RESILIENCE ANALYSIS OF THE FUTURE BOSNIA AND HERZEGOVINA TRANSMISSION GRID

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ABSTRACT

Thesis Title: Resilience Analysis of the Future Bosnia and Herzegovina's Transmission Grid

Key words: Transmission system, Congestions, High-Temperature Low-Sag Conductors, Phase Shifting Transformers, Optimal Positioning Methodology

Driven by the deregulation of power utilities, power lines are nowadays used to send more electric energy through longer distances to end consumers, compared to previous decades. Transmission system operators within interconnected electric power systems import and export not only electricity, but also transmission grid related problems.

The research goal is to propose a generalized approach and methodology for the integration of those technologies, as well as to identify the optimal set of location of a phase shifting transformer for the potential use within an interconnected system.

The focus of this thesis is to identify the transmission system weak spots in Bosnia and Herzegovina. Secondly, the goal is to determine the technologies that can be used to improve this grid. Thirdly, to propose approaches for the solution of the identified issues. Finally, a financial overview is given, as an additional input for relevant institutions when performing further financial analyses with the goal to identify the key economic impacts of the proposed technological solutions.

With regard to the selection and use of advanced technologies, the most important outcomes are: the evaluation methodology to be used for determination of phase shifting transformers installation location and the identification of potential applications for advanced conductors. The mentioned outcomes are demonstrated in case studies on the example of Bosnia and Herzegovina's transmission grid, as part of larger interconnected ENTSO-E system.

THESIS OUTLINE

Case Study #1

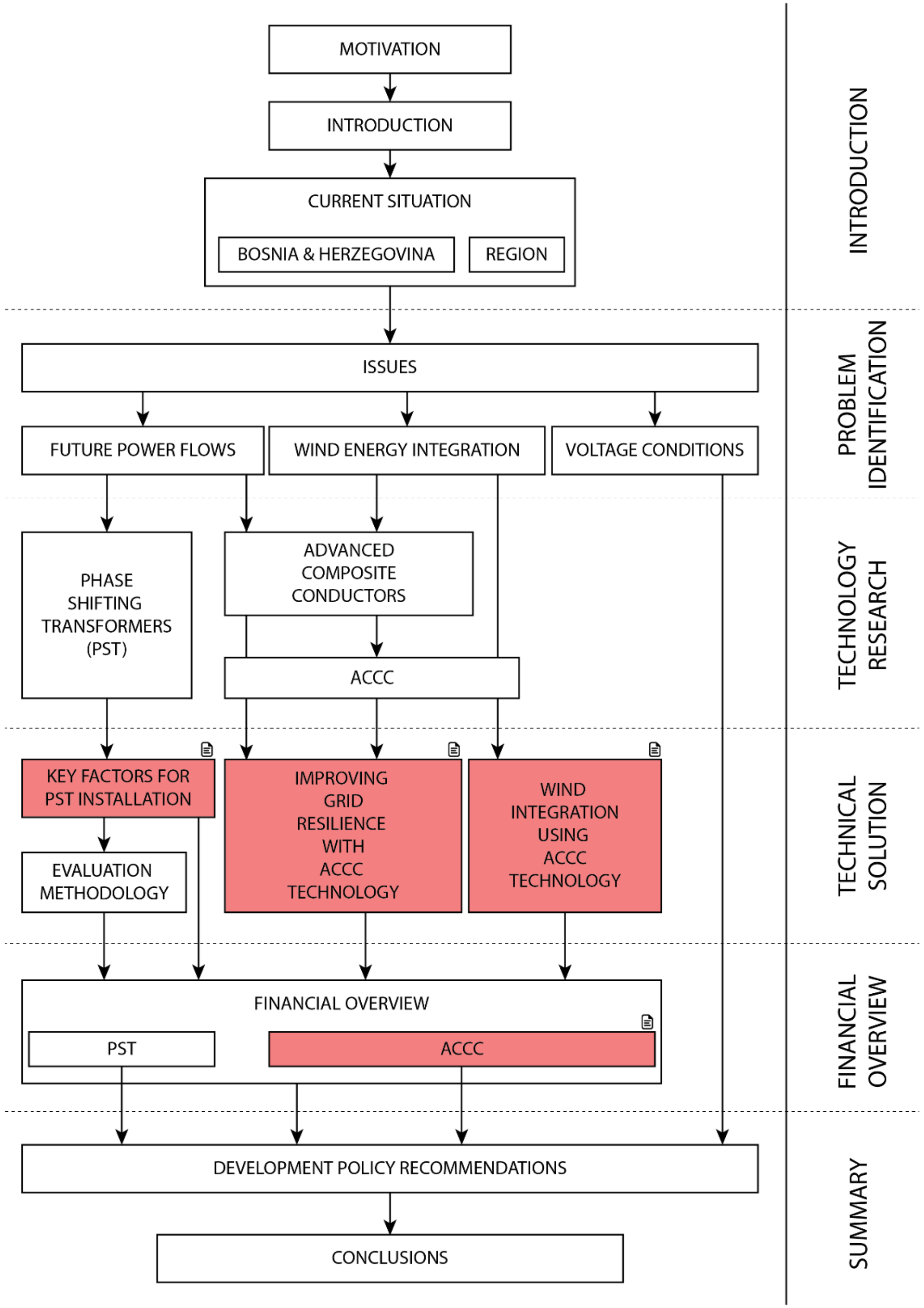
Evaluation Matrix for PST Installation in Bosnia and Herzegovina

