

Dynamic Stability Analysis of the National Power Grid of the Republic of the Congo: STATCOM-PSS Interactions on Voltage Regulation and Electromechanical Oscillations

Mavie Grâce Mimiesse^{1*}, Rostand Martialy Davy Souamy Loembe¹,
Smaël Magloire Elombo Motoula², Désiré Lilonga-Boyinga¹

¹Laboratory of Electrical and Electronic Engineering (LGEE), National Higher Polytechnic School, Marien Ngouabi University, Brazzaville, Republic of the Congo

²Higher Institute of Architecture, Urban Planning, Building and Public Works, Denis Sassou N'Guesso University, Kintélé, Republic of the Congo

Email: *lucianamimiesse@gmail.com

How to cite this paper: Mimiesse, M.G., Souamy Loembe, R.M.D., Elombo Motoula, S.M. and Lilonga-Boyinga, D. (2026) Dynamic Stability Analysis of the National Power Grid of the Republic of the Congo: STATCOM-PSS Interactions on Voltage Regulation and Electromechanical Oscillations. *Open Journal of Applied Sciences*, 16, 4207-4228.

<https://doi.org/10.4236/ojapps.2026.1610229>

Received: November 30, 2025

Accepted: October 27, 2026

Published: October 30, 2026

Copyright © 2026 by author(s) and Scientific Research Publishing Inc. This work is licensed under the Creative Commons Attribution International License (CC BY 4.0).

<http://creativecommons.org/licenses/by/4.0/>



Open Access

Abstract

This article investigates the interactions between Power System Stabilizers (PSS), used to mitigate power oscillations, and STATCOM-type FACTS devices, employed for voltage support, in order to enhance the dynamic stability of the transmission network of the Republic of the Congo. The study is performed using the Power System Analysis Toolbox (PSAT) in MATLAB. Without control devices, several nodes show significant voltage drops, notably 10.97 kV at Tsielampo (node 20) and 14.55 kV at Djiri (node 30) for a nominal voltage of 30 kV, while an unstable mode emerges at the Moukouloulou generator (node 19). The addition of PSS at nodes 1, 6, and 34 improves the damping of power oscillations, with voltages stabilizing around 242 kV and 211 kV and damping ratios of 0.256 at Djéno and 0.187 at Moukouloulou. The combined integration of PSS and two STATCOM units installed at nodes 25 and 29 further enhances system stability: voltages in Brazzaville remain within the acceptable $\pm 10\%$ range around 30 kV, and generator voltages stabilize around 231.13 kV (CEC), 224.46 kV (Imboulou), 213.51 kV (Djéno), and 112.26 kV (Moukouloulou). The unstable mode ($\lambda_{19} = 3.2115$) only appears after the joint addition of the PSS and STATCOM, suggesting that it arises from their interaction.

Keywords

Voltage Stability, Electromechanical Oscillations, STATCOM, Power System

1. Introduction

The stability of a national power grid is essential for ensuring a reliable and continuous electricity supply. Among the major challenges faced by these networks are voltage variations and electromechanical oscillations. Voltage variations refer to fluctuations in electrical voltage relative to the nominal value, which must be kept within an acceptable range, often specified as $\pm 5\%$ of the nominal voltage. In the case of Brazzaville, for example, if the voltage profile consistently remains below this range, it can pose risks to the stability and efficiency of the grid. These variations can be caused by changes in load, generator or transmission line failures, or even by weather phenomena [1] [2]. Electromechanical oscillations are oscillating or unstable movements of the potentials of generators and other network elements. These oscillations, which occur in response to disturbances or changes in network operation (such as line or generator outages), can have serious consequences. They affect the synchronization of the grid and can lead to generator shutdowns, sector outages, or even system collapse if not quickly mitigated [3]. FACTS (Flexible AC Transmission Systems) are technological devices used to improve the control and management of energy in AC power grids. Their main role is to regulate key network parameters, such as voltage, power flow, and dynamic stability, to address challenges related to load variability and network disturbances [4]. Among the FACTS devices, the STATCOM (Static Synchronous Compensator) stands out as an effective solution for voltage regulation. The STATCOM is a static synchronous compensator that allows for the real-time provision or absorption of reactive power. This device plays a crucial role in improving the voltage profile by dynamically regulating the grid voltage. It compensates for voltage variations due to load fluctuations and maintains the stability of frequency as well as electromechanical oscillations [5] [6]. Therefore, the STATCOM is a valuable tool for stabilizing voltage in critical areas of the grid, such as Brazzaville, where voltage often remains below the acceptable range. The challenge of this study lies in managing voltage variations and electromechanical oscillations that affect the stability of the national power grid, particularly in Brazzaville. These disturbances can compromise the performance of the grid and pose risks to the quality of the electricity supply. It is therefore crucial to find solutions to improve voltage regulation and ensure system stability [7]. The main objective of this study is to evaluate the impact of integrating STATCOM devices on the stability of the national power grid of the Republic of the Congo, particularly regarding the improvement of the voltage profile and the management of electromechanical oscillations. The study aims to analyze how STATCOMs can reduce voltage fluctuations and mitigate oscillations to ensure optimal regulation and maintain grid stability, especially in critical areas like Brazzaville [8] [9]. This article is structured as follows: Section 2 presents

