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Challenges to system stability and EU regulatory alignment for Bosnia and Herzegovina's renewable energy integration: Focus on transient system stability during fault-induced disturbances

Abstract: This paper reviews the legal and regulatory framework in Bosnia and Herzegovina (BiH) for connecting renewable energy production facilities. It assesses how well BiH's regulations align with European Union (EU) standards for grid connections, focusing on stability criteria from the EU network code for generators. The paper also establishes a theoretical foundation for the transient stability of distributed generators and presents a verification methodology for distribution system operators in general. By developing a distribution network model and offering practical examples, this study aims to enhance the application of stability criteria, which are crucial for managing grids with high shares of renewable energy sources. This study underscores the importance of harmonized regulatory frameworks for the successful integration of renewable energy sources into the BiH power grid, aligning with the Energy Community Treaty objectives. It also identifies key gaps in the regulatory oversight of distribution networks, offering practical methodologies for distribution system operators to ensure compliance with stability requirements. Ultimately, this research provides actionable insights for policymakers, advancing practices for integrating renewable energy. These findings are essential not only for the sustainable expansion of renewable

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energy sources and the reliable operation of the distribution network but also for informing regulatory oversight and ensuring consistent implementation of EU standards across the sector.

Keywords: stability, renewable energy, Bosnia and Herzegovina, distributed generators, EU regulative

Introduction

Southeast European governments are actively pursuing decentralization of energy production by encouraging the development of renewable energy-based power plants and enticing citizens to generate electricity on their own. The majority of such production facilities, including hydropower plants (HPP), photovoltaic power plants (PVPPs), and biomass power plants, connect to the electrical distribution grid, categorized as distributed generation (DG). The Mixed Holding Power Utility of the Republic of Srpska is one prominent example of this trend, as it actively encourages citizen production. Under the Sustainability Energy Program for Homes and Businesses (ERS 2022), the utility invited 50,000 households, or about 10% of its end users, to install 3–7 kW small PVPPs on their rooftops and turn their homes into renewable energy consumers. By turning their homes into renewable energy consumers, these households contribute to a more sustainable energy future. Sustainable energy systems, in the formal legal context of the European Union, provide an integrated framework of interconnected components, policies, and actions aimed primarily at mitigating greenhouse gas emissions and safeguarding the environment. These measures have additional objectives, including reducing the dependency of EU member states on the import of fossil fuels, enhancing the competitiveness of the European economy, and enabling the transition to renewable energy sources. This approach is strengthened by legislative acts such as Directive (EU) 2019/944 on standard rules for the internal electricity market (Directive (EU) 2019) and Regulation (EU) 2021/1119 (European Climate Law). All of these initiatives will lead to the transformation of the EU into a climate-neutral continent by 2050, with the energy sector playing a crucial role in achieving these goals. In this context, compliance with EU regulations is of vital importance for candidate countries, including Bosnia and Herzegovina, as they are expected to adopt similar strategies and measures in preparation for EU membership, which inherently involves adherence to shared values, standards, and policies. A complicating factor is the complex state structure of Bosnia and Herzegovina, which consists of three administrative units, including two entities: the Republic of Srpska and the Federation of BiH, along with the Brčko District. Within the same area, multiple independent distribution system operators (DSOs) operate, and their work is regulated by different legislative and sub-legislative acts.

On the other hand, the Treaty establishing the Energy Community (Treaty EC 2006), which BiH decided to accept, and other international obligations bind the energy sector in the countries of Southeast Europe. The establishment of a stable and unified regulatory framework and market space, ensuring a reliable supply of electrical energy, is achieved through the gradual adoption of the EU ACQUIS, involving the implementation of relevant EU directives and regulations in the areas of electric power. In this context, concerning the subject matter, the importance of adopting, embracing, and practically implementing these standards is emphasized to ensure uniform action among different DSOs in BiH.

BiH boasts significant potential for renewable energy, with solar power plants having an estimated annual output of 70.5 milion GWh per year according to (Sher et al. 2024), with Herzegovina being the most favorable location. Additionally, hydropower holds promise with a potential capacity of 22.050 GWh, and currently, there are 15 large HPP in operation, 35 under construction, and 390 in the planning stages (Sher et al. 2024). However, integrating these renewable sources presents challenges for the grid, as evidenced by the essential load indicators outlined in (SERC 2022). The maximum hourly load of 1,893 MW (recorded in January 2022) and the historic maximum of 2,207 MW (recorded in December 2014) highlights the system's peak demand. Conversely, a minimum hourly load of 678 MW (recorded in June 2022) demonstrates the variability.