Case Study #2

Impact of Gradual Replacement of Old Conductors with HTLS Technology

Case Study #3

ACCC as a Solution for Wind Integration



CASE STUDY 1:
EVALUATION MATRIX FOR PST INSTALLATION IN BOSNIA AND HERZEGOVINA

OPTIMAL LOCATION IN POWER SYSTEM

MAJOR FACTORS

Determination of Network Loadability

Before committing to the investment of a PST, it is necessary to analyze the loadability of all lines, for different time periods (day, night, winter, summer, maximum, minimum, etc…). Determining this factor should justify following steps for investment in PST.

Determination of Bottlenecks

Bottlenecks have to be singled out by various power flow analyses, including contingency analyses, Net Transfer Capacity (NTC) analyses, etc…

A simple approach is to insert a phase shifter on each bottleneck line, in order to reduce the flow on these lines. But this "one constraint-one phase shifter" approach is not sufficient, because it leads to creating constraints on new lines. Therefore, a more detailed analysis is recommended

Future Network Developments Plans

Network development plans have to be analyzed in order to check impact of future investments on present bottlenecks. National and regional plans should be taken into account.

Alternative Solutions

Alternative solutions for present bottlenecks should be analyzed. A possible solution could be the construction of a new line, or replacement of weak lines using new conductor technologies, such as Aluminum Composite Core Conductor (ACCC).

Financial Factors

Different financial factors should be analyzed at this point. What would be the savings from re-dispatching, capacity allocation, and what would be the pay-off time of such an investment?

Regional Impact

By their purpose and definition, effects of Phase Shift Transformers go beyond national borders, especially if installed on interconnectors. It is necessary to perform analyses on neighboring systems, as well as to get the project approved by all affected parties.

MINOR FACTORS

Existance of Double Lines

Installation of a PST on buses connected to double lines can always be observed as added value. In case of maintenance of one line, using a PST, the flows on the other line can be limited to allowed values.

