

ANALYSIS OF LOW-FREQUENCY OSCILLATIONS IN THE BOSNIA AND HERZEGOVINA POWER SYSTEM

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Abstract: This paper presents a detailed model of low-frequency oscillations and their damping within the Electric Power System (EPS) of Bosnia and Herzegovina (B&H). The system is modeled using MATLAB software, analysing the steady state and dynamic responses. This research highlights the challenges and impacts of integrating renewable energy sources, such as wind farms, on grid stability and oscillation damping. The paper utilizes eigenvalue analysis to investigate the dynamic characteristics of the system, emphasizing the need for efficient damping strategies to maintain system stability. The methodology includes a comprehensive review of existing literature, the creation of a detailed EPS model of B&H, and the application of eigenvalue and oscillation amplitude analysis to determine damping ratios. The dynamic responses of hydro power plants, HPP Mostar and HPP Jablanica, to transient disturbances are analysed to validate the model and refine damping strategies. The results indicate that the B&H EPS is well-damped, with all eigenvalues possessing negative real parts, and demonstrate the system's resilience to small disturbances. The results are compared with the technical report on the integration of the wind power plant WPP Podveležje. This comparative analysis shows consistent patterns between the modeled calculations and empirical data, confirming the robustness of the EPS model. This alignment underscores the effectiveness of current damping mechanisms and provides a foundational strategy for enhancing system stability with increasing renewable energy penetration. The findings highlight the importance of developing advanced control strategies to sustain system stability as the integration of variable renewable energy sources continues to grow.

Keywords: low-frequency oscillations, power system stability, renewable energy integration, eigenvalue analysis, electric power system (EPS), damping

INTRODUCTION

Inter-area low-frequency oscillations in power systems are critical for maintaining power system stability and efficiency, particularly as systems integrate more renewable energy sources. These oscillations, which involve power swinging between large grid areas, can pose significant stability risks, potentially leading to system-wide blackouts if not properly managed [1]. They also lower transmission efficiency, increase infrastructure degradation, and impose stricter operational limits, consequently reducing economic performance. As grids become more dynamic with the addition of variable renewable energies, understanding and mitigating these oscillations become crucial. Studies like those in references [2, 3] are providing insights into the dynamics of these oscillations and aiding in the development of effective damping strategies that enhance grid reliability and operational flexibility. The need to integrate renewable energy sources, like the wind power plants and ensure system stability under varying load conditions, requires an accurate modeling of the electric power system (EPS). This paper presents a detailed model of the EPS of Bosnia and Herzegovina (B&H), highlighting

system behavior under critical conditions to explore the dynamics of low-frequency oscillations.

1. LITERATURE REVIEW

This chapter provides an overview of the existing research on low-frequency oscillations and their impacts on power system stability, particularly in the context of integrating renewable energy sources. The literature highlights the importance of understanding and mitigating these oscillations to maintain power system stability and efficiency. Various researches have employed different methodologies, including simulation models, eigenvalue analysis, and advanced measurement techniques, to explore the dynamics of low-frequency oscillations and develop effective damping strategies.

In the paper [2] the authors explore the impacts of inter-area oscillations on the Greek power system through a comprehensive simulation model. This study primarily focuses on identifying and analysing low-frequency oscillations (LFOs) that pose risks to system stability, potentially reducing power transfer capabilities and

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increasing the risk of blackouts. A specially developed automatic toolbox is pivotal in this analysis, facilitating the definition of oscillation modes and enabling graphical representations that highlight potential area separations at critical frequencies. A case study involving simulated oscillations between Greece and Bulgaria demonstrates the toolbox's effectiveness in accurately determining system frequencies, amplitudes, damping, and modes.

The study [3] addresses the phenomenon of inter-area low-frequency oscillations, which pose a significant threat to the stability and safety of modern interconnected power systems. The research is motivated by the need to enhance understanding of these oscillations, which involve the exchange of power among generators across different areas and can lead to system instability if poorly damped. The study aims to develop a deeper insight into the energy dynamics of these oscillations by introducing methods to analyse and quantify the kinetic and potential energies involved, thereby providing a theoretical basis for designing better damping controls and stabilizing measures. The research explores the vulnerabilities of model-based techniques in analysing low-frequency oscillations under varying system topologies and loads, highlighting the limitations of traditional methods and advocating for measurement-based approaches, such as phasor measurement units, to enhance accuracy and reliability [4].