In such a dynamic environment, where a large number of distributed generators are expected to be connected to the grid, ensuring these production modules within each synchronous area of the interconnected system remain connected within defined voltage and frequency ranges becomes crucial for maintaining overall grid stability. That is crucial because a frequency change in one synchronous zone would immediately impact the frequency and potentially jeopardize production functionality in other zones within the synchronous area. This aspect is problematic due to the fact that distributed generators have significantly smaller inertial mass, and some, such as PVPPs, even have zero inertia, as they do not operate based on any inertial mass. As Jenkins and Hamidi (2014) have described, the essential factor determining the system's resistance to frequency disturbances is the inertial mass of the system, which poses a significant challenge given the smaller inertial mass of distributed generators. The practical application and significance of adhering to the stability requirements for production modules before, during, and after network disturbances have become a pressing topic at numerous regional events, exemplified in the report CIRED Serbia (2022). We must ensure that the current topic does not jeopardize the triumphant narrative of the broader integration of renewable energy sources (RES) into the energy system in BiH, nor allow the integration of DG to compromise its stability. The integration of DG into distribution grids offers numerous benefits, such as improved energy efficiency and reduced dependence on centralized production. However, increased deployment of DG units can pose new challenges, such as maintaining the transient stability of the system.

Transient stability refers to the system's ability to recover after a short circuit or other disturbance that causes significant rotor angle displacement. Several studies (Sivanandan et al. 2014; Hidayatullah et al. 2011) have explored this issue and its implications for the integration of DG units. Sivandan et al. (2014) used short-circuit simulation to analyze the transient stability of DG units in distribution systems. They demonstrated that the location and type of fault can significantly impact system stability, which was taken into account during the verification in the practical part of the study. Hidayatullah et al. (2011) focused on the general impact of DG integration on the transient stability of smart distribution grids. The research emphasized the importance of fault-clearing time for maintaining stability, a factor that was also tested in this study. The methodology employed in this paper builds upon key concepts and steps from existing methodologies, such as DG unit modeling, short circuit simulation, and behavioral analysis. However, the applied methodology distinguishes itself by incorporating regulatory criteria and by being applied to a real-world distribution network model in BiH. This topic was addressed in the paper, which is relevant and significant for BiH, considering the need to increase the integration of renewable energy sources and align with EU standards.

This analysis provides a comprehensive review of the existing legal and sub-legal framework in Bosnia and Herzegovina governing the connection of renewable energy-based production facilities. It critically evaluates the application of stability criteria outlined in EU Regulation, aiming to achieve uniformity among all entities responsible for decision-making on this matter in BiH, to which BiH has previously committed. The paper can assist DSOs in BiH in integrating more renewable energy sources and maintaining grid stability. It also serves as a practical guide for professionals and researchers involved in the domain of electrical power systems. Additionally, the paper aims to establish a theoretical foundation for the transient stability of distributed generators, offering a methodology for verification to aid distribution system operators. By developing a distribution network model and providing practical examples, the study enhances understanding and application.

1. Regulatory requirements and practical implementation in BiH

Respecting the Energy Community requirements, the Permanent High-Level Group decided to include the connection network codes in the Energy Community acquis on electricity on January 12, 2018. This includes Commission Regulation (EU) 2016/631, Commission Regulation (EU) 2016/1388, and Commission Regulation (EU) 2016/1447, as clearly outlined in SERC (2019). Generators of type B are required by Regulation (EU) 2016/631 (Regulation EU 2016) to satisfy operational stability requirements during voltage collapse in both symmetric and asymmetric short circuits within the system. Furthermore, generators of type C are required to adhere to extra voltage stability standards for operating conditions that are sensitive to frequency, such as primary frequency regulation. On December 15, 2021, the State Electricity Regulatory Commission of BiH issued a Decision on the approval and application of the Grid Code of Independent System Operator in Bosnia and Herzegovina (Code 2021). According to what was noted in SERC (2022), all EU regulations about network connectivity requirements were incorporated into the Grid Code of Independent System Operators in Bosnia and Herzegovina (Code 2021), which was tailored to the Energy Community's legal framework during the approval procedure. Additionally, this adaptation harmonizes with regulations 2016/631, 2016/1388, and 2016/1447 of the European

Commission (EU) and complies with the decisions made by the Permanent High-Level Group, bringing them into compliance with Bosnia and Herzegovina's legal framework.