the basic principles of STATCOMs and their role in voltage and reactive power regulation; Section 3 discusses the basic principles of Power System Stabilizers (PSS) and the different components that make up a PSS; Section 4 reviews recent studies related to the application of STATCOMs and PSS; Section 5 outlines the methodology adopted; Section 6 presents the results obtained; Section 7 is dedicated to discussing the results; and Section 8 concludes the article.

2. Basic Principles of STATCOM

STATCOMs (Static Synchronous Compensators) are reactive power compensation devices based on static converters. Their main function is to regulate the grid voltage by quickly supplying or absorbing reactive power. A STATCOM uses power conversion equipment (usually semiconductor-based inverters) to dynamically adjust the reactance of the grid [10]. The STATCOM typically consists of a converter made up of thyristors for triggering/injection (current injection or absorption) and is connected to the grid through a transformer. The STATCOM modifies the reactance of the grid, allowing it to control the voltage locally at various points in the transmission system, as shown in **Figure 1** [11].

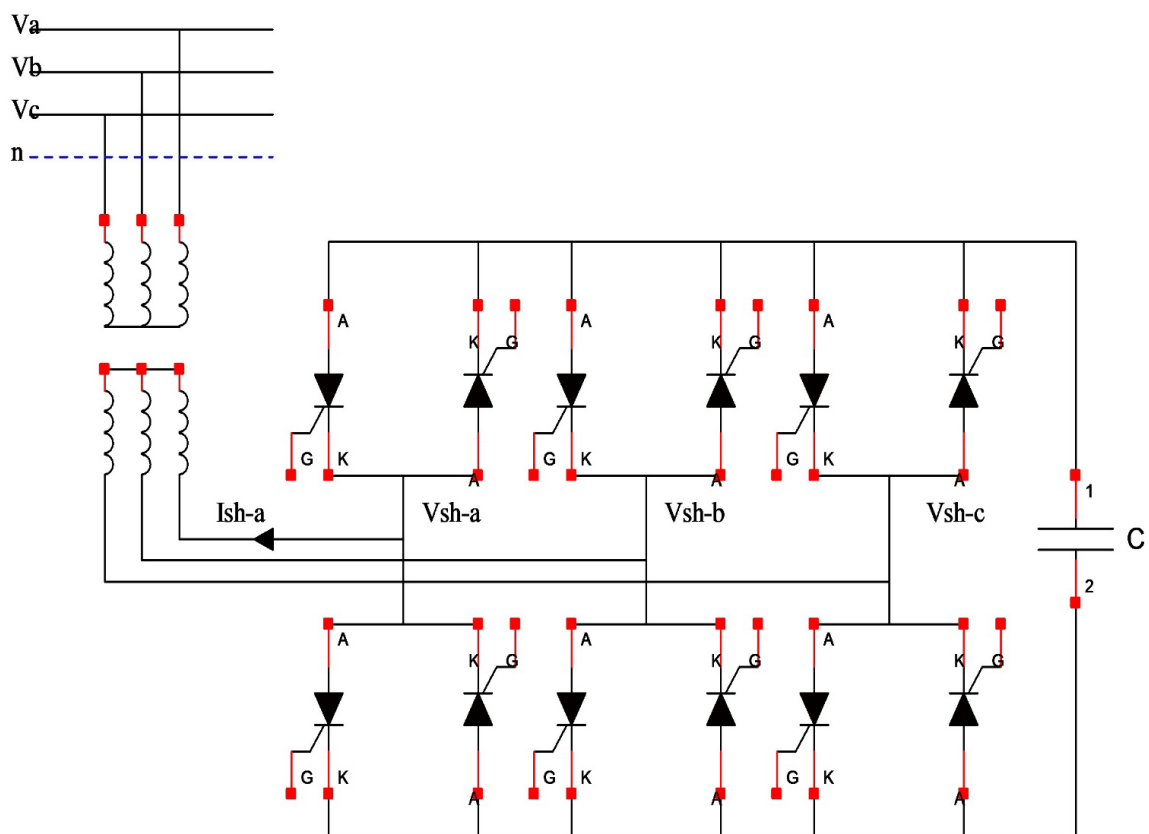


Figure 1. Schematic diagram of the STATCOM.

Function in Voltage and Reactive Power Regulation

The key functions of STATCOMs are as follows [10] [11]:

- Voltage Regulation

The STATCOM adjusts the grid voltage in real time by injecting or absorbing reactive power. This is particularly useful for maintaining voltage within acceptable ranges, especially during significant load variations or system failures:

$$V = V_0 + jX \cdot I_Q \quad (1)$$

where V is the regulated voltage, V_0 is the reference voltage, X is the reactive impedance, and I_Q is the reactive current injected or absorbed by the STATCOM.

- Reactive Power Compensation

It provides dynamic compensation of reactive power, thus helping to maintain the stability of the grid. This is essential for reducing the risk of overvoltage:

$$Q = V \cdot I_Q \quad (2)$$

where Q is the reactive power of the STATCOM.

3. Basic Principles of Power System Stabilizer