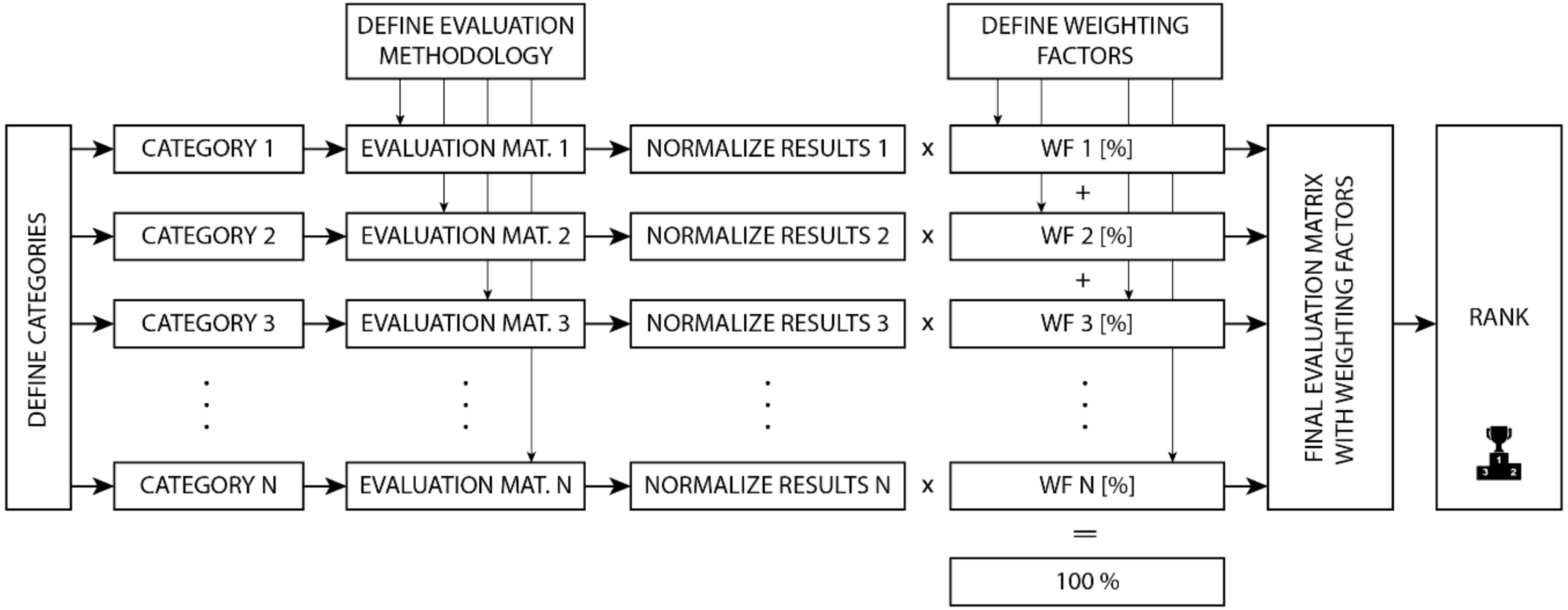
Increasing PST Capacity

Experiences from several transmission system operators indicate that increasing PST capacity by up to 5-10% compared to the calculated values, has had a positive effect on future operation and also added value to the system when confronted with severe overloading of lines.

Determination of Weak Spots

Recommendations from transmission system operators also indicate that it is preferable and beneficial to allocate a PST in a location that has more than one weak line.

PST EVALUATION METHODOLOGY



The figure shows a generalized overview of the proposed methodology using evaluation matrices with weighting factors as a way to determine the optimal location of PST installation within an interconnected power system. As explained below, the number of categories can vary depending on the specificity of the installation, stage of the project, available data and other requirements.