Another research investigates the effects of high photovoltaic integration on small signal stability, revealing that replacing conventional generation with photovoltaic systems reduces system inertia and damping of critical modes. This underscores the importance of considering how renewable integration alters power system dynamics in response to disturbances [5].

Research on the damping of inter-area oscillations using non-synchronized wide-area measurements introduces innovative methods to improve system stability through advanced measurement and control technologies, critical for systems undergoing dynamic changes due to disturbances or renewable integration [6].

Furthermore, a research investigates the impact of wind power integration on damping characteristics of low-frequency oscillations, providing insights into how the interconnection of wind energy sources affects system stability. This research highlights the changes in system damping characteristics brought about by wind power integration, using updated system state equations to analyse these effects [7].

In the paper [8] the authors address the influence of wind farms on the small signal stability of power systems, focusing specifically on the Bosnia and Herzegovina power system. The study analyses the impact of integrating wind farms into the power grid, examining how these additions affect the overall stability of the

system, particularly in terms of inter-area low-frequency oscillations. This research is pertinent for understanding the dynamic responses of power systems to small disturbances caused by the variable nature of wind energy production. The insights gained from this research contribute to the broader literature on renewable energy integration and its implications for power system stability, making it a valuable reference for research on dynamic response changes in the Bosnia power system presented in this paper.

The paper [9] explores the stability challenges posed by integrating Wind Power Plants (WPPs) into electrical grids of 110 kV and higher, particularly focusing on the role of Power System Stabilizers (PSS) in mitigating low-frequency oscillations (LFOs) and maintaining system stability. It highlights the importance of revising existing PSS settings at conventional power plants to accommodate the distinct dynamics introduced by WPPs, using a 60 MW WPP in the Almaty region as a case study. The study covers rotor-angle stability, small signal stability, and voltage stability during WPP integration.

In addition, the paper [10] investigates how integrating wind power affects the small signal stability of power systems. It uses a sensitivity-based index and eigenvalue sensitivity analysis to assess system stability under different levels of wind power integration. The research emphasizes the importance of balancing system stability with the increased use of renewable energy.

The research referenced in [11] outlines the effects of wind power integration on the small-signal stability of power systems. It provides insights into the challenges and advancements in understanding how large-scale wind power influences these systems, focusing on issues related to oscillation modes and damping characteristics. The literature reviewed is important for the research presented in this paper as it lays the foundational understanding of low-frequency oscillations and their impact on power system stability. These researches provide insights into the challenges and solutions associated with integrating renewable energy sources, which is directly relevant to the analysis of the Bosnia and Herzegovina power system discussed in this paper.

2. BOSNIA AND HERZEGOVINA EPS MODEL

The B&H EPS is detailed through a model comprising 400 kV, 220 kV, and 110 kV lines and transformers, depicted in MATLAB software format. The network's representation includes PQ nodes at 110 kV and 220 kV network nodes for steady-state analysis, with power generators modelled as PV nodes. In all analyses, due to the electrical distance from the area under study, the power and reserves for the production of active and reactive power, the TPP Tuzla is chosen as the balance node [12].

The B&H power system model presumes fixed tap ratios for power transformers and is modeled without iron losses and shunt admittances, and represents HV transmission lines through a π model. Limits for voltage, current, and power transformer capacities are followed according to specified plans and codes from the Independent System Operator in Bosnia and Herzegovina (NOSBiH) and the Company for the Transmission of Electric Power in Bosnia and Herzegovina (Elektroprijenos BiH). These include the indicative production development plan for 2018–2027 [13], the long-term transmission network development plans for 2016–2025 and 2017–2026 [14, 15], and the Grid Code [16].

In the static model, all synchronous machines are modeled as PV generators, except for one “slack” generator, with bus loads modeled as constant PQ loads within given voltage limits, converting to constant impedance if these limits are exceeded.