The Grid Code of Independent System Operator in Bosnia and Herzegovina (Code 2021) and the connection regulations (RC 2008; RC-1 2010; RC-2 2012) define the procedure for issuing connection conditions to the power transmission network (110kV, 220kV, and 400kV) under the jurisdiction of the Transmission System Operator (TSO). The Grid Code of Independent System Operator in Bosnia and Herzegovina (Code 2021) explicitly requires the verification of stability for production modules and compliance with the capability conditions for passing through the fault state for modules of type B, C, and D. Regulations (RC 2008; RC-1 2010; RC-2 2012) impose the obligation to prepare an elaborate Optimal Technical Solution for connecting new production modules. The compliance check during the trial operation of new production facilities with the provisions of the European Network of Transmission System Operators for Electricity (ENTSO-E) Network Code (ENTSO-E 2013) is conducted according to the document (ISO BiH 2018). Therefore, for production modules connecting to the TSO network at voltage levels > 110 kV, i.e., production modules of type D, there is an unambiguous verification of meeting the capability conditions for passing through the fault state. The DSOs in Bosnia and Herzegovina are mandated to revise the regulations concerning the connection of production modules A, B, and C to align with the requirements and constraints outlined in Grid Code of Independent System Operator in Bosnia and Herzegovina (Code 2021) and Regulation (EU) 2016/631 (Regulation EU 2016). Additionally, there is still uncertainty regarding the fulfillment of the requirements for production modules connected at voltage levels under the DSO's jurisdiction – 0.4, 10, 20, and 35 kV – to pass through the fault state. It is important to note that the installed power threshold for categorizing production modules between types C and D is 20 MW. The maximum power for production modules of type C is 20 MW, while for type B, it is 10 MW.

The subsequent text will critically analyze the state of compliance with legal requirements and the practical application of stability requirements outlined in Regulation (EU) 2016/631 (Regulation EU 2016) for generators of types B and C connected to the electrical network of the DSOs in BiH. As previously mentioned, BiH is comprised of three administrative units, including two entities: Republika Srpska and the Federation of Bosnia and Herzegovina, along with the Brčko District. The energy sector falls under the jurisdiction of these entities.

In BiH, there is a unified company, "Elektroprenos BiH", responsible for the transmission of electric power. This means there is a singular TSO in BiH. Eight registered entities, including electric power company „JP Elektroprivreda BiH dd Sarajevo", electric power company „JP Elektroprivreda HZHB d.o.o. Mostar", Public Utility Company "Komunalno Brčko d.o.o. Brčko" and five independent DSOs within the Mixed Holding Power Utility of the Republic of Srpska, conduct distribution activities. Legal foundations for compliance with stability requirements for generators connected to the electrical distribution network of DSOs must be individually examined.

An exception is the connection of production modules to 10 kV, 20 kV, or 35 kV busbars in the 110/x kV substation owned by the TSO. Following the requirements of Grid Code of Independent System Operator in Bosnia and Herzegovina (Code 2021), the TSO has notified all

DSOs in BiH in document (TSO BiH 2022) about their obligation to prepare an elaborate optimal technical solution for connecting new production modules in case of connection to 10 kV, 20 kV, or 35 kV busbars in the 110/x kV substation according to the requirements from Grid Code of Independent System Operator in Bosnia and Herzegovina (Code 2021). This confirms that the production modules in this scenario have met the capability conditions needed to pass through the fault state.

In the Federation of Bosnia and Herzegovina, two DSOs are registered within the electric power company Distribution System Operator Public Enterprise Electric Utility of Bosnia and Herzegovina and Distribution System Operator Public Company Electric Utility HZHB. The connection of production facilities to the network is regulated by document (Rules FERK 2018) for the Distribution System Operator Public Enterprise Electric Utility of Bosnia and Herzegovina and document (Rules FERK 2017) for the Distribution System Operator Public Company Electric Utility HZHB. None of these documents is compliant with the document (Regulation EU 2016) or the conditions related to the stability of production modules during network faults. Hence, there are no legal obligations mandating checks for conditions related to the stability of production modules during network faults.

In the Republic of Srpska, five DSOs operate within the Mixed Holding Power Utility of the Republic of Srpska. The connection of production objects to the electrical distribution network in 2014. is regulated by Regulation ERS (2014). Although (Regulation ERS 2014) is not compliant with (Regulation EU 2016), it has been aligned with (ENTSO-E 2013), ensuring that power plants must be capable of stable operation during short circuits in the power system. Since 2014, clear legal predispositions and obligations have existed for implementing stability requirements for production modules connected to the distribution network in this entity. However, considering that the DSOs are solely responsible for verifying these conditions, doubts arise regarding their practical implementation, as also discussed at regional professional forums, such as the one referenced in CIRED Serbia (2022).

In Brčko District, as a separate administrative unit, the connection of production modules to the electrical distribution network is regulated by Rules BDK (2011). However, this document is not in compliance with (Regulation EU 2016), and consequently, the conditions related to the stability of production modules during network faults are not addressed.