The Power System Stabilizer (PSS) is a device used to enhance the dynamic stability of electrical grids by reducing electromechanical oscillations that can occur after disturbances, such as line outages or load variations. It is typically installed in generator control systems to regulate reactive power and help maintain the generator's synchronization with the rest of the grid. The main components of a PSS are illustrated in **Figure 2** [12] [13]:

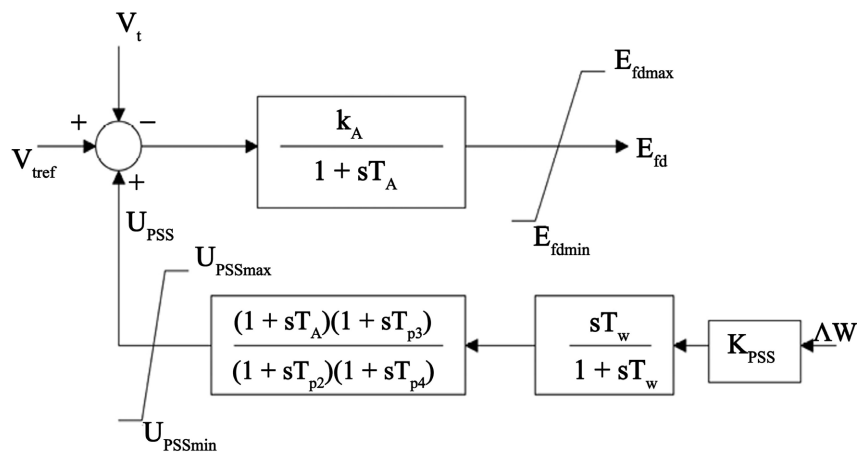


Figure 2. Power stabilizer.

- **Frequency Filter:** The PSS detects frequency variations using frequency filters, which isolate the frequencies of low-amplitude oscillations.
- **Signal Amplifier:** The filtered signal is then amplified and sent to the machine's control system to adjust the reactive power output.
- **Gain Control:** The PSS gain can be adjusted to modulate the intensity of the compensation based on the severity of the oscillation and the characteristics of

the grid.

4. Previous Studies on the Application of STATCOM and PSS

Recent studies have been conducted by various authors on the application of STATCOM in electrical networks, such as:

- **Voltage Profile Enhancement Using STATCOM in Power System Network (Satish Kumar, Lalit Kumar, Sanjay Kumar):** This book addresses how integrating a STATCOM into an electrical network helps stabilize voltage levels, particularly under variable load conditions. The authors may explore the benefits of using a STATCOM to minimize voltage fluctuations, improve power quality, and ensure a more reliable power distribution [14].
- **Voltage Regulation with STATCOM on a Distribution Network (Kamel Djamel Eddine Kerrouche *et al.*):** The D-STATCOM control method reduces harmonics and eliminates power oscillations, thereby improving network efficiency and decreasing voltage flicker [15].
- **Simultaneous Design of Fuzzy PSS and Fuzzy STATCOM Controllers for Power System Stability Enhancement:** The topic deals with the design of fuzzy PSS and STATCOM controllers to stabilize power grids, better managing uncertainties and variations to ensure reliable power supply [16].