In the dynamic setting, synchronous machines are modeled as type 6, disregarding saturation, with their voltage and turbine regulators corresponding to standard IEEE type I and type 2 specifications, respectively. Each wind turbine is modeled individually based on either default PSAT values or specific manufacturer data, with wind speeds adhering to the Weibull distribution. Details on wind turbines equipped with DFIG and DDSG are presented in the cited literature [17].

In the analyzed model, four wind farms are connected. The input data (taken from the PSAT application) for the model of wind turbines with a doubly-fed induction generator include those for WPP Mesihovina, WPP Jelovača, WPP Trusina, and the model of wind turbines with direct AC/DC/AC conversion and permanent magnet for WPP Podveležje. [8, 17]

The power balance on the transmission network connected includes a total generation of approximately 2220 MW, a total consumption of approximately 2180 MW, and total power losses amounting to about 39 MW. The EPS B&H includes 364 buses, 303 lines, 149 transformers, 38 generators, and 192 loads.

All simulations are conducted using the PSAT power system toolbox version 2.1.11 for MATLAB 2021 to analyze steady state and transient conditions.

3. METHODOLOGY

In this paper, a detailed analysis and comparison of the obtained results is conducted focusing on the damping mechanisms and identification of low-frequency oscillations within the power system as described in the technical report concerning the integration of the WPP Podveležje into the B&H EPS [12]. This report provides

crucial insights into the technical aspects of integrating wind power into the power system of Bosnia and Herzegovina, which is interconnected with neighboring countries, forming part of the regional electrical grid. This interconnection enhances the stability and reliability of the power supply by allowing for the exchange of electricity between countries.

The primary goal of this paper is to provide a comprehensive understanding of the dynamic stability characteristics of the power system through eigenvalue analysis derived from MATLAB's modal analysis reports.

This research specifically focuses on the impact of oscillation amplitudes. In addition, the research examines the documented responses in the report, particularly in relation to low-frequency oscillations, and compares them against newly derived data from MATLAB simulations and eigenvalue analysis.

The comparative assessment aims to validate the modeling approaches and refine damping strategies to enhance system stability in the face of increasing renewable energy sources.

The analysis of the dynamic characteristics of the B&H EPS is conducted based on the response of hydro power plants HPP Mostar and HPP Jablanica generators to a simulated short-term transient disturbance. The simulation is performed using MATLAB software on the model of the B&H EPS for maximum operating mode with full production. This approach allowed for the consideration of non-linear effects on the system's dynamic response through simulation. The responses and damping are compared with results obtained from the small signal stability analysis.

The oscillations of the electrically closest generators, HPP Mostar and HPP Jablanica, which could be affected by the three-phase transient short-circuit at the 110 kV bus of WPP Podveležje, are observed. The hydroelectric power plants are connected to the network as follows: HPP Jablanica is connected to the 110 kV network. HPP Mostar is connected to the transmission network via a double 110 kV line.

Initially, eigenvalue analysis is applied to the power system of Bosnia and Herzegovina. Following this, a method that estimates the damping of low-frequency oscillations using oscillation amplitudes is employed. By identifying the peaks of these oscillations and measuring their amplitudes, one can analyze how the amplitudes decrease over time. This decrease is used to estimate the damping, by examining how the first and second amplitudes of the oscillations change, along with the overall time series data. This approach helps in understanding the rate at which oscillations are damped, which is crucial for maintaining the stability of the power system.

This method is applied because damping data can be obtained directly from oscillation amplitudes, time series of oscillations, or graphical representations. In contrast, eigenvalue analysis yields a complex report after modal analysis, which includes all modes and is more challenging to interpret. Therefore, it is simpler to calculate damping using the oscillation approach.

3.1. Eigenvalue analysis

In conducting the eigenvalue analysis using the PSAT application, a detailed evaluation of the system's eigenvalues is performed. This analysis investigates the damping characteristics and frequency of oscillations of the eigenvalues, expressed as $\lambda_i = \sigma_i + j\omega_i$. Here, the real part σ_i reflects the damping of the eigenvalue, with more negative values indicating better damping. Conversely, the imaginary part ω_i is related to the frequency of oscillation.