2. Theory and method

The testing of the transient stability of an electrical system fundamentally revolves around investigating the behavior of the power system during significant disturbances, such as short circuits. The transient stability requirements imposed on a power plant connected to the distribution network are examined by simulating a three-phase short circuit in the immediate electrical vicinity of the power plant's connection point. During a symmetrical fault, the objective is to keep the voltage at the connection point at the limit of the phase-to-phase voltages until the protective device disconnects the fault-affected line.

Regulation (EU) 2016/631 (Regulation EU 2016) defines obligations, among other things, related to meeting the conditions of transient stability for power plants in the event of a transient fault causing a voltage drop of a certain depth and duration. These requirements also apply to lower-capacity power plants connecting to the voltage levels of the electro-distribution network. The criterion for transient stability is considered satisfied if the system, after a short circuit, returns to a balanced state in which all system parameters are within permissible limits. An additional condition is that the voltage curve over time at the connection point of the power plant falls within the range defined by regulatory authorities (Regulation EU 2016) and (ENTSO-E 2013).

In Regulation (EU) 2016/631 (Regulation EU 2016) itself, for production modules of types B and C, the fulfillment of transient stability criteria is defined based on the diagrams shown in Figure 1, which also correspond to the requirements of (Regulation EU 2016) and (ENTSO-E 2013).

Fig. 1. Fault ride through the profile of a power generating module (Regulation EU 2016; ENTSO-E 2013)

Rys. 1. Przebieg awarii przez profil modułu wytwarzania energii

As is noticeable, specific parameter values to be achieved are not provided in (Regulation EU 2016) and (ENTSO-E 2013) instead, specific values are recommended, and the network user is directed to national TSOs and DSOs to obtain conditioned specific values.

The methodology employed in this work builds upon key concepts and steps from existing methodologies, such as DG unit modeling, short circuit simulation, and behavioral analysis, exemplified in Sivanandan et al. (2014) and Hidayatullah et al. (2011). This paper presents a refined methodology for transient stability calculations. The core algorithm, initially developed for a separate project Study on modalities to include electricity from Renewable Energy Sources into the Serbian distribution network and smart grids (CGIOP 2020), has been generalized for broader applicability. The effectiveness of the approach has been previously demonstrated in its application to the Distribution Network (EDM) in the Republic of Serbia (CGIOP 2020). The methodology incorporates detailed modeling of the network and DG units following relevant industry standards and guidelines to accurately represent the system's dynamic behavior during short circuits and other disturbances. In this study, the methodology is further adapted and employed for transient stability calculations within the context of the electricity distribution network in BiH.

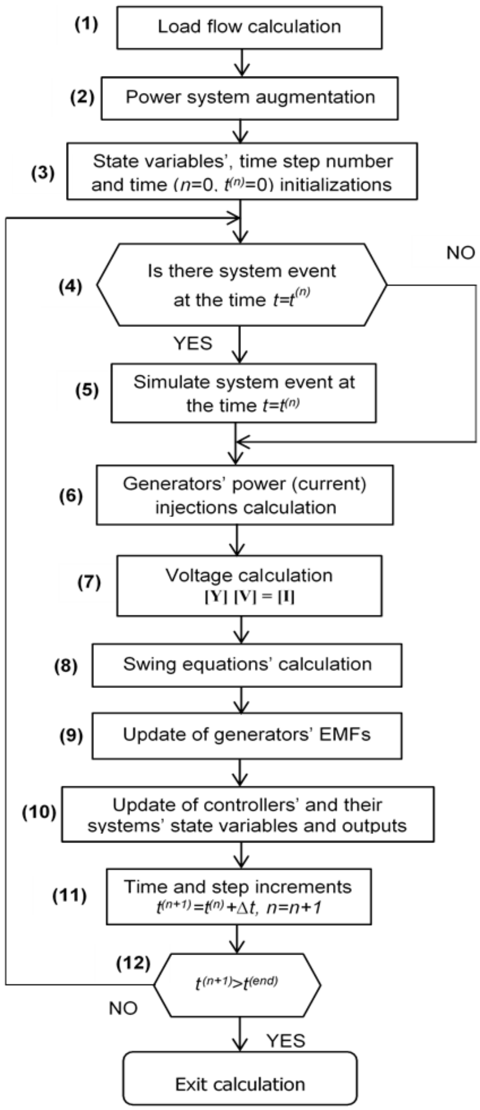

Fig. 2. Algorithm for transient stability assessment (CGIOP 2020)

Rys. 2. Algorytm oceny stabilności przejściowej

Each algorithm block is marked by a number in brackets on its left side. These numbers are used to describe each block separately in the text that follows:

(1) Power (load) flow calculation is an essential power system calculation, and its results are a starting point for stability calculation. Only once the load flow calculation has been successful should stability simulations be initiated.