5. Network Modeling

The schematic representation of the power grid, in a single-phase diagram created using the PSAT (Power System Analysis Toolbox) software of MATLAB, provides an overview of the main components of the network, helping to understand its layout and operation for electricity distribution across the country. The grid includes five power plants: the Congo Power Plant (CEC) in Pointe-Noire (node 1), the Imboulou Power Plant (node 34) in the Pool, the Djeno Power Plant (node 6) in Pointe-Noire, the Moukoulou Power Plant (node 19) in Bouenza, and the Djoué Power Plant (node 23) in the Pool, currently out of service. These plants are strategically placed to meet the country's energy needs while minimizing line losses. The network serves 22 loads distributed across the territory, requiring efficient management to ensure a stable and reliable supply. With 24 transmission lines connecting the plants to the loads, the network covers large distances, requiring careful management to ensure continuous distribution and minimize interruptions. Finally, the network is organized around 34 nodes, convergence points that allow for the redistribution of electricity. These nodes ensure a meshed network design, enhancing supply security in case of failures and allowing for electricity redirection to maintain service continuity.

6. Results

To begin our analysis, we first examine the behavior of the power grid in its natural state, without the influence of any regulation devices.

6.1. Analysis of the Power Grid without Regulation Devices

In order to assess the performance of the grid, we first present the voltage profile of the Congo power grid.

6.1.1. Voltage Profile of the Congo Power Grid

In this section, we analyze the system without regulation devices (STATCOMs), focusing on the dynamic behavior of the generating units and the resulting power flow. Load-flow analysis, performed using the Newton-Raphson method in MATLAB, provides voltage magnitudes, angles, power injections, transfers, and losses. The dominant electromechanical modes are identified using the first Lyapunov method by linearizing the system and extracting the eigenvalues of the state matrix. The voltage profile of all nodes in the grid is shown in **Figure 3**.

