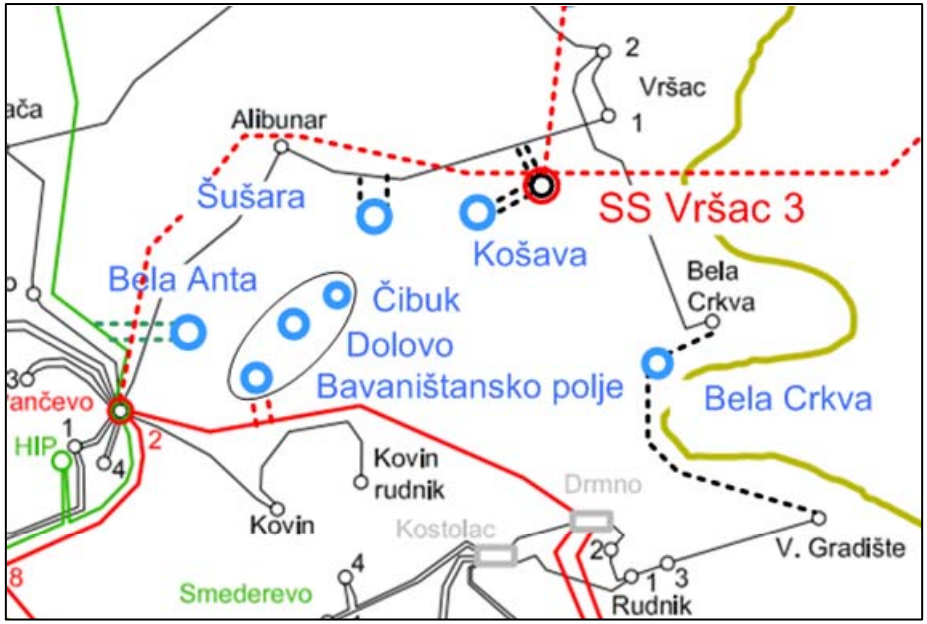
Transmission network analysis

- **Bela Anta (120MW) – in/out to 220kV line Pančevo 2 – Zrenjanin 2**
- **Šušara (60MW) – in/out to 110kV line Alibunar – Vršac 1**
- **Bela Crkva (37,5MW + 150MW) – in/out to planned 110kV line Bela Crkva – V. Gradište**



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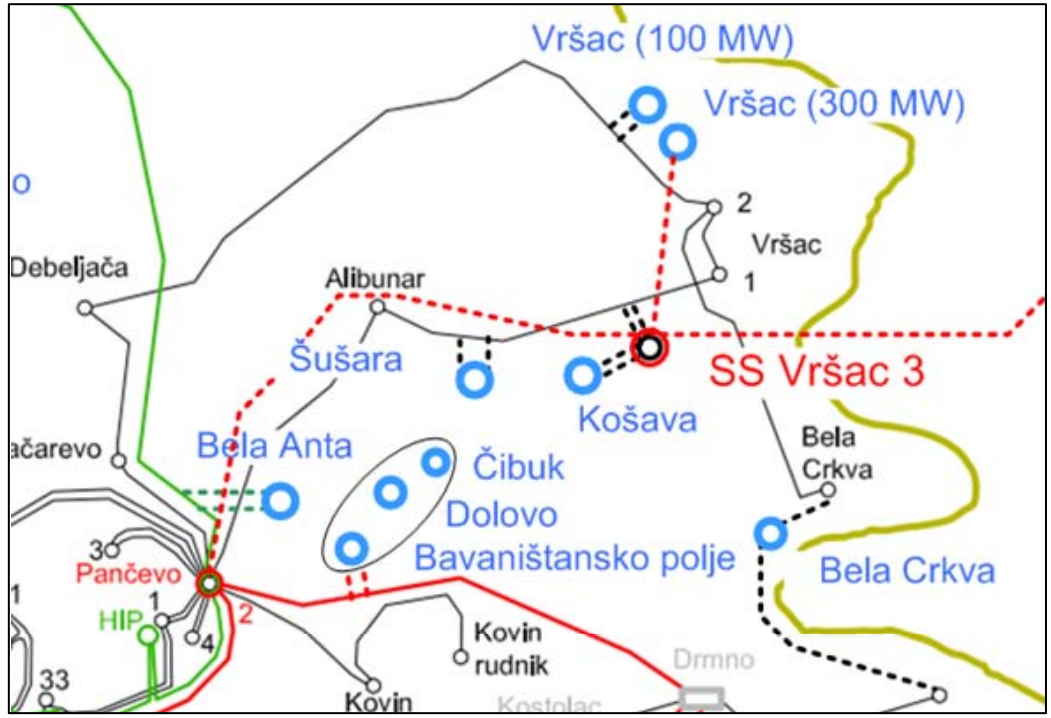
Transmission network analysis