The damping ratio ξ for each eigenvalue is determined by the equation:

$$\xi = \frac{-\sigma_i}{\sqrt{(\sigma_i)^2 + (\omega_i)^2}} \quad (1)$$

This ratio describes the decay rate of the oscillation's amplitude, where ξ_i ranges from 1 to N, with N representing the order of the system, corresponding to the number of three-phase buses in the power system.

3.2. Analysis of dynamic response

The analysis of the dynamic behaviour of the B&H EPS, focusing on small signal stability, is conducted using simulations in MATLAB toolbox for electric power system analysis and control. These simulations demonstrate how the HPP Mostar and HPP Jablanica generators respond to a short-term disturbance, specifically a 40 ms three-phase short-circuit at the 110 kV WPP Podveležje.

To calculate the damping, the equation:

$$\xi = \frac{-\alpha}{\sqrt{\alpha^2 + \beta^2}} \quad (2)$$

is used, where the coefficient α is calculated from the damping of oscillation amplitudes, and β from the oscillation frequency. The coefficient α is calculated using the logarithmic decrement method:

$$\alpha = \frac{\ln\left(\frac{A_1}{A_2}\right)}{T} \quad (3)$$

where A_1 and A_2 are the amplitudes of adjacent peaks of the oscillation. T represents the time between these peaks. The coefficient is calculated using the oscillation frequency f :

$$\beta = 2 \cdot \pi \cdot f \quad (4)$$

Combining these equations, the damping ratio ξ can be expressed as:

$$\xi = \frac{-\ln\left(\frac{A_1}{A_2}\right)}{\sqrt{\left(\ln\left(\frac{A_1}{A_2}\right)\right)^2 + (2 \cdot \pi)^2}} \quad (5)$$

Figure 1 illustrates the dynamic response of HPP Mostar's generator angles to a transient three-phase short-circuit. The blue curve represents the oscillation observed over a period from 0.1 to 1.5 seconds post-disturbance. In the displayed figure, A1 and A2 are measured as the peak amplitudes of the generator angle oscillations at HPP Mostar following a three-phase short-circuit. The red horizontal line, indicating the generator's angle under normal conditions, represents the steady state variable.

This line indicates the generator's angle under normal conditions, providing a baseline for measuring the oscillations caused by the disturbance. The first peak, A1, and the second peak, A2, demonstrate the maximum deviations from this baseline immediately following the fault. These deviations are critical for calculating the system's damping characteristics. Understanding how quickly the system returns to its steady state after a disturbance provides key insights into the power system's stability.

By accurately measuring these amplitudes and applying the derived equations, one can determine the damping ratio, which is essential for assessing and improving the stability of the power system.

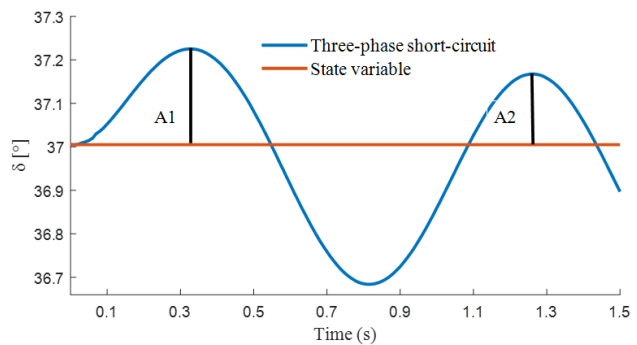


Figure 1: The oscillation of generator angles HPP Mostar with amplitudes A1 and A2 according to state variable

4. CASE STUDY

The dynamic response of the B&H EPS to a small disturbance, small signal stability, is conducted based on the results of the simulation of HPP Mostar and HPP Jablanica generator's response to a short-term disturbance (a transient three-phase short-circuit at the 110 kV WPP Podveležje lasting 40 ms).

The results of a comprehensive modal analysis conducted on the B&H EPS are presented. Modal analysis, serves as

a fundamental tool for examining the dynamic behavior of power systems. By determining the eigenvalues of the system matrix, this analysis helps in assessing the stability and damping characteristics of the system under study. The eigenvalues indicate the system's ability to return to its steady state after a disturbance, with their real parts suggesting the rate of decay of oscillations and the imaginary parts indicating the frequency of oscillations. The results detailed herein provide valuable insights into the stability margins of the B&H EPS, focusing on the response of specific hydroelectric power plant generators to transient disturbances.