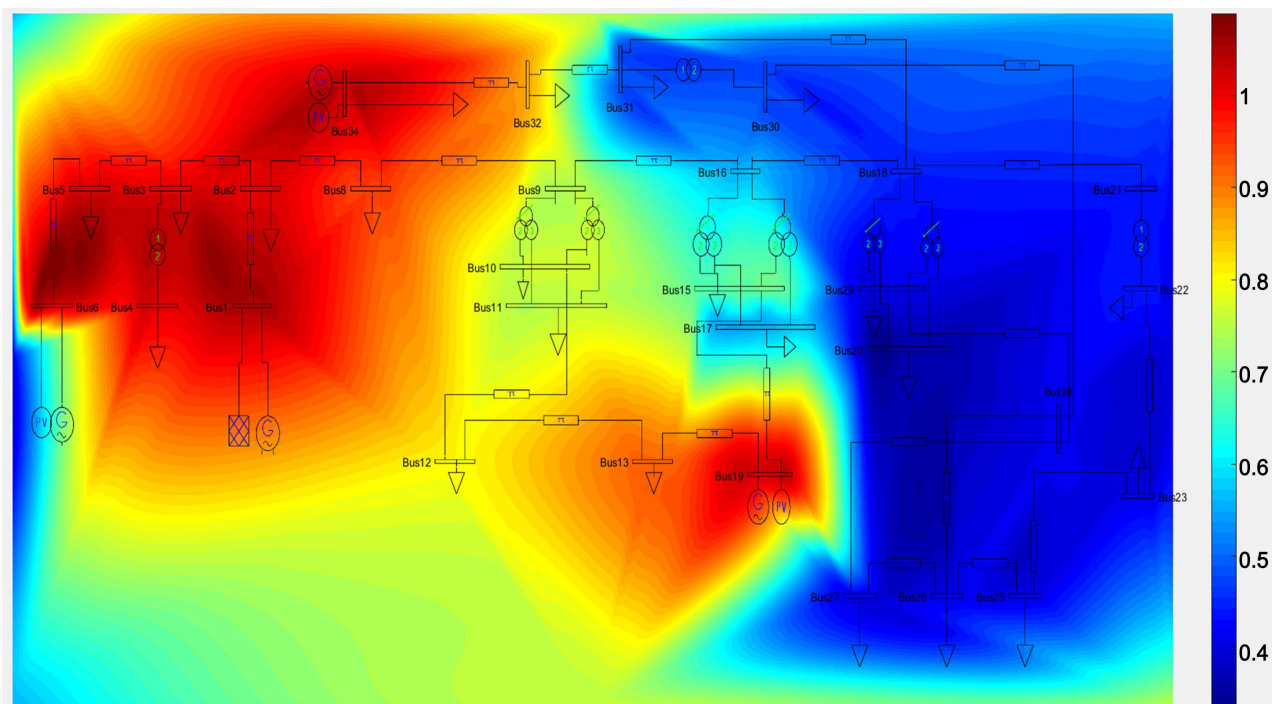


Figure 3. Thermal voltage profile of the nodes in the electrical network of the Republic of the Congo.

The thermal profile in **Figure 3** shows that the voltages vary across the nodes of the power grid. The voltages are within the acceptable range, especially in the Pointe Noire area and its surroundings, from the Congo Power Plant (CEC) at node (1) to Moukoulou at node (19), passing through Mindouli at node (9). However, the Brazzaville area, supplied from three (3) substations at 30 kV, namely Djiri at node (30), Tsielampo at node (18), and Mbouono at node (21), shows a blue thermal color, indicating voltages lower than the acceptable limit.

6.1.2. Dynamic Evolution of Various Network Parameters

Understanding the dynamics of a power grid is a key factor in controlling its stability. In order to stabilize the Republic of the Congo's power grid, we focused on

its essential parameters, namely the voltages at the generator nodes and the rotor angles of the generators.

- Voltages at Generator Nodes

The time evolution of the voltages at the various generator nodes of the Republic of the Congo's power grid, as obtained from the dynamic simulation carried out without the integration of the Power System Stabilizer (PSS), is presented in **Figure 4**. This simulation allows for the observation of the impact of voltage fluctuations at the generator level over time, providing an in-depth analysis of the grid's behavior under specific conditions.