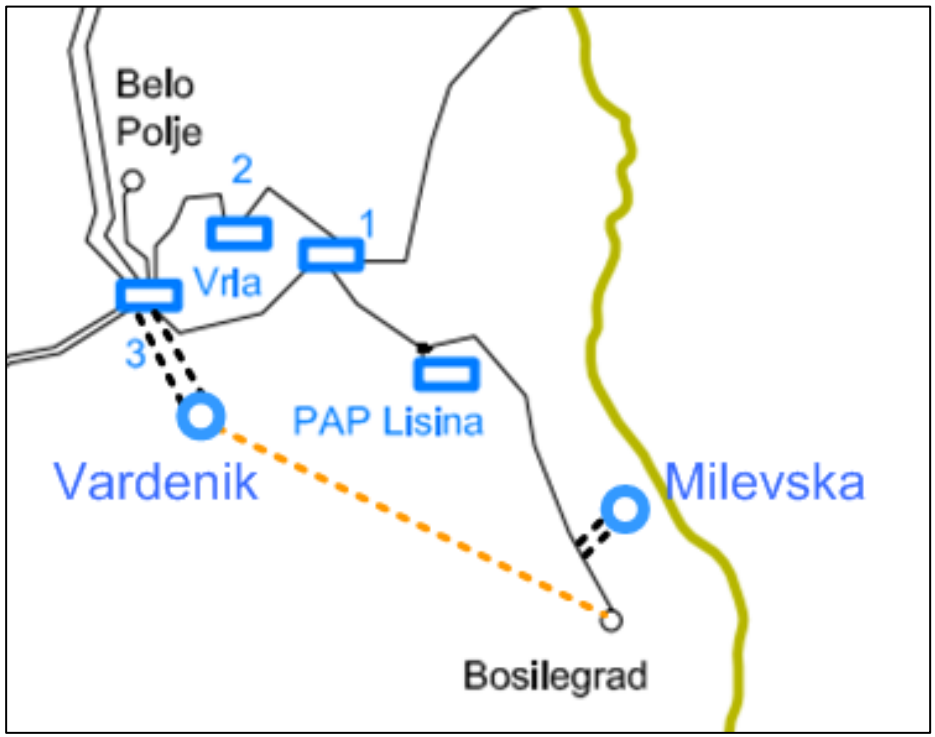
- **Vršac (100MW) – in/out to 110kV line Vršac 2 – Debeljača**
- **Vršac (300MW) – 400kV line to SS 400/110kV Vršac 3**
- **Košava (50MW + 67MW) – single/double 110kV line to SS 400/110kV Vršac 3**
- **Bavaništansko polje (188MW), Čibuk (50MW + 250MW), Dolovo (150MW + 200MW)**
  - **in/out to 400kV line Drmno – Pančevo 2**