Figure 2 illustrates the eigenvalue analysis of the system, demonstrating the distribution of eigenvalues in the complex plane, which is crucial for assessing system stability.

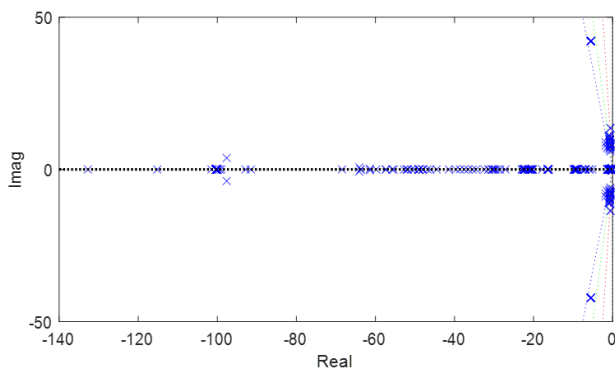


Figure 2: Eigenvalue Analysis

The modal analysis, depicted in Figure 2, shows a total of 757 eigenvalues, all of which possess negative real parts, confirming that the system is well-damped. Notably, among these, there are 109 complex eigenvalue pairs with a minimum damping ratio of approximately 5.12%. This value exceeds the commonly accepted threshold of 5% below which oscillations are considered poorly damped. This threshold is illustrated with a red dotted line in Figure 2, highlighting the system's robust damping characteristics.

Table I from the PSAT report for a system order of 757 lists eigenvalues for HPP Mostar and HPP Jablanica, detailing oscillatory modes crucial for system stability analysis. For HPP Mostar (Eig As #235, #236), the eigenvalues are $-0.6847 \pm 7.0549i$ $-0.6847 \pm 7.0549i$, indicating a damping ratio of approximately 9.66% and a frequency of 1.128 Hz. For HPP Jablanica (Eig As #277, #278), the values are $-0.65361 \pm 9.6538i$, $-0.65361 \pm 9.6538i$, with a damping ratio around 6.755% and a frequency of 1.54 Hz. corresponding to the natural frequency of these oscillatory modes.

Table I: Eigenvalues extracted from PSAT report (order of the system 757)

HPP Mostar		
	Eig As #235	Eig As #236
Real part	-0.6847	-0.6847
Imag.part	7.0549	-7.0549
Damping ratio (%)	-9.66	
Frequency	1.128	
HPP Jablanica		
	Eig As #277	Eig As #278
Real part	-0.65361	-0.65361
Imag.part	9.6538	-9.6538
Damping ratio (%)	-6.755	
Frequency [Hz]	1.54	

The oscillations of generator angles at HPP Jablanica and HPP Mostar, are shown in the following figures.

Figure 3 depicts the oscillation of generator angles at the HPP Mostar during transient short circuits. The graph displays periodic changes in generator angles, expressed in degrees (°). The oscillation frequency of the generator angles for HPP Mostar is $f_M=1.1$, while the damping coefficient is $\alpha_M=0.51$. The angular frequency is $\beta_M=6.91$ rad/s, and the damping ratio is $\zeta_i=-0.074$ or 7.4%, indicating weaker damping compared to the threshold of 5%, which is considered the limit for weakly damped oscillations.

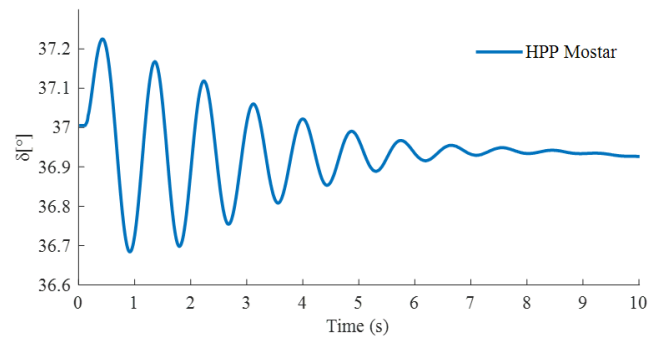


Figure 3: The oscillation of generator angles HPP Mostar during transient short circuits