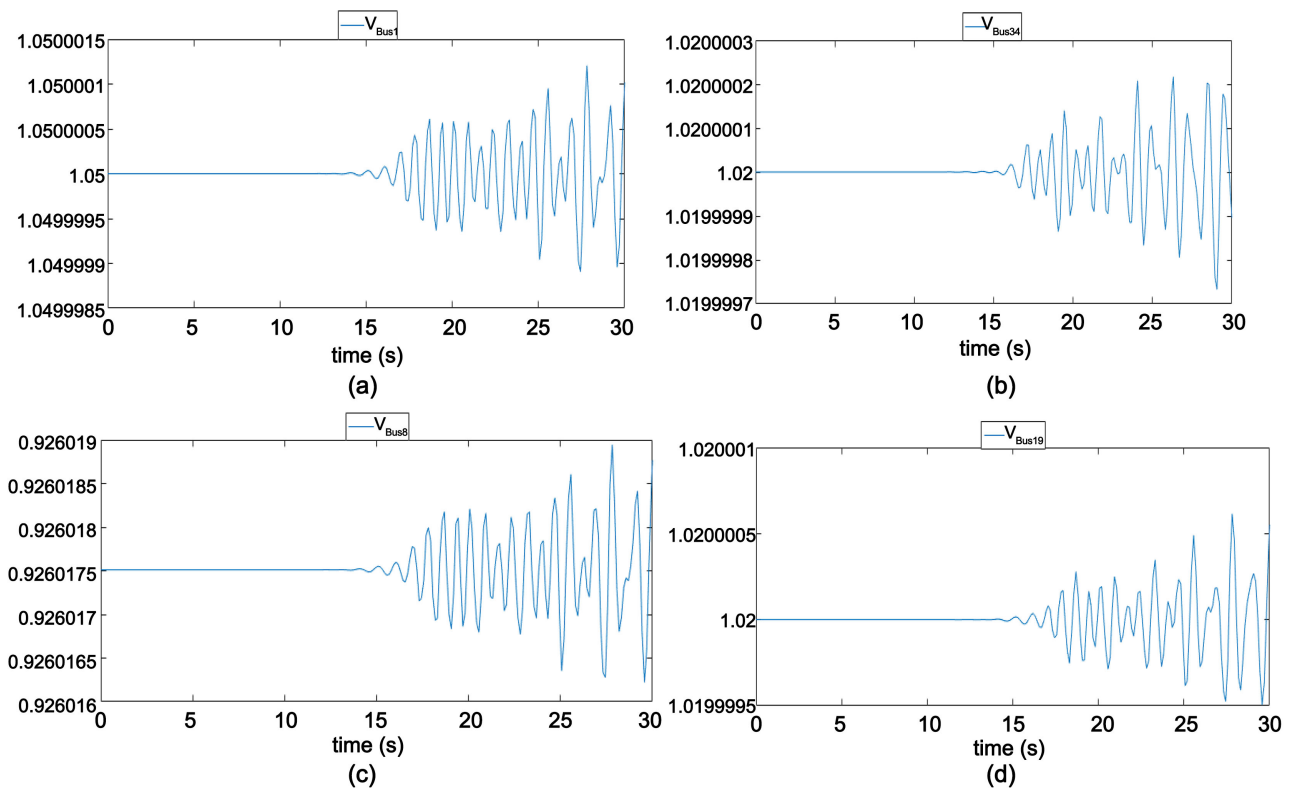


Figure 4. Voltage at the machine nodes. (a) CEC; (b) Imboulou; (c) Djeno; (d) Moukoulou.

It can be observed in **Figure 4** that the voltages at the machine nodes remain constant until $t = 15$ s. After that, the voltages become very unstable and continue to fluctuate over time. However, these fluctuations have relatively small amplitudes. This situation can be explained by a lack of regulation.

- Rotor Angles of the Generators

In **Figure 5**, we have represented the evolution of the rotor angle of each generator over time for the CEC, Imboulou, Djeno, and Moukoulou power plants.

- Oscillation Modes

The small signal theory, based on the first Lyapunov method, provides the necessary tools to identify the different interactions and oscillation modes present in the network. To obtain the eigenvalues of the state matrix of the Republic of the Congo's power grid, we simulated this network using the Power System Analysis

Toolbox (PSAT) in MATLAB. This approach allowed us to model the dynamic behavior of the grid and analyze its inherent characteristics. The results obtained from this simulation are presented in **Table 1** below, providing a detailed view of the oscillation modes and interactions that influence the stability of the grid under the specified conditions.