CASE STUDY 2:

IMPACT OF GRADUAL REPLACEMENT OF OLD CONDUCTORS WITH HTLS TECHNOLOGY

ANALYSIS SCENARIOS

Power flows analyses were performed for a total of 8 scenarios:

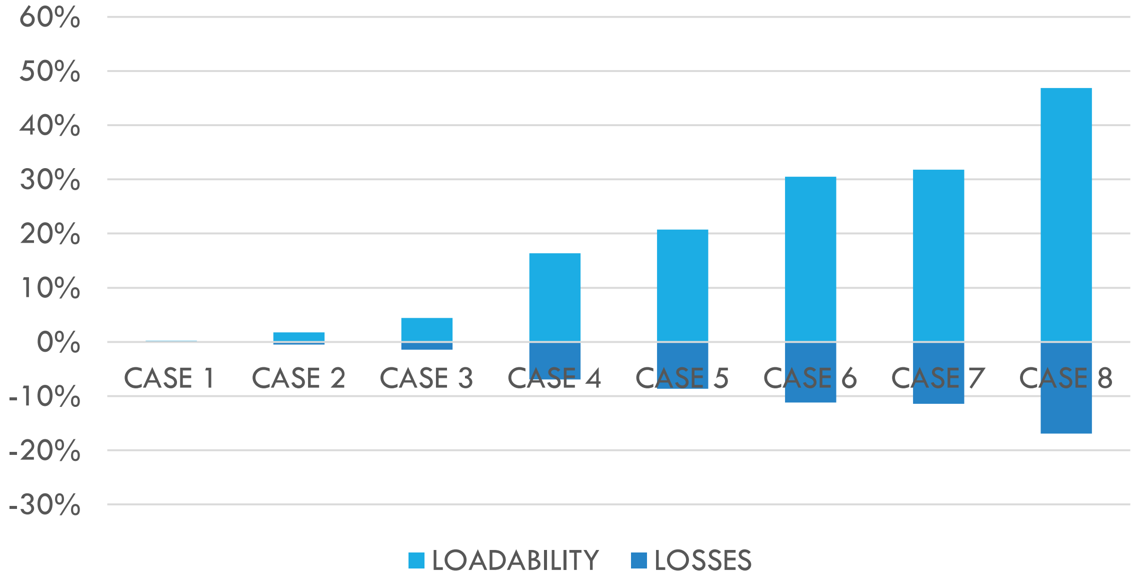
- Base Case - This scenario is the reference case for all further analyses. In this model, all the lines were modeled as ACSR conductors.
- Scenario 1 - ACSR lines aged 60 to 70 were are replaced with relevant ACCC conductors.
- Scenario 2 - ACSR lines aged 50 to 70 years are replaced with relevant ACCC conductors.
- Scenario 3 - ACSR lines aged 40 to 70 years are replaced with relevant ACCC conductors.
- Scenario 4 - ACSR lines aged 30 to 70 years are replaced with relevant ACCC conductors.
- Scenario 5 - ACSR lines aged 20 to 70 years are replaced with relevant ACCC conductors.
- Scenario 6 - ACSR lines aged 10 to 70 years are replaced with relevant ACCC conductors.
- Scenario 7 - ACSR lines aged 0 to 70 years are replaced with relevant ACCC conductors.