Figure 4 illustrates the oscillation of generator angles at the HPP Jablanica hydro power plant during transient short circuits. Similar to the previous figure, it shows periodic changes in generator angles on the graph. The oscillation frequency for HPP Jablanica is $f_j=1.33$ Hz, and the damping coefficient is $\alpha_j=0.94$. The angular frequency is $\beta_j=8.37$ rad/s, and the damping ratio is $\zeta_i=-0.111$ or 11.1%, indicating that damping is higher in this case compared to HPP Mostar.

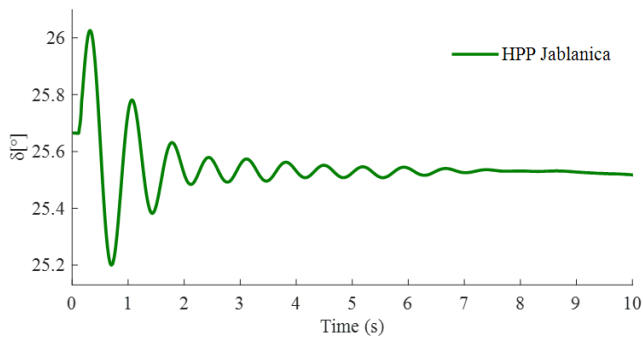


Figure 4: The oscillation of generator angles at HPP Jablanica during transient short circuits

5. RESULTS AND DISCUSSION

In the power system of Bosnia and Herzegovina, simulations of small disturbances are carried out to verify the outcomes of prior eigenvalue analyses.

One specific simulation involved a 3-phase short circuit introduced at 0 seconds and lasting for 0.04 seconds, situated between the 110 kV overhead line from WPP Podveležje to HPP Jablanica. The simulation results indicated that the most significant rotor angle oscillations occurred at HPP Jablanica, which is geographically and electrically nearest to the disturbance. Across all monitored power plants, the amplitude of rotor angle oscillations for the synchronous generators remained relatively low, suggesting a resilient system response to these types of disturbances.

In the comprehensive analysis of the B&H EPS, significant attention is dedicated to the modal and oscillatory characteristics using amplitude measurements from simulations and comparing these results with those in the referenced technical report [12]. The research revealed consistent patterns in the damping of low-frequency oscillations, crucial for maintaining stability with the integration of renewable energy sources. Both the modal analysis derived from the MATLAB simulations and the amplitude calculations underscored a robust damping capacity within the B&H power system, evidenced by negative eigenvalues and a decrement in oscillation amplitudes over time.

Comparatively, the technical report offered insights that are largely corroborated by the simulation data, affirming the effectiveness of current system configurations and damping mechanisms. The dynamic responses of specific grid components, notably at the HPP Mostar and HPP Jablanica, suggested that while the system generally maintains stability, the integration of higher levels of variable renewable energies could necessitate advanced control strategies to sustain this stability.

The comparison between the calculated damping from oscillation amplitudes and the eigenvalue analysis provided

a dual perspective on the system's ability to withstand disturbances. This dual analysis approach not only confirmed the adequacy of the existing damping controls but also suggested potential enhancements to cope with the anticipated complexities resulting from further renewable integrations. Ultimately, this detailed examination between modeled predictions and empirical report observations offers a foundational strategy to refine damping mechanisms, thereby enhancing the resilience and stability of the B&H EPS in an era of significant energy transition.

6. CONCLUSION AND FUTURE WORK

The detailed modeling of the Bosnia and Herzegovina electric power system serves as a fundamental tool for understanding the system's behavior, particularly in scenarios involving transient faults resulting low-frequency oscillations. This paper provides a comprehensive analysis of low-frequency oscillations (LFOs) in the EPS of Bosnia and Herzegovina with an emphasis on the implications of integrating renewable energy sources, particularly wind power. The research detailed a series of simulations and modal analyses that underscore the EPS's robust response to small disturbances and its overall dynamic stability. Through eigenvalue analysis and the assessment of damping characteristics, the research established that the system possesses a well-damped response, evident in the predominantly negative eigenvalues and acceptable damping ratios.