Transmission network analysis

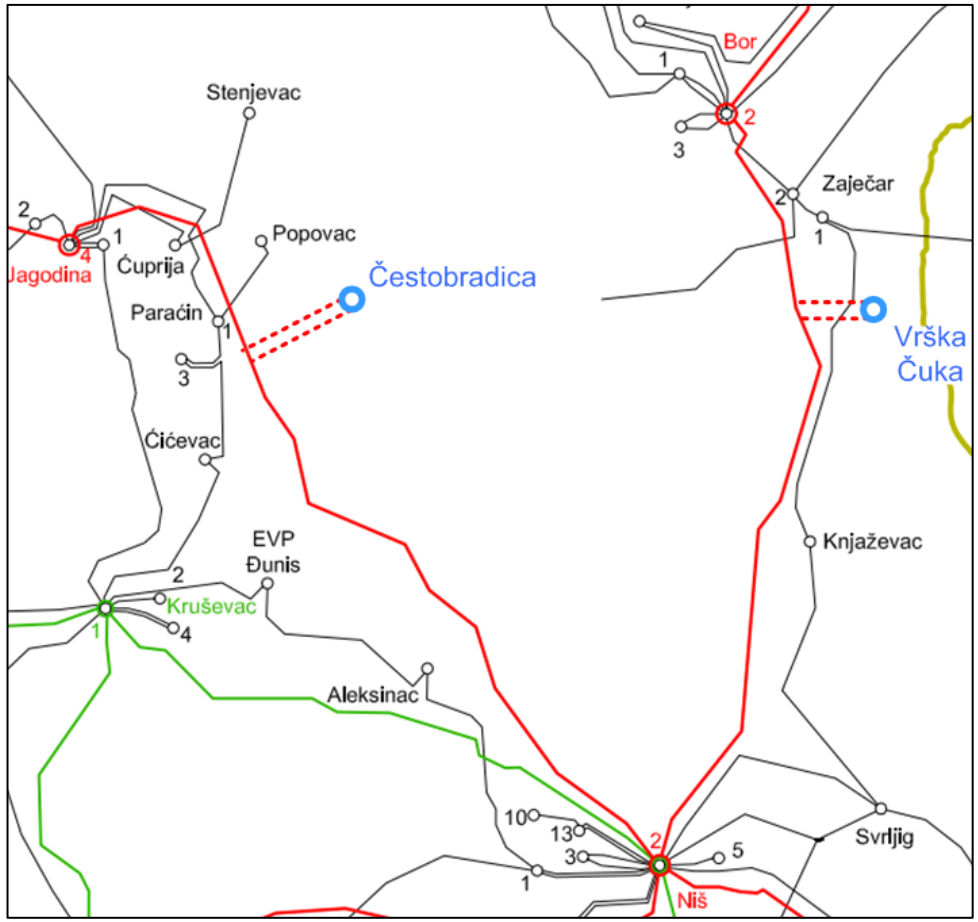
- **Vardenik (102MW) – double (single) 110kV line to SS Vrla 3**