ANALYSIS RESULTS

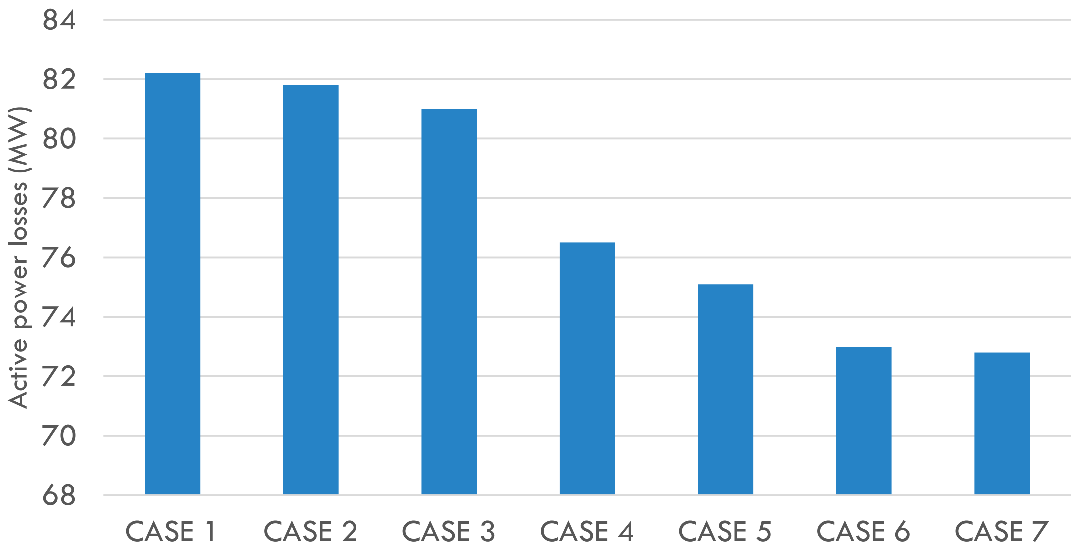
In the base case, the total active power losses for the entire transmission system of Bosnia and Herzegovina (composed of 400, 220 and 110 kV) elements, amounts to 82 MW, however, by replacing all 110 kV lines with advances ACCC conductors, additional 9.4 MW of active power losses are saved.

Due to the fact that the reactance and susceptance remain mostly unchanged, it is important to note that the Surge Impedance Loading (SIL), isn't subject to change. This can be regarded as an additional advantage, resulting in the fact that the lower loadings will not affect reactive power flows, and therefore will not have an impact on the voltages.

$$P_{nat} = SIL = \frac{U^2}{Z_0} = \frac{U^2}{\sqrt{\frac{L}{C}}}$$



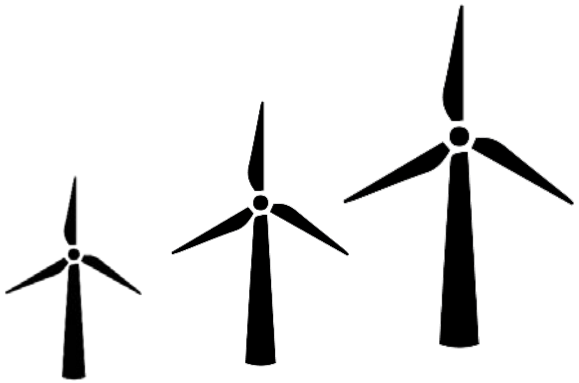
Loadability and losses compared to the base case (accumulated values)



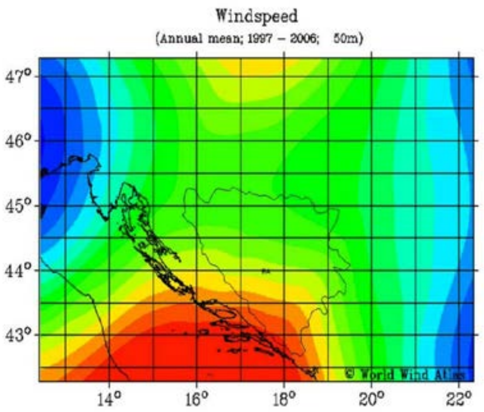
Total active power losses (MW)