(2) More nodes – one for each generator – are required to be added to the power system model described in step (1). These nodes represent the generators' internal subtransient electromotive force (EMF). These EMFs run the system during the entire simulation period, meaning their values are used to calculate power (current) injections at added EMF nodes, which are, in turn, used to calculate voltages and currents in the power network. After that, calculated currents and rotor displacements are used to update EMF. Additional lines are also introduced that connect these new nodes with generators' terminal nodes that already exist in the power flow model. Impedances of these lines are generators' subtransient impedances.

(3) The State variables of control (excitation and turbine) systems are initially calculated. At this step, the state variables' time derivatives should be zero.

(4) Checking of event occurrence at time $t = t(n)$ is done at the beginning of each simulation cycle to update the *Ybus* matrix.

(5) We simulate a short-circuit event by introducing a significantly high shunt admittance at the line or bus where it occurs. Similarly, the process of fault clearance is simulated by either eliminating the shunt admittance if the fault arises at the bus or by isolating the line at both ends in case of a fault on the line.

(6) The power (current) injections of generators are computed using Kron's method, which considers the generators' equivalent subtransient EMFs and *Ybus* matrix. The *Ybus* matrix is reduced to include only the nodes of the generators through Kron's method, and power injections are determined based on the generators' equivalent subtransient EMFs and their mutual admittances. More about Kron's method can be found in Grainger and Stevenson (1994).

(7) After computing the generators' power (current) injections, the voltages in the network are determined by solving a set of algebraic equations:

$$[I] = [Ybus]\,[V] \tag{1}$$

The set of preceding algebraic equations is solved by decomposing the *Ybus* matrix into lower [*Lbus*] and upper [*Ubus*] matrices and applying the forward-backward algorithm.

(8) Swing equation or equation of motion is:

$$J\frac{d\omega_m}{dt} = T_a = T_m - T_e = \frac{P_m}{\omega_m} - \frac{P_e}{\omega_{sm}} \tag{2}$$

where:

J	–	moment of inertia of both generator and turbine [kg·m^2],
T_m, P_m	–	mechanical moment and power, respectively,

T_e, P_e – electrical moment and power, respectively,
ω_m – angular velocity of the rotor in mechanical radians per second,
ω_{sm} – synchronous angular velocity of the rotor in mechanical radians per second,
t – time in seconds.

Equation (2) is usually written as:

$$\frac{2H_{mach\_system}}{\omega_s}\frac{d\omega}{dt}=\frac{P_m\left[p.u.\right]}{\frac{\omega}{\omega_s}}-P_e\left[p.u.\right] \tag{3}$$

where:
ω – angular velocity of the rotor in electrical radians per second,
ω_s – synchronous angular velocity of the rotor in electrical radians per second.

(9) Rotor angle displacement $\delta^{(n)}$ calculated in (8) and currents through lines calculated based on voltages that are calculated in (7) are used to update the EMFs of the generators.

(10) At this stage, the time derivatives of state variables for all control systems are computed, considering the machine's angular velocity, terminal voltage, power, and current. The state variables and outputs of controllers are then updated using the calculated time derivatives, employing the selected time integration method.

(11) Time and simulation steps are incremented.

(12) Simulation is stopped when time becomes higher than simulation duration *t*(end).

Using the previously outlined methodology, a real-world example of verifying the transient stability of generators was carried out for a typical DSO area in the northern region of BiH. Standardized equipment was used for HPP with three installed synchronous generator units.

Three separate power transformers, rated at 1 MVA, 0.25 MVA, and 0.25 MVA, with a transmission ratio of 10/0.4 kV/kV, are linked to each generator separately. The transformers are single-core, three-phase, two-winding standard energy transformers. We practically have three separate DG connected at one point, at the 10 kV busbar, in a facility where the HPP is connected to a 10 kV overhead transmission line, following the input-output principle, as per Regulation ERS (2014). There are no plans to operate the power plant in an islanded or combined mode; HPP runs in parallel with the network DSO. For these purposes, the excitation system of the synchronous generator is modeled according to the standard (IEEE Std 421.5-2005), with the ST1A excitation system model being selected. This type is flexible enough to simulate the reduction of transient amplification in the direct path through the time constants, making it a suitable choice for the desired simulation representation in this case. For model development, a nonlinear model of the hydro turbine was applied, considering the effects of the traveling water column, corresponding to the applied SPHH type in this region as per Working Group (1992).

