OPTIMIZATION OF THE ELECTRIC POWER SYSTEM OF MACEDONIA

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• Introduction
• The electric power system of Macedonia
• The model of the electric power system of Macedonia
• Typical examples
• Conclusion
Introduction

- Classification of energy models
  - The model analyses energy production and is based upon technical aspects of the energy system and is concerned with meeting the requirements for equilibrium between energy supply and demand
  - The users have to make assumptions about the values of the parameters
  - The engineering approach of bottom up is used
  - The model can be classified as optimization and simulation model
  - The linear programming technique is applied
  - Geographical coverage is national
  - The model is intended for the analysis of energy production and consumption in regions of Macedonia
  - Time period: short term
  - Input data: electricity demand and electricity generation and transmission capacities and prices.

In this paper the authors presented the bottom-up model that addresses a medium term operational horizon (several months to 2–3 years) and follows an optimization methodology that captures the physical and environmental restriction of the coal, natural gas, and electricity flows.

We have modified and extended this work in several directions to include short-term (on daily basis) analysis of the Macedonian power system.
The electric power system of Macedonia is operated by four entities, namely:

- AD **ELEM**, company for generation and supply of electricity,
- AD **MEPSO – Skopje**, company for transmission of electricity and management with the electric power system of Macedonia,
- The distribution company **EVN Macedonia** AD and
- AD **TPP Negotino**, company for electricity generation.
### Electricity generation

<table>
<thead>
<tr>
<th>TPP</th>
<th>$P_{\text{min}}$ [MW]</th>
<th>$P_{\text{max}}$ [MW]</th>
<th>Fuel type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bitola I</td>
<td>160</td>
<td>225</td>
<td>Lignite</td>
</tr>
<tr>
<td>Bitola II</td>
<td>160</td>
<td>225</td>
<td>Lignite</td>
</tr>
<tr>
<td>Bitola III</td>
<td>160</td>
<td>225</td>
<td>Lignite</td>
</tr>
<tr>
<td>Oslomej</td>
<td>90</td>
<td>125</td>
<td>Lignite</td>
</tr>
<tr>
<td>Negotino I</td>
<td>70</td>
<td>105</td>
<td>Heavy fuel oil</td>
</tr>
<tr>
<td>Negotino II</td>
<td>70</td>
<td>105</td>
<td>Heavy fuel oil</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>710</strong></td>
<td><strong>1010</strong></td>
<td></td>
</tr>
</tbody>
</table>

- **Basic parameters of TPPs**

### Basic parameters of HPPs

<table>
<thead>
<tr>
<th>HPP</th>
<th>Catchment</th>
<th>Number of units</th>
<th>$Q_{\text{inst/unit}}$ [m$^3$/s]</th>
<th>$H_{\text{gross}}$ [m]</th>
<th>Volume [10$^6$ m$^3$]</th>
<th>$P_{\text{inst}}$ [MW]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vrutok</td>
<td>Mavrovo</td>
<td>4</td>
<td>9</td>
<td>574</td>
<td>277</td>
<td>172</td>
</tr>
<tr>
<td>Tikvesh</td>
<td>Crna Reka</td>
<td>4</td>
<td>36</td>
<td>100</td>
<td>272</td>
<td>116</td>
</tr>
<tr>
<td>Globocica</td>
<td>Crn Drim</td>
<td>2</td>
<td>27</td>
<td>110,9</td>
<td>228</td>
<td>42</td>
</tr>
<tr>
<td>Shupilje</td>
<td>Crn Drim</td>
<td>3</td>
<td>36</td>
<td>95</td>
<td>212</td>
<td>84</td>
</tr>
<tr>
<td>Kozjak</td>
<td>Treska</td>
<td>2</td>
<td>50</td>
<td>102</td>
<td>260</td>
<td>88</td>
</tr>
<tr>
<td>Raven</td>
<td>Mavrovo</td>
<td>3</td>
<td>10,6</td>
<td>66</td>
<td>0</td>
<td>21,6</td>
</tr>
<tr>
<td>Vrben</td>
<td>Mavrovo</td>
<td>2</td>
<td>4,6</td>
<td>193</td>
<td>0</td>
<td>12,8</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td><strong>536</strong></td>
</tr>
</tbody>
</table>
Basic parameters of small HPPs in the network of EVN Macedonia