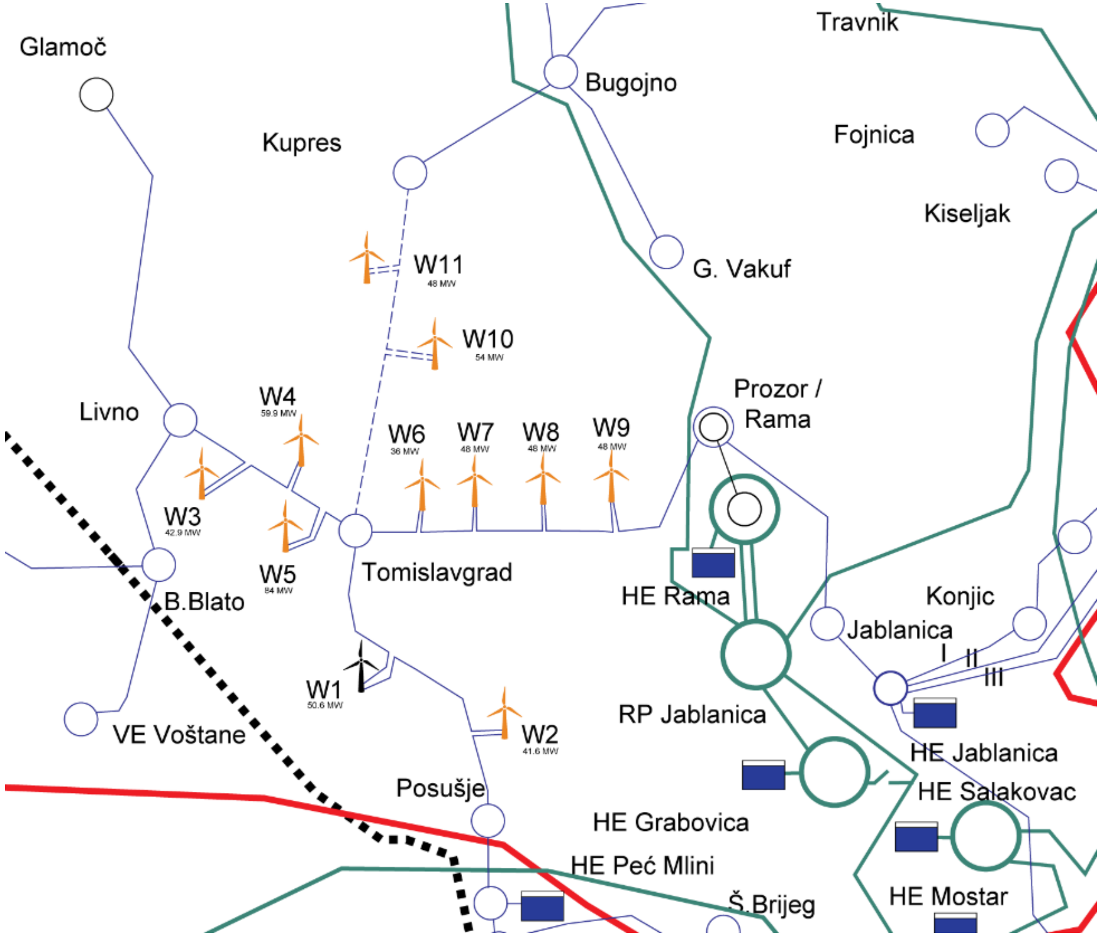
CASE STUDY 3:

ACCC AS A SOLUTION FOR WIND INTEGRATION



WIND POWER IN BOSNIA AND HERZEGOVINA





WPP	Installed power (∑)	Line	Type	Capacity
W1, W2	92.2 MVA	Tomislavgrad – Posušje	ACSR HAWK 240/40 mm^2	122 MVA
W3, W4, W5	186.8 MVA	Tomislavgrad – Livno	ACSR HAWK 240/40 mm^2	122 MVA
W6, W7, W8, W9	180 MVA	Tomislavgrad – Rama	ACSR HAWK 240/40 mm^2	122 MVA
W10, W11	104 MVA	Tomislavgrad – Kupres	ACSR HAWK 240/40 mm^2	122 MVA
	563 MVA			

ANALYSIS

CASES

- **Case A** – WPP operating at maximum installed capacity, ACSR conductors in all relevant 110 kV lines.
- **Case B** – WPP operating at maximum installed capacity, ACCC conductors in all relevant 110 kV lines.
- **Case C** – WPP operating at maximum installed capacity, ACSR conductors in 110 kV lines Tomislavgrad – Kupres and Tomislavgrad – Posušje, ACCC conductors in 110 kV lines Tomislavgrad – Livno and Tomislavgrad – Rama.
- **Extension 1** – New single 220 kV ACSR line Tomislavgrad – HPP Rama, with one 110/220 kV power transformer at Tomislavgrad with installed power 150 MVA.
- **Extension 2** – New double 220 kV ACSR line Tomislavgrad – HPP Rama, with two 110/220 kV power transformers at Tomislavgrad with installed power 150 MVA (per transformer).