- **Milevska (66MW) – in/out to 110kV line PAP Lisina – Bosilegrad**



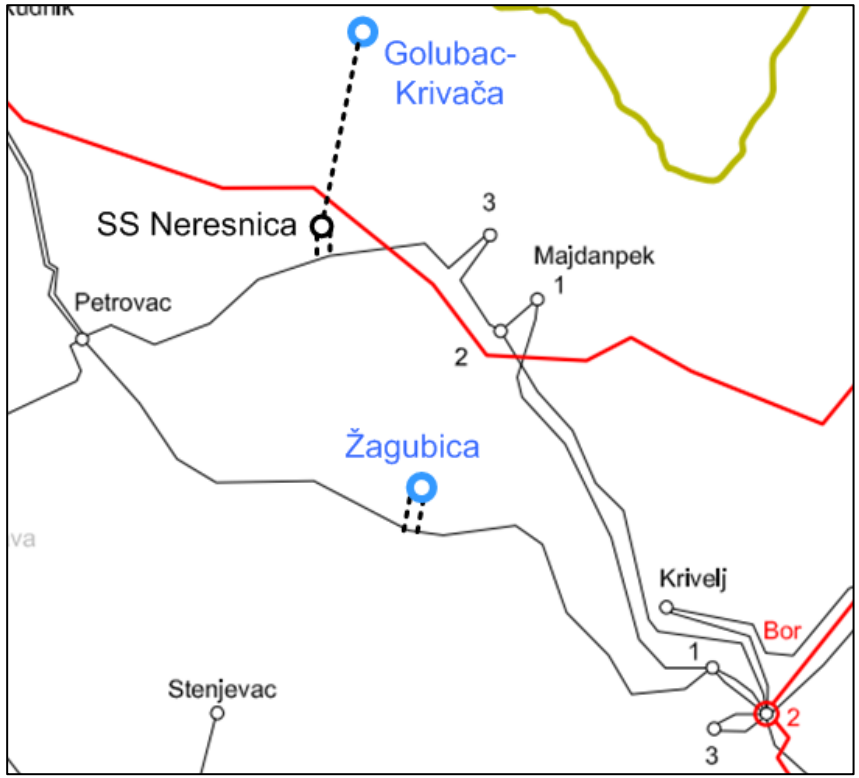
Transmission network analysis

- **Čestobrodica (50MW + 230MW) – in-out to 400kV line Niš 2 – Jagodina 4**
- **Vrška Čuka (189MW) – in-out to 400kV line Bor 2 – Niš 2**



Transmission network analysis

- **Golubac – Krivača (112,8MW) – 110kV line to planned SS Neresnica**
- **Žagubica (63MW) – in/out to 110kV line Petrovac – Bor 1**



Transmission network analysis

- **2,000 MW of coincident wind power in-feed supported from transmission capacity point of view causes only few reinforcement and extension measures in the 110kV network**

Grid reinforcements necessary for high wind penetration					
Type of reinforcement	From	To	Voltage level [kV]	Initial conductor cross-section [mm2]	Main conductor cross-section [mm2]
Cross-section upgrade	SS Alibunar	WP Šušara	110	150	240
Cross-section upgrade	SS Pančevo	SS Alibunar	110	150	240
Cross-section upgrade	SS Smederevo 1	SS Smederevo 2	110	150	240
New line	SS Rudnik Kovin	WP Bela Crkva	110	-	240

Grid extensions necessary for WPPs conection						
Type of reinforcement	From	To	Voltage level [kV]	Length [km]	No. of circuits	Main conductor cross-section [mm2]
New line	SS Bosilegrad	WP Vardenik (or SS Vrla 3)	110	26 (35)	1	240
New substation	SS 400/110 kV Vršac 3		400/110			300 MVA