<table>
<thead>
<tr>
<th>Small HPPs</th>
<th>( P_{\text{inst}} ) [MW]</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>MAK ROT program</strong></td>
<td></td>
</tr>
<tr>
<td>Sapunchica</td>
<td>2,9</td>
</tr>
<tr>
<td>Kalimanci</td>
<td>13,8</td>
</tr>
<tr>
<td>Zrnovci</td>
<td>1,4</td>
</tr>
<tr>
<td>Doshnica</td>
<td>4,1</td>
</tr>
<tr>
<td>Pesochani</td>
<td>2,7</td>
</tr>
<tr>
<td>Matka</td>
<td>9,6</td>
</tr>
<tr>
<td>Pena</td>
<td>2,5</td>
</tr>
<tr>
<td><strong>Other EVN</strong></td>
<td></td>
</tr>
<tr>
<td>Babuna</td>
<td>0,7</td>
</tr>
<tr>
<td>Belica</td>
<td>0,3</td>
</tr>
<tr>
<td>Turija</td>
<td>2,2</td>
</tr>
<tr>
<td>Popova Shapka</td>
<td>4,8</td>
</tr>
<tr>
<td><strong>Other companies</strong></td>
<td></td>
</tr>
<tr>
<td>Strezhevo</td>
<td>3,4</td>
</tr>
<tr>
<td>Komunalec</td>
<td>1,2</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td>49,6</td>
</tr>
</tbody>
</table>

Basic parameters of high voltage power lines

<table>
<thead>
<tr>
<th>Voltage [kV]</th>
<th>Length [km]</th>
</tr>
</thead>
<tbody>
<tr>
<td>400</td>
<td>594</td>
</tr>
<tr>
<td>220</td>
<td>103</td>
</tr>
<tr>
<td>110</td>
<td>1480</td>
</tr>
</tbody>
</table>
# Electric and Power System of the Republic of Macedonia

## Planned Situation with Connection of Future HPPs

### Substations
- SS 400/110 kV/kV
- SS 220/110 kV/kV
- SS 110/x kV/kV

### Power Lines
- 400 kV
- Planned
- 400 kV interconnection
- 220 kV
- 110 kV
- Planned
- 110 kV PL

### Power Plants
- Hydro PP
- Thermal PP

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**Date:** June 2008

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**References:**

- MACEDONIAN ELECTRICITY SYSTEM OPERATOR
- UNMIK

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**Map Overview:**

- MACEDONIA
- GREECE
- BULGARIA
- SERBIA
- ALBANIA

**Key Locations:**

- Skopje
- Tetovo
- Ohrid
- Bitola
- Prilep
- Kumanovo

**Power Plants:**

- TPP Negotino
- TPP Bitola
- HPP Kozjak
- HPP Vrutok
- HPP Shpilej
- HPP Globocica
- HPP Tikvesh
- TPP Oslomej

**Substations:**

- Skopje 1, 2, 3, 4
- Tetovo
- Ohrid
- Kumanovo
- M.Kamenica
- Kanchevo
- Kavadarci
- Negotino
- Prilep

**HPPs:**

- HPP Vrutok
- HPP Kozjak
- HPP Shpilej
- HPP Globocica
- HPP Tikvesh
- TPP Oslomej
- TPP Negotino
- TPP Bitola

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**Legend:**

- Red: 400 kV
- Green: 220 kV
- Blue: 110 kV
- Black: Planned
- Dashed: Interconnection

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**Additional Details:**

- June 2008
- Electric and power system of the Republic of Macedonia
- Planned situation with connection of future HPPs
- Substations

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**Map Accuracy:**

- The map is an overview and should be used for reference purposes only.
- The exact location of power plants and substations may vary.
Generation and transmission price

- Average electricity generation price

<table>
<thead>
<tr>
<th>Power plant</th>
<th>€/MWh</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lignite TPP</td>
<td>40</td>
</tr>
<tr>
<td>Heavy fuel oil TPP</td>
<td>60</td>
</tr>
<tr>
<td>Natural gas CHP (234 MW)</td>
<td>45</td>
</tr>
<tr>
<td>Natural gas CHP (30 MW)</td>
<td>48</td>
</tr>
<tr>
<td>HPP</td>
<td>50</td>
</tr>
<tr>
<td>Import</td>
<td>60</td>
</tr>
</tbody>
</table>

- Electricity transmission price (1-9 € per MWh)
Network diagram of the model
Mathematical model of the electric power system of Macedonia