SCENARIOS

- **Base Case –** to determine the flows prior to any changes initialized in the following scenarios
- **Scenario 1 –** Case A
- **Scenario 2 –** Case A + Extension 1
- **Scenario 3 –** Case A + Extension 2
- **Scenario 4 –** Case B
- **Scenario 5 –** Case B + Extension 1
- **Scenario 6 –** Case B + Extension 2
- **Scenario 7 –** Case C
- **Scenario 8 –** Case C + Extension 1
- **Scenario 9 –** Case C + Extension 2

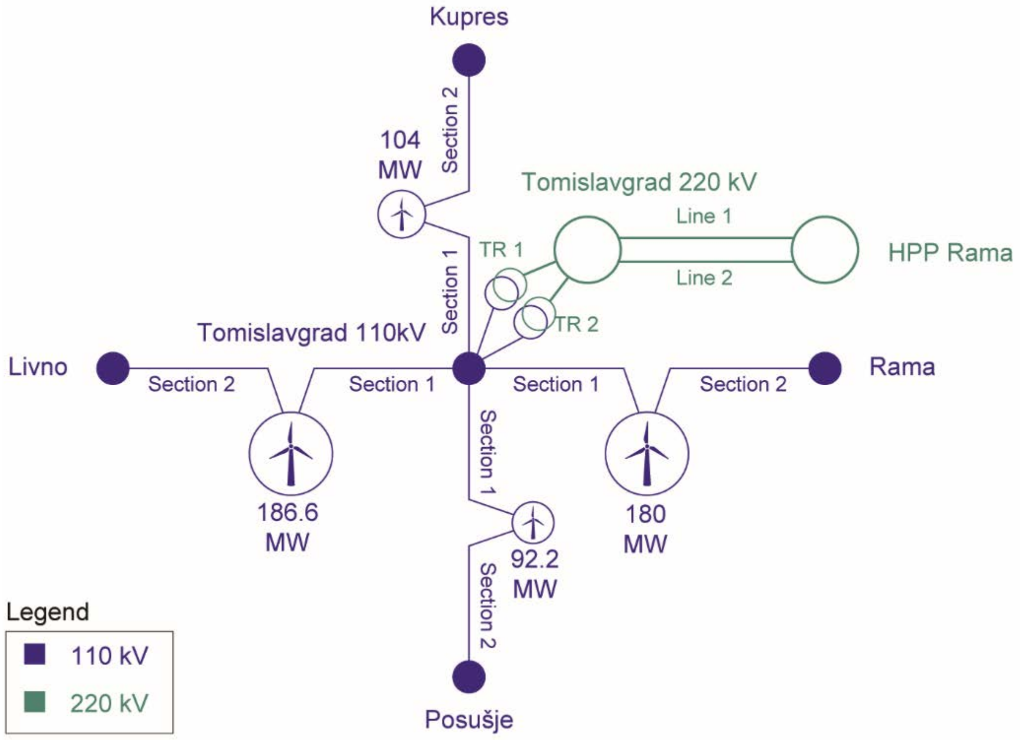
ASSUMPTIONS

The following facts and assumptions are taken into account:

- All existing 110 kV lines from Figure 6. are type ACSR HAWK.
- In the scenarios including reconductoring, ACSR HAWK is replaced with ACCC LISBON.
- Wind power plants on the four lines are aggregated and represented as one power source per line.
- Hydro power plant Rama is operated close to the maximum installed capacity (2 units at 75 MW).