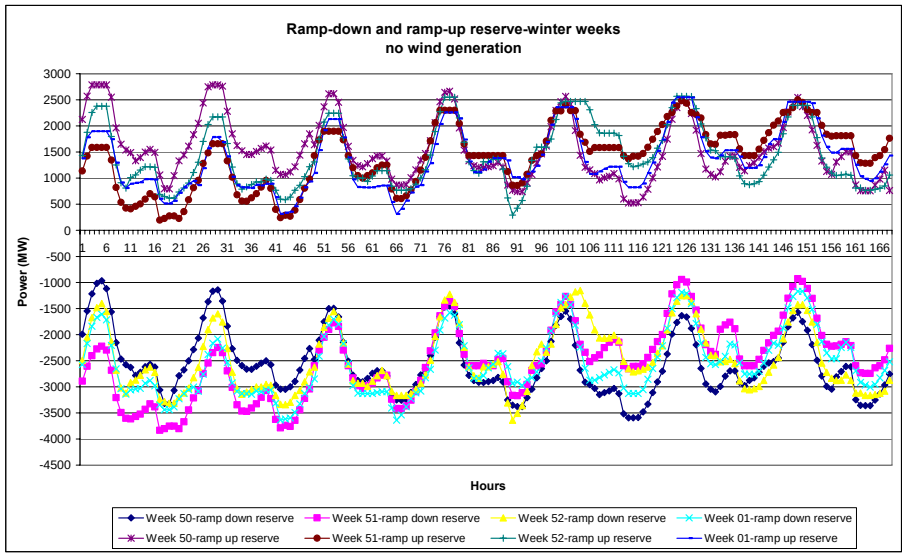
System reserve analysis

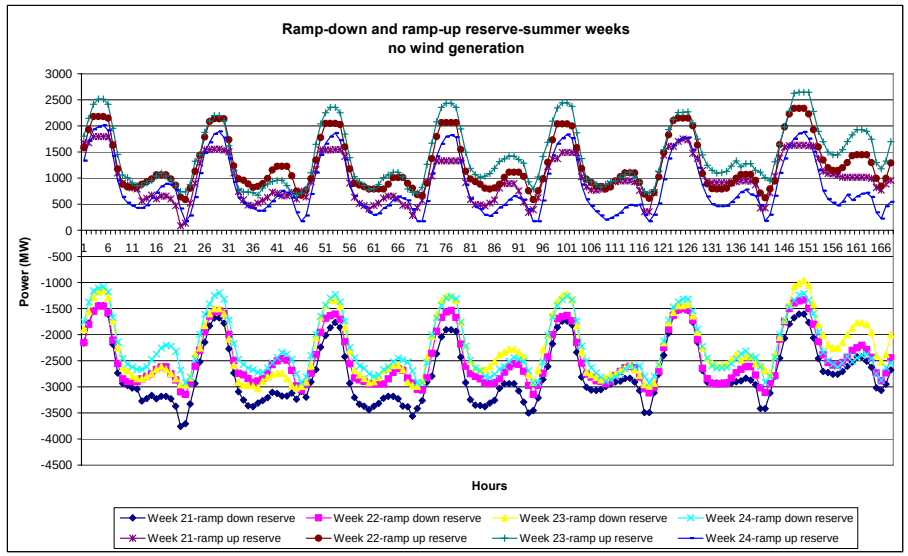
Wind penetration limits from the aspect of system reserve

- The aim of the analyses was to define the limits for possible wind penetration in terms of system reserve in the current development stage of the Serbian power system
- The following operating conditions were respected during simulations of the system operation in cases with and without wind generation in selected 4 weeks during winter and 4 weeks during summer season:
  - Full balance inside EMS control area, i.e. no additional import/export
  - No switch-off of thermal power plants due to high wind in-feed
  - With the aim to simulate same hydrology conditions as in realized weeks, the given same weekly generation from HPP's has been applied for detailed simulation
  - Engagement (generation and pumping) of the PSPP Bajina Basta has been defined within the analyses as a result of the optimization process

Wind penetration limits from the aspect of system reserve

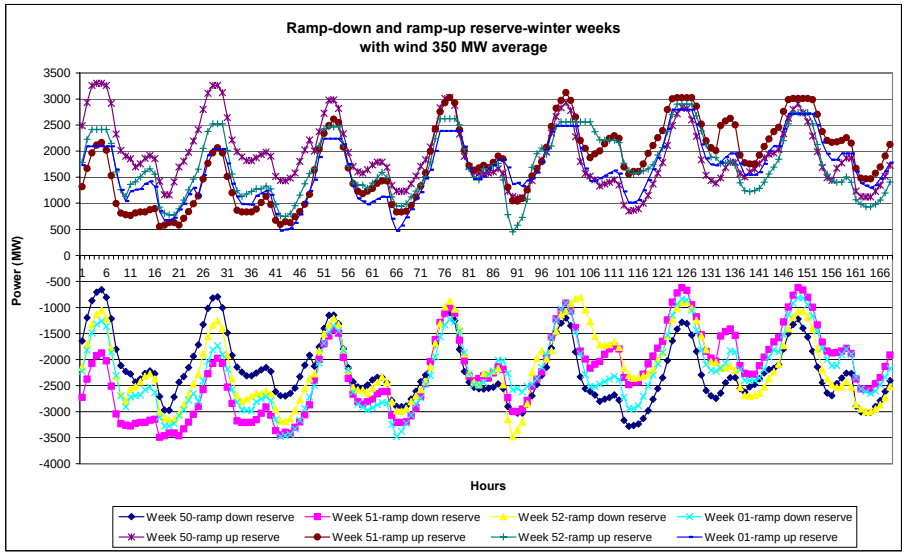
- **Ramp-up and ramp-down reserves for simulated weeks**
  - **– without wind generation**