\[
\begin{align*}
  x_{1.4} & \leq 225 \\
  x_{2.4} & \leq 225 \\
  x_{3.4} & \leq 225 \\
  -x_{1.4} - x_{2.4} - x_{3.4} + x_{4.51} + x_{4.52} + x_{4.53} + x_{4.54} + x_{4.55} + x_{4.56} + x_{4.57} + x_{4.58} + x_{4.59} = 0 \\
  x_{5.6} & \leq 580 \\
  -x_{6.6} + x_{6.51} + x_{6.52} + x_{6.53} + x_{6.54} + x_{6.55} + x_{6.56} + x_{6.57} + x_{6.58} + x_{6.59} = 0 \\
  x_{7.8} & \leq 230 \\
  -x_{8.8} + x_{8.51} + x_{8.52} + x_{8.53} + x_{8.54} + x_{8.55} + x_{8.56} + x_{8.57} + x_{8.58} + x_{8.59} = 0 \\
  x_{9.10} & \leq 30 \\
  -x_{9.10} + x_{10.51} + x_{10.52} + x_{10.53} + x_{10.54} + x_{10.55} + x_{10.56} + x_{10.57} + x_{10.58} + x_{10.59} = 0 \\
  x_{11.12} & \leq 5 \\
  -x_{11.12} + x_{12.57} = 0 \\
  x_{13.14} & \leq 30 \\
  -x_{14.14} + x_{14.51} + x_{14.52} + x_{14.53} + x_{14.54} + x_{14.55} + x_{14.56} + x_{14.57} + x_{14.58} + x_{14.59} = 0 \\
  x_{15.16} & \leq 10 \\
  -x_{15.16} + x_{16.53} = 0 \\
  x_{17.18} & \leq 125 \\
  -x_{17.18} + x_{18.51} + x_{18.52} + x_{18.53} + x_{18.54} + x_{18.55} + x_{18.56} + x_{18.57} + x_{18.58} + x_{18.59} = 0 \\
  x_{19.20} & \leq 210 \\
  -x_{19.20} + x_{20.51} + x_{20.52} + x_{20.53} + x_{20.54} + x_{20.55} + x_{20.56} + x_{20.57} + x_{20.58} + x_{20.59} = 0 \\
  x_{21.22} & \leq 500 \\
  -x_{21.22} + x_{22.51} + x_{22.52} + x_{22.53} + x_{22.54} + x_{22.55} + x_{22.56} + x_{22.57} + x_{22.58} + x_{22.59} = 0 \\
  x_{4.51} + x_{4.52} + x_{4.53} + x_{4.54} + x_{4.55} + x_{4.56} + x_{4.57} + x_{4.58} + x_{4.59} = 500 \\
  x_{4.52} + x_{4.53} + x_{4.54} + x_{4.55} + x_{4.56} + x_{4.57} + x_{4.58} + x_{4.59} + x_{22.52} = 200 \\
  x_{4.53} + x_{4.54} + x_{4.55} + x_{4.56} + x_{4.57} + x_{4.58} + x_{4.59} + x_{22.53} + x_{22.54} = 200 \\
  x_{4.54} + x_{4.55} + x_{4.56} + x_{4.57} + x_{4.58} + x_{4.59} + x_{22.54} = 20 \\
  x_{4.55} + x_{4.56} + x_{4.57} + x_{4.58} + x_{4.59} + x_{22.55} = 200 \\
  x_{4.56} + x_{4.57} + x_{4.58} + x_{4.59} + x_{22.56} = 200 \\
  x_{4.57} + x_{4.58} + x_{4.59} + x_{22.57} + x_{22.58} = 200 \\
  x_{4.58} + x_{4.59} + x_{4.60} + x_{4.61} + x_{4.62} + x_{4.63} + x_{4.64} + x_{4.65} + x_{4.66} + x_{4.67} = 100 \\
  x_{4.60} + x_{4.61} + x_{4.62} + x_{4.63} + x_{4.64} + x_{4.65} + x_{4.66} + x_{4.67} = 0
\end{align*}
\]
Mathematical model of the electric power system of Macedonia

- Adding new consumer - Radovish
  
  \[ 58' \quad x_{4,58} + x_{6,58} + x_{8,58} + x_{10,58} + x_{14,58} + x_{18,58} + x_{20,58} + x_{22,58} - x_{58,71} = 80 \]

  \[ 71 \quad x_{58,71} = 20 \]

- Adding small hydropower plant – Ohrid
  
  \[ 80 \quad x_{80,81} \leq 9 \]

  \[ 81 \quad x_{81,57} - x_{80,81} = 0 \]

- The model solution

Program for winter day
Typical examples

- Winter day
- Winter day 2, very high electricity consumption
- Winter night
- Summer day
- Summer night
Consumption in a winter day
Electricity production in a winter day

[Bar chart showing power output for various sources including TPP Bitola 1, TPP Bitola 2, TPP Ceglev, TPP Negotino, HPP, CHP Skopje, CHP Kogel, Photovoltaics, Wind, Small HPP, Import, Export, with minimum, generation, and maximum power levels indicated.]
Link flow in a winter day
Consumption in a winter day 2

![Graph showing consumption in different locations](image-url)
Electricity production in a winter day 2
Consumption in a winter night
Electricity production in a winter night
Consumption in a summer day

![Bar chart showing consumption in a summer day for different locations.

- Skopje: 250 MW
- Kumanovo: 100 MW
- Tetovo: 150 MW
- Feni: 20 MW
- Gevgelia: 100 MW
- Bitola: 125 MW
- Ohrid: 80 MW
- Strp: 30 MW
- Radoviš: 10 MW]
Electricity production in a summer day
Consumption in a summer night
Electricity production in a summer night
Link flow in a summer night
Conclusion

- An original model for solving a multidisciplinary problem of Macedonian electric power system is developed that can optimize and analyze every (real) state of the system.

- Future works include
  - More detail analysis of the power system of Macedonia
  - Extending the model to larger regions and/or EU power grid
  - Extending the model to $E^3$ class of models (energy, ecology, economy)