ANALYSIS RESULTS

	OHL 110 kV Tomislavgrad - Posušje		OHL 110 kV Tomislavgrad – Rama		OHL110 kV Tomislavgrad - Kupres		OHL 110 kV Tomislavgrad – Livno		Transformer 220/110 kV Tomislavgrad		OHL 220 kV Tomislavgrad – HPP Rama	
Element	Section 1	Section 2	Section 1	Section 2	Section 1	Section 2	Section 1	Section 2	Unit 1	Unit 2	Single line	Double line
Base Case	3.1%		14.1%		5.9%		5.4%					
Scenario 1	23.1 %	**97.7 %**	13.4 %	**132.0 %**	18.8 %	**103.0 %**	31.2 %	**112.3 %**				
Scenario 2	26.7 %	50.5 %	66.2 %	74.0 %	28.5 %	56.0 %	88.5 %	58.1 %	**173.5 %**		81.5 %	
Scenario 3	26.7 %	50.5 %	66.2 %	74.0 %	28.6 %	56.0 %	88.5 %	58.1 %	86.8 %	86.8 %	40.8 %	40.8%
Scenario 4	10.5 %	48.3 %	9.0%	64.7 %	14.4 %	57.0 %	20.1 %	55.7 %				
Scenario 5	13.8 %	25.2 %	34.0 %	36.8 %	14.0 %	29.6 %	44.9 %	28.7 %	**175.5 %**		82.5 %	
Scenario 6	13.8 %	25.2 %	34.0 %	36.8 %	14.0 %	29.6 %	44.9 %	28.7 %	87.8 %	87.8 %	41.3 %	41.3%
Scenario 7	22.7 %	**98.0 %**	6.2%	67.0 %	18.4 %	**103.0 %**	18.3 %	57.0 %				
Scenario 8	26.5 %	50.6 %	33.8 %	37.0 %	28.4 %	56.2 %	44.9 %	28.8 %	**175.5 %**		82.5 %	
Scenario 9	26.6 %	50.6 %	33.9 %	37.0 %	28.4 %	56.1 %	44.9 %	28.7 %	87.8 %	87.8 %	41.3 %	41.3%



RESEARCH QUESTIONS

1. What are the resilience **constraints** of the future Bosnia and Herzegovina transmission grid?
2. How can these constraints be **addressed** by using advanced technologies
3. What are the **qualitative and quantitative factors** for defining the optimal location of phase shifting transformers (PST)
4. What quantitative algorithm/methodology can be used to **determine the optimal location of phase shifting transformers** (PST) within an interconnected electric power system?
5. To what extent can the replacement of old lines with composite lines (High-Temperature Low-Sag, i.e. HTLS) improve the system from a technical perspective?
6. Can new conductor technologies help (and to which extent) increase renewable energy source penetration and integration?
7. **Which are the financial impacts** of replacing old transmission lines with composite lines?
8. **What recommendations** could be given to relevant authorities in charge of energy policies related to transmission system operation in order to improve the system's resilience?

SUMMARY

- In accordance with the best practice of scientific work, and in order to achieve the research goals, several scientific methods have been applied which can encompass the overall complexity of the problem related to the analysis, modeling, and research of transmission grids resilience:
  - Evaluation of the current state-of-affairs and the identification of issues,
  - Assessment of available and published literature referenced to the implementation of advanced transmission technologies,
  - Comparison of different advanced technology,
  - Modeling of interconnected power systems,
  - Creating algorithms describing the involved processes,
  - Automating calculation procedures through complex multi-language programming skills,
  - Creating questionnaires for evaluation purposes,
  - Creation of a code list matrix for modeling system studies with different data inputs,
  - Gaining operational experience from field trips and interviews,
  - Report creating.

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* *A more elaborate and detailed list is given in the thesis.*