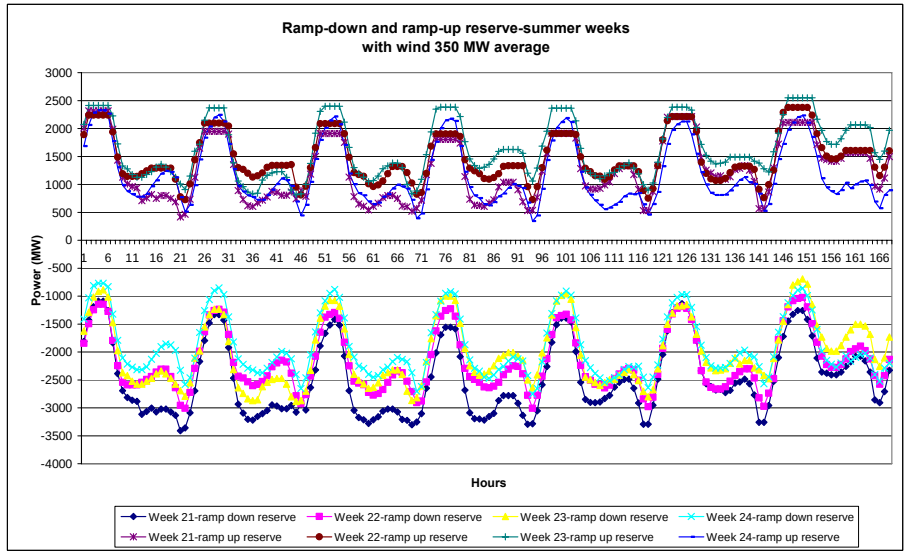




Wind penetration limits from the aspect of system reserve

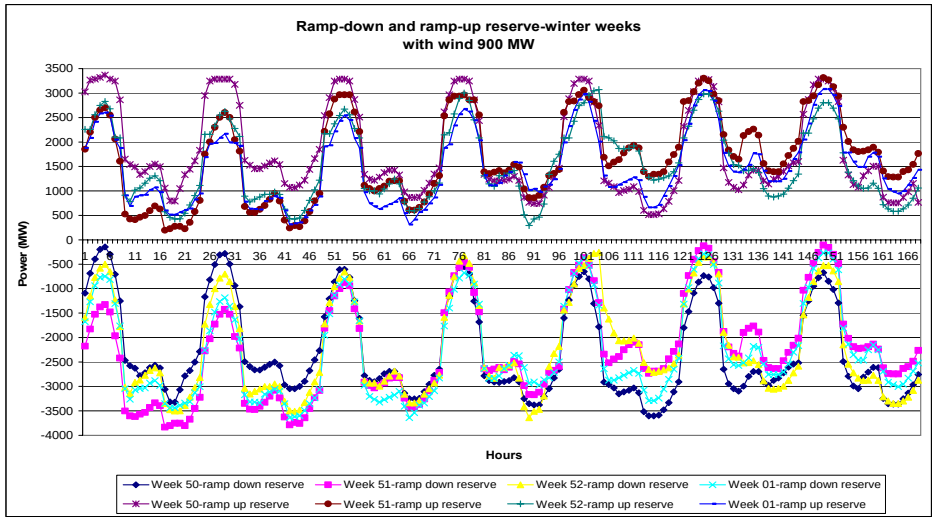
- **350 MW as constant wind power in-feed is the limit from the aspect of unit commitment**
- **Ramp-down reserve during summer season creates the limit**

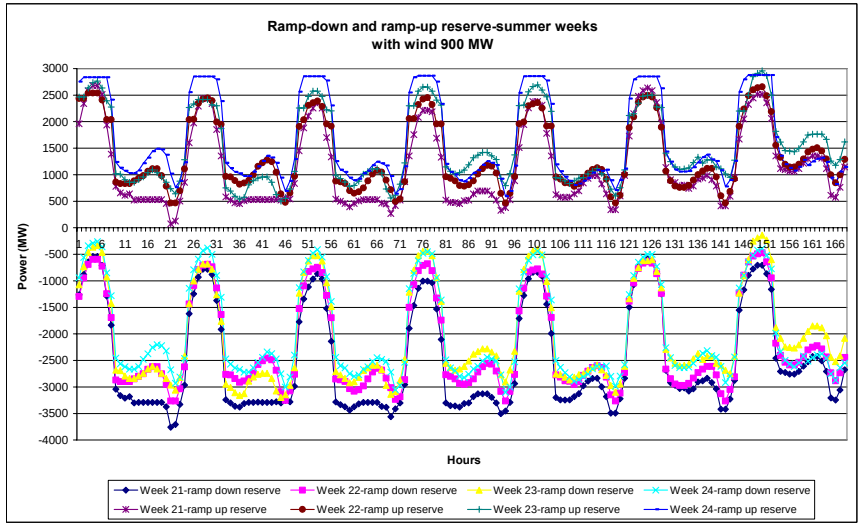




Wind penetration limits from the aspect of system reserve

- **900 MW is the maximal wind power in-feed with which the existing Serbian power system can operate without changes in the unit commitment and using all potentials in load dispatching among existing generators**
- **Assumed hourly distribution of wind generation provokes maximal disturbance of the system**