For future research, it is essential to explore the impact of larger-scale wind turbine integration, considering potential new locations and the accurate modeling of wind turbines. Additionally, the use of PSAT, an open-source tool, suggests that results could be compared with those from more advanced commercial software to validate and refine the modeling approaches and simulation methods used. In addition, the development and implementation of more sophisticated real-time monitoring and control technologies will be crucial. These technologies will enhance the operational flexibility and responsiveness of the power system to dynamic changes and disturbances. Furthermore, it would be beneficial to explore the long-term impacts of renewable energy integration on system reliability, economic performance, and environmental sustainability in the context of the global shift towards greener energy solutions.

REFERENCES

- [1] P. Kundur, Power system stability, Power system stability and control 10 (2007): 7-1
- [2] J. F. P. Duque, et al. "Inter-area oscillation study of the Greek power system using an automatic toolbox." 2021 IEEE PES Innovative Smart Grid Technologies Europe (ISGT Europe). Espoo, Finlande, 2021

- [3] Y. Yiping, et al. "Oscillation energy analysis of inter-area low-frequency oscillations in power systems." *IEEE Transactions on Power Systems*, Vol. 31, No. 2, 2015, pp. 1195-1203
- [4] A. Odienat, et al. "Low frequency oscillation analysis for dynamic performance of power systems." 12th International Renewable Engineering Conference (IREC), Amman, Jordan, 2021.
- [5] S. Eftekharnajad, et al. "Small signal stability assessment of power systems with increased penetration of photovoltaic generation: A case study." *IEEE Transactions on Sustainable Energy*, Vol. 4, No. 4, 2013, pp. 960-967
- [6] A. Patel, G. Sandip and F. A. Komla, "Inter-area oscillation damping with non-synchronised wide-area power system stabiliser." *IET Generation, Transmission & Distribution*, Vol. 12, No. 12, 2018, pp. 3070-3078
- [7] J. Chen, et al. "Investigating the impact of wind power integration on damping characteristics of low frequency oscillations in power systems." *Sustainability* Vol. 14, No. 7, 2022, pp. 1-23
- [8] S. Nurković, S. Avdaković. "The Small Signal Stability Analysis of a Power System with Wind Farms-Bosnia and Herzegovina Case Study." *Advanced Technologies, Systems, and Applications III: Proceedings of the International Symposium on Innovative and Interdisciplinary Applications of Advanced Technologies (IAT)*, Volume 1. Springer International Publishing, 2019
- [9] A. Aman, A. Bektimirov, N. Dyussebekova, A. Ilyasov, A. Saukhimov and A. Gunin, "Small signal stability research on integrating Wind Power Plant – An Almaty Region Example," 57th International Universities Power Engineering Conference (UPEC), Istanbul, Turkey, 2022, pp. 1-6, doi: 10.1109/UPEC55022.2022.9917676
- [10] M. Arghya. "Small signal stability analysis of power systems integrated with wind power using sensitivity-based index." *Wind Engineering* Vol. 45, No. 1, 2021, pp. 35-49
- [11] L. Yan and K. Wang. "A summary of impacts of wind power integration on power system small-signal stability." *IOP Conference Series: Earth and Environmental Science*. Vol. 64, No. 1, IOP Publishing, 2017
- [12] "Technical Report on the Connection Solution of the Podveležje Wind Farm to the 110 kV Transmission Network", *Energoinvest d.o.o.*, Sarajevo, February, 2014
- [13] "Indicative Production Development Plan for the Period 2018–2027"; NOSBiH, March 2017
- [14] "Long-Term Transmission Network Development Plan 2016–2025"; *Elektroprijenos BiH*, May 2016
- [15] "Long-Term Transmission Network Development Plan 2017–2026"; *Elektroprijenos BiH*, November 2016
- [16] *Grid Code*, NOSBiH, 15 December 2016.
- [17] Milano, Federico. "Power System Analysis Toolbox Documentation for PSAT." version 2.1 (2020): 89-98

BIOGRAPHY

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