3. Results and discussion

This section presents the results and discussion of a transient stability analysis following a three-phase short circuit on the distribution network. The short circuit was simulated at a neighboring branch, located 60% of the circuit breaker's length away, using the connection method described in Section 2. The fault event had a duration of 0.13 seconds, with a fault clearing time of 0.63 seconds from the start of the simulation. Due to the identical characteristics of the two smaller generators, the rotor angle and active power will be analyzed for the more significant generator, G1, and one of the smaller generators, G2. The rotor angles, the power of generators G1 and G2, and the voltage at the HPP connection point are graphically depicted in Figure 3 throughout the 130 ms fault duration. The figure illustrates how the rotor angle rises as a result of the machine shaft imbalance during the fault duration, while the generator's active power shows a declining trend. At the fault-clearing moment, the active electrical power of the machines sharply rises, and a damped oscillatory process occurs in both generators.

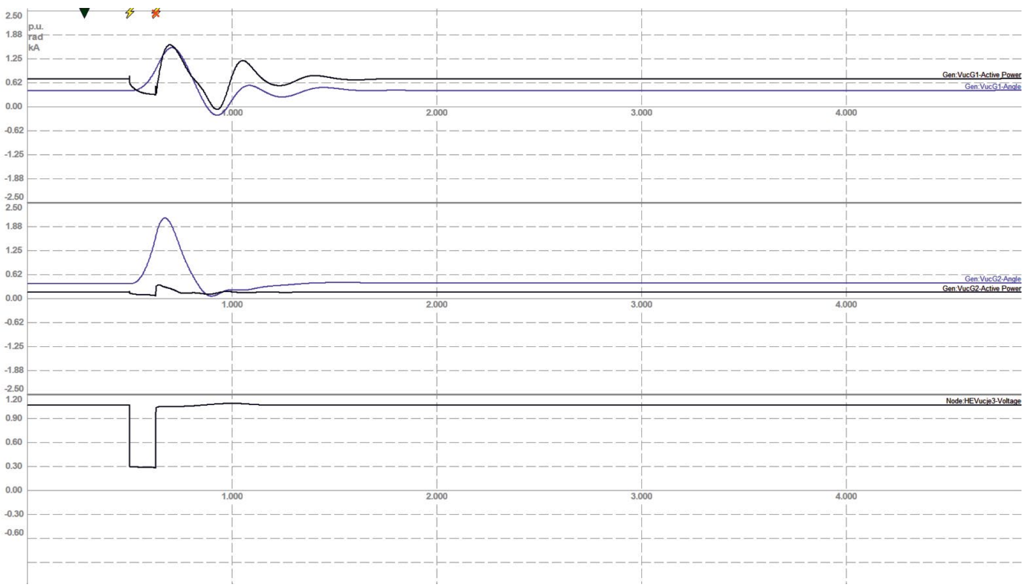

Fig. 3. Rotor angle and active power of generators G1 and G2, as well as the voltage at the point of HPP connection, during the 130 ms fault duration

Rys. 3. Kąt obrotu wirnika i moc czynna generatorów G1 i G2 oraz napięcie w punkcie przyłączenia HPP w czasie trwania awarii 130 ms

Figure 4 depicts the impact of a longer fault duration (0.14 seconds, clearing at 0.64 seconds) on the response of generators G1 and G2, as well as the voltage at the HPP connection point.

The figure illustrates how extending the fault duration leads to unstable operation in the smaller generator G2. This is evident from the rapid increase in rotor angle and the large amplitude oscillations in its active power waveform, which do not attenuate over time. In contrast, the more significant generator, G1, demonstrates stable operation after fault clearing. The rotor angle returns to its pre-fault value, and only small oscillations are observed in its active power. These oscillations are not a result of G1's instability but rather the influence of the unstable G2 within the same electrical environment.