Wind penetration limits from the aspect of system reserve

- **Considering correlation of the spatially distributed wind farms and fact that majority of the planned wind farms will be realized in the northern part of Serbia (Vojvodina), the ratio between installed capacity in wind farms and maximum possible in-feed is estimated as 1,1 to 1,2**

- **Maximum installed capacity in Serbia under the circumstances given in chapter 5 (no additional import/export, no switching-off of TPPs, assumed wind power output curve, etc.) amounts not less than 1,000 MW.**

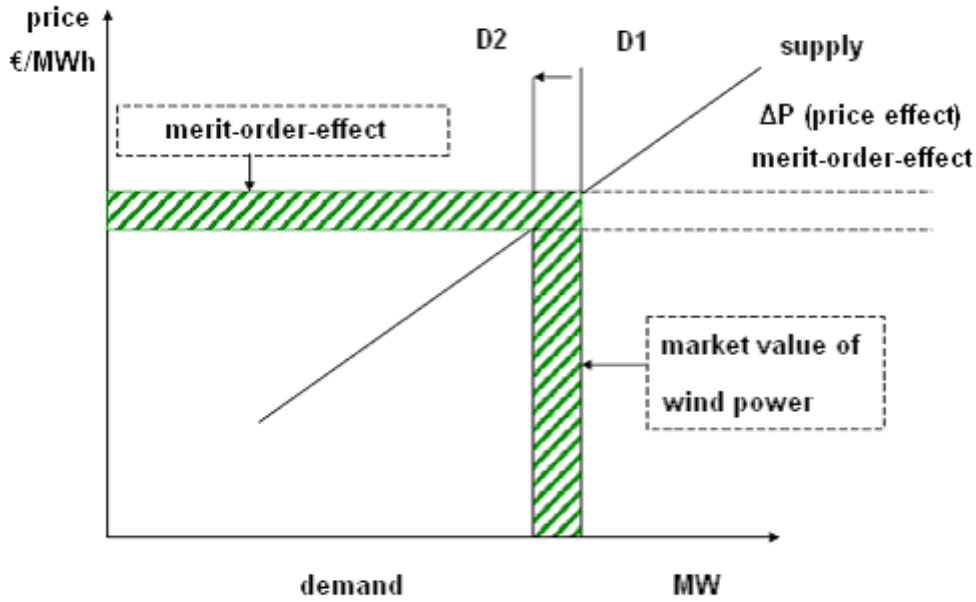
- **Integration of the wind generation will require changes in power and transmission system operators' practice and involvement of more sophisticated software tools for prediction and management of system operation taking into account wind forecast management systems with forecasting scenarios for wind velocities**

Economical effects of wind power in-feed

Economical effects of wind power in-feed

- **Decreasing operation and full capacity hours of power plants → accordingly increasing generation costs**
- **2,000 MW of wind power in-feed → increase of total energy price by 1.7Ct/kWh till 2020.**

- **In the Market environment - Merit-Order-Effect:**
  - **Switching-off of most unefficient and most expensive power plants**
  - **Decreasing due to increasing total efficiency of all remaining power plants in operation**
  - **Fraunhofer Study: average price reduction of up to 0,8Ct/kWh**



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Economical effects of wind power in-feed

- **The tendered renewable energy reserve amounts to approximately 10-15 % of the forecasted total wind power in-feed (15 years of experience in 50Hz Transmission control area)**
- **Accordingly 200MW – 300MW for 2,000MW of maximum wind power in-feed to be kept ready for Serbian TSO**
- **In European energy markets wind reserve compensation energy is to be tendered monthly**
- **Typical capacity prices:** **1,700€/MW*a** **positive comp. power**
  2,500€/MW*a **negative comp. power**