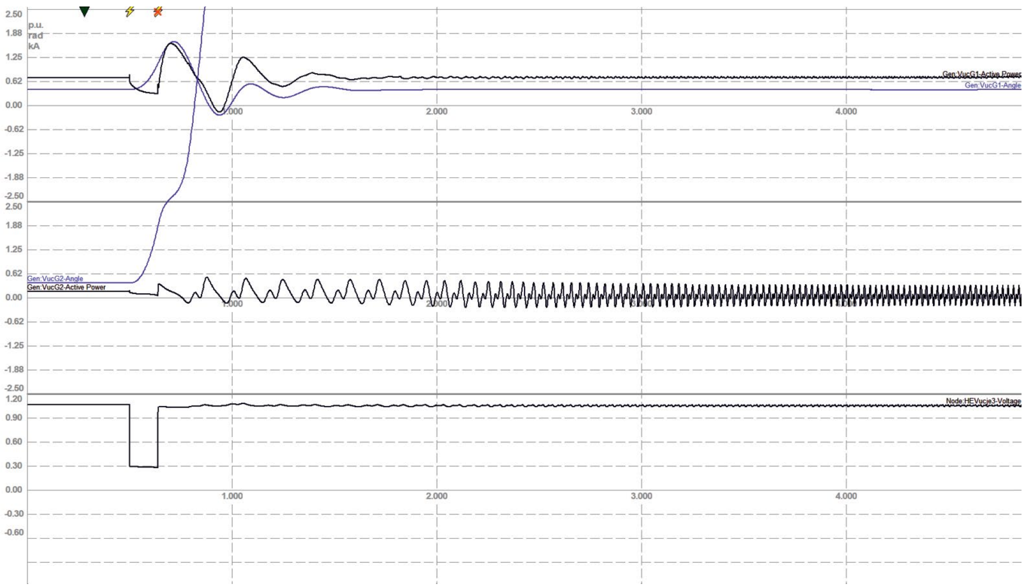

Fig. 4. Rotor angle and active power of generators G1 and G2, and voltage at the connection point of the HPP during a fault duration of 140 ms – Unstable operation of smaller generators

Rys. 4. Kąt obrotu wirnika i moc czynna generatorów G1 i G2 oraz napięcie w punkcie przyłączenia HPP podczas awarii trwającej 140 ms – niestabilna praca mniejszych generatorów

The provided example successfully illustrates the significance of applying the transient stability criteria for DG with decisiveness, the possible influence of operational instability in one DG on the operation of other DG, and the more general operational conditions within the designated area's distribution network. This reinforces the need to address potential instability issues and their impact on DSOs. Resolving the problem of unstable DG operation, as simulated in the presented example, can be approached in several ways: prompt fault clearing, readjustment of generator parameters, reduction of the transient gain of the Automatic Voltage Regulator, etc. On the waveform of the active power of generator G1, small amplitude oscillations are observed. These oscillations are not caused by the instability of generator G1 but by generator G2, located in its immediate electrical environment, whose unstable operation induces small amplitude oscillations in generator G1. This example vividly illustrates the significance of the diligent application of transient stability criteria verification for DG and the impact of potential instability in the operation of one DG on the operation of another DG and the overall distribution system in the subject area. Resolving the issue of unstable DG operation and its adverse impact on the stability of other nearby DG, as well as the overall stability of the distribution system, can be straightforward by simply setting the required generator operating parameters.

Considering and comparing with the results of the study analysis by Sivanandan et al. (2014) and Hidayatullah et al. (2011), they also emphasize the significance of rotor angle and voltage in analyzing various types of faults. Sivanandan et al. (2014) focused their simulations on faults occurring at busbars where DG units are connected. Also, studies analysis by Sivanandan et al. (2014) and Hidayatullah et al. (2011) utilize a test system compatible with IEEE standards, likely for generalization. In contrast, this study focuses on a digital model specifically designed to represent a real distribution system in BiH and established practices for connecting DG units (Regulation ERS 2014). This enables customized analysis, considering the specific regulatory framework, such as EU Regulation 613/2016, for the most critical scenario, which is a three-phase short circuit. In addition, the paper also focused on the impact of the size of DG units on stability, demonstrating the significance of inertia and the overall size of the generator on operational stability, as well as the importance of fault duration in this context. It has been shown how a smaller generator, G2, became unstable after extending the fault duration, while the more significant generator, G1, exhibited better recovery characteristics. However, Sivandan et al. (2014) demonstrate the positive impact of the presence of battery storage systems together with DG on the overall transient stability of the distribution system, which was not examined in this study on the example of BiH.

This study's limitation could be that its scope primarily focuses on the regulatory framework and alignment with EU standards, with less attention given to the technological advancements necessary for the broader integration of renewable energy sources. Additionally, the study does not take into account regional differences in infrastructure and the capacity of various distribution networks to accommodate the increased penetration of renewable sources.

Future research should prioritize the integration of energy storage systems alongside renewable energy sources to enhance grid stability. In addition, it is essential to evaluate the economic viability and additional benefits of implementing battery storage systems, as this could play a critical role in promoting their widespread adoption and facilitating the long-term integration of renewable energy into the grid.

Conclusion and policy implications

This paper highlights the crucial role of regulatory frameworks in the successful integration of RES into the BiH power grid. The findings emphasize the need for harmonized regulations across the entities in BiH to ensure stable and sustainable grid operation. This aligns with the broader objectives of the Energy Community Treaty, of which BiH is a part, aiming to adopt and implement EU directives and regulations for a unified and reliable energy market. Through the development of this paper, the author has recognized the consistent application of the conditions for passing through the fault state for production modules connecting to the network under the jurisdiction of the TSO BiH with a voltage level > 110 kV, i.e., Type D production modules. Clear legal predispositions for this have been established in BiH. However, the paper also emphasizes the inconsistent verification of required conditions for Type B and C production modules, in part because the legal and sub-legal acts that define how DSOs operate in BiH are not in line with EU legal achievements and BiH's duties. This has been made explicitly clear for each DSO in the BiH and the regions under their purview. By demonstrating through practical examples and simulations, the paper provides a methodology that DSOs can adopt to ensure compliance with stability requirements. The study concludes that while BiH has established a solid legal foundation for the integration of RES, particularly for high-voltage networks, there is a need to address the gaps in the regulatory framework for distribution networks. This is crucial for mitigating potential stability issues that could arise from the increased integration of RES, thereby supporting the broader policy goals of sustainable energy development.

Given the dynamic environment of BiH's energy sector, characterized by a high potential for renewable energy generation and a significant number of DG connecting to the grid, the paper's findings have several practical implications. Based on the findings of this study, several key recommendations for decision-makers can be identified: (1) accelerated alignment with EU standards, (2) harmonization of the regulatory framework between entities and DSOs, (3) strengthening regulatory oversight, (4) securing financial instruments for grid modernization, and (5) engaging the public and building support for energy transitions. The need for a unified approach to regulatory oversight across all DSOs is evident. This involves not only adopting EU standards but also ensuring their practical implementation through consistent verification and enforcement mechanisms.

In summary, the findings of this study provide valuable insights for policymakers, regulators, and industry stakeholders. By adopting a harmonized and practical approach to regulatory implementation, BiH can effectively integrate renewable energy sources, ensuring grid stability and supporting the broader goals of sustainable energy policy. However, achieving this requires continued grid enhancements to handle increased renewable generation alongside essential financial mechanisms that facilitate these improvements and incentivize further development. In addition, it is crucial to ensure that the public and consumers understand that their active use of renewable energy is essential for contributing to energy and climate independence, not only in Bosnia and Herzegovina but also across the broader European continent.

The Authors have no conflicts of interest to declare.

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Saša Đekić

Wyzwania dla stabilności systemu i dostosowanie przepisów UE do integracji energii odnawialnej w Bośni i Hercegowinie: Ukierunkowanie na przejściową stabilność systemu podczas zakłóceń wywołanych awarią

Streszczenie

W niniejszym artykule dokonano przeglądu ram prawnych i regulacyjnych w Bośni i Hercegowinie (BiH) w zakresie przyłączania zakładów produkujących energię odnawialną. Oceniono, w jakim stopniu przepisy Bośni i Hercegowiny są zgodne z normami Unii Europejskiej (UE) dotyczącymi przyłączania do sieci, koncentrując się na kryteriach stabilności z unijnego kodeksu sieci dla generatorów. Artykuł ustanawia również teoretyczne podstawy stabilności przejściowej generatorów rozproszonych i przedstawia metodologię weryfikacji dla operatorów systemów dystrybucyjnych. Opracowując model sieci dystrybucyjnej i oferując praktyczne przykłady, niniejsze opracowanie ma na celu poprawę stosowania kryteriów stabilności, które mają kluczowe znaczenie dla zarządzania sieciami o wysokim udziale odnawialnych źródeł energii. Analiza ta podkreśla znaczenie zharmonizowanych ram regulacyjnych dla udanej integracji odnawialnych źródeł energii z siecią energetyczną BiH, zgodnie z celami Traktatu o Wspólnocie Energetycznej. Identyfikuje również kluczowe luki w nadzorze regulacyjnym sieci dystrybucyjnych, oferując praktyczne metodologie dla operatorów systemów dystrybucyjnych w celu zapewnienia zgodności z wymogami stabilności. Ostatecznie przeprowadzone badania dostarczają praktycznych spostrzeżeń dla decydentów politycznych, rozwijając praktyki integracji energii odnawialnej. Ustalenia te są niezbędne nie tylko dla zrównoważonej ekspansji odnawialnych źródeł energii i niezawodnego działania sieci dystrybucyjnej, ale także dla informowania o nadzorze regulacyjnym i zapewnienia spójnego wdrażania standardów UE w całym sektorze.

Słowa kluczowe: stabilność, energia odnawialna, Bośnia i Hercegowina, rozproszone generatory, regulacje UE