Task 3

Grid Extension and refurbishment measures

Environmental and Social Implications

Grid Extension and refurbishment measures

Grid Extension

Line		Type of grid extension	Voltage level [kV]	Length [km]	No. of circuits	Main conductor cross-section [mm²]
From	To					
SS Bosilegrad	WP Vardenik / SS Vrla 3	New line	110	26 / 35	1	240
SS 400/110 kV Vršac 3		New substation	400/100	-	-	-

and refurbishment measures

Line		Type of grid rein-forcement	Voltage level [kV]	Length [km]	No. of circuits	Initial cross-section [mm²]	New cross-section [mm²]
From	To						
SS Alibunar	WP Šušara	Cross-section upgrade	110	29	1	150	240
SS Pančevo	SS Alibunar	Cross-section upgrade	110	31	1	150	240
SS Smederevo 1	SS Smederevo 2	Cross-section upgrade	110	5	1	150	240
SS Rudnik Kovin	WP Bela Crkva	New line	110	25	1	-	240

due to high wind power in-feed

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Grid Extension and refurbishment measures

- Based on the single costs the total costs for all considered wind park connection lines amount to 133 million € approximately.
- Depending on the chosen strategy mentioned in Task 1 defraying of the connection costs has to be agreed.
- Following strategy 2 these connection lines have to be paid by the respective wind park investors.
- With the implementation of 2,000MW of coincident wind power in-feed only minor measures are necessary that will cost about 21 million €.
- Reinforcing extensively the Serbian 400-kV-, 220-kV- and 110-kV-grid bigger amounts of wind power in-feed and installed capacity are possible
- Independent of the chosen strategy as per Task 1 these costs have to be born by EMS, but can be shifted to the final customers, which will influence the Serbian energy prices.

Environmental and Social Implications

Environmental and Social Implications

- **Description of project areas' existing environment**
  - **The country of Serbia contains high biodiversity, both in terms of ecosystems and species**
  - **Land use in Serbia is dominated by agriculture, which makes up 65% of the total surface of the country**
  - **Four ecological regions as per World Wildlife Fund**

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Environmental and Social Implications

- Project proposes approximately 100 km transmission lines in agricultural areas and 60 km transmission lines in forestry areas.
- Expected impacts are different in construction and operation phases

Construction phase	Operation phase
Erosion	Electric and Magnetic Fields
Noise	Visual amenity
Land changes	Minor migration obstacle
Land aquisition (Right-of-Way)	Potential impact on aviation and communication equipment
Air emissions	

- Transmission lines and substations normally do not give rise to significant, pernament negative impacts. The main disturbance occurs during the constructions phase.

Environmental and Social Implications

- Impacts on national parks and other protected areas:
  - Golubac-Krivaca
    - Djerdap National Park along the Serbian bank of the Danube River.
  - Vrska Cuka
    - the Stara Planina Natural Park (Balkan Mountains, eastern Serbia).
- Impacts on national parks and other protected areas:
  - Cestobrodica
    - the proposed natural park Kučaj Mountains along the Resava River.
  - Bela Crkva
    - the proposed natural park Lower Danube and potentially also the RAMSAR Wetlands Site Labudovo Okno.
  - Cibuk
    - the Special Nature Reserve Deliblato Sands.
- The application and approval process for projects, wind farms and overhead lines, in protected areas is more complicated and construction may require additional environmental management and mitigation measures.

Environmental and Social Implications

- **Individual permitting processes for each grid reinforcement, refurbishment and WP connection measure**
- **Minor discrepancies between Serbian legislation and requirements from EBRD (or other international financing institution)**
- **Possible differences in the timing of an Impact Assessment in the project development cycle. EBRD expects EIA earlier in the process compared to Serbian regulations.**
- **Some connection lines and windparks are located in protected areas and may require special attention**
- **Mitigation measures have to be considered**

Thank you for your attention!

Vattenfall Europe PowerConsult GmbH

Electricity Coordinating Center Ltd.

Belgrade, 5th of April 2011