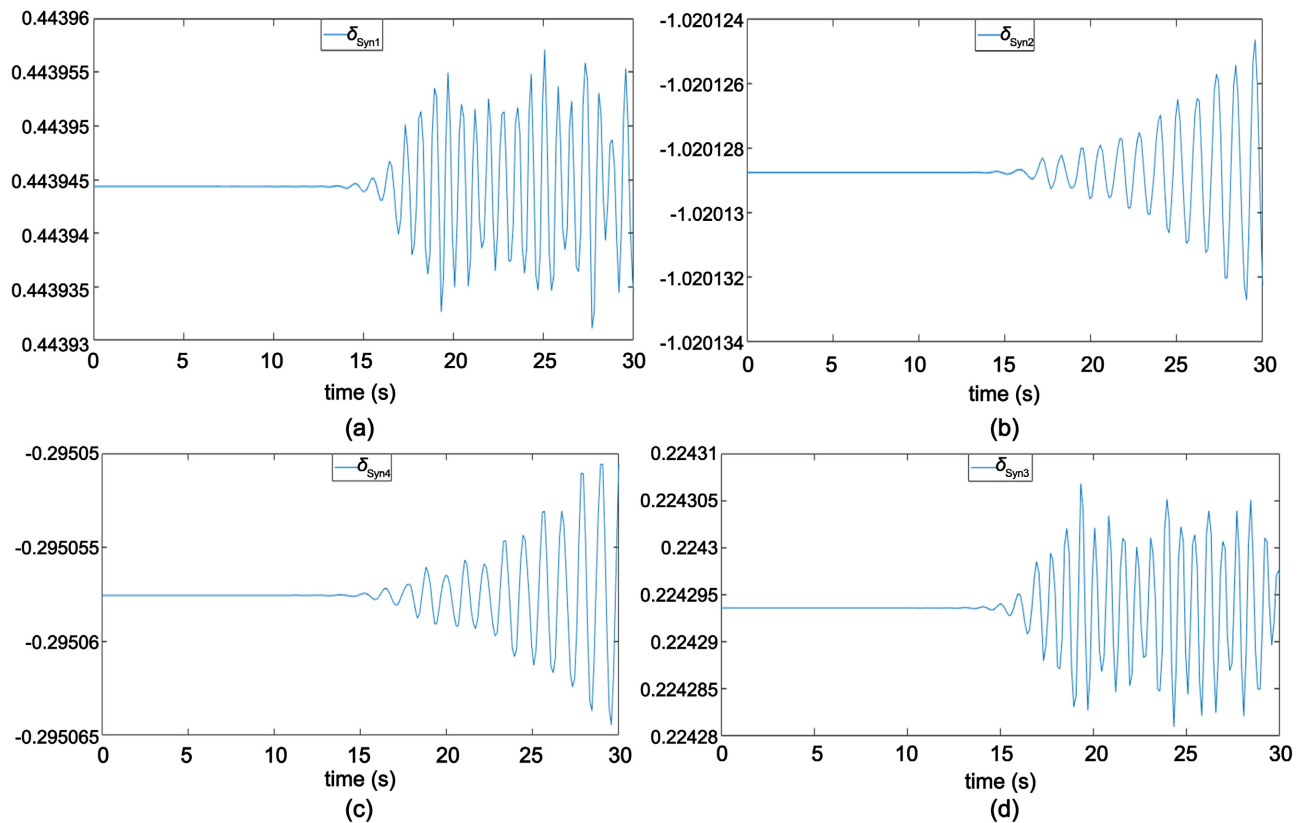


Figure 5. Rotor angle of the machines. (a) CEC; (b) Imboulou; (c) Djeno; (d) Moukoulou.

Table 1. Eigenvalues of the system without PSS.

Department/Power Plants	λ	Eigenvalues	Damping
Pointe Noire (Power Plant Djeno)	λ_1	-0.2827 ± 0.88218	0.3051
Bouenza (Power Plant Moukoulou)	λ_2	0.069914	
Pointe Noire (Power Plant CEC)	λ_3	-0.60953 ± 0.74551	0.6330
Bouenza (Power Plant Moukoulou)	λ_4	0.17047 ± 0.75999	-0.2189
Bouenza (Power Plant Moukoulou)	λ_5	0.066912	
Pointe Noire (Power Plants Djeno)	λ_6	0.56356	
Pool (Power Plant Imboulou). Pointe Noire (Power Plant Djeno)	λ_7	0.54215 ± 0.00028	-1
Pointe Noire (Power Plant CEC)	λ_8	0.026065	
Pointe Noire (Power Plant Djeno)	λ_9	0.023051	

Continued

Pool (Power Plant d'Imboulou)	λ_{10}	0.16771	
Pool (Power Plant Imboulou)	λ_{11}	-0.15781	
Pointe Noire (Power Plant CEC)	λ_{12}	0.01192	
Pointe Noire (Power Plant Djeno)	λ_{13}	-0.01271	
Bouenza (Power Plant Moukoulou)	λ_{14}	-1	
Pool (Power Plant Imboulou)	λ_{15}	-0.8887	
Pointe Noire (Power Plant CEC). Pointe Noire (Power Plant Djeno)	λ_{16}	-0.90657 ± 0.01699	0.9999
Pointe Noire (Power Plant Djeno). Bouenza (Power Plant Moukoulou)	λ_{17}	-0.97067 ± 0.00368	1

The results in **Table 1** show that the generator in the Pointe Noire department, specifically the Djeno generator, and the generator at the Imboulou power plant located at the boundary between the Plateaux department and the Pool department, participate in the interregional modes. The modes λ_4 and λ_7 have damping ratios of **-0.2189** and **-1**, respectively. These represent critical modes.

The previous analysis of the characteristics of the Republic of the Congo's power grid allows us to affirm that this grid is on the verge of instability, and the absence of control devices does not ensure stability. To guarantee the stability of the grid and improve its overall damping, we will add PSSs and STATCOMs.

6.2. Analysis of the Republic of the Congo's Power Grid with PSS and STATCOM

In this section, we aim to examine the dynamic operation of the Republic of the Congo's power grid in the presence of Power System Stabilizers (PSS) and STATCOMs. Based on the analysis of the eigenvalue results from the grid without control devices, we introduce three (3) PSSs at nodes (1) at the Congo Power Plant in the Pointe Noire department, node (6) at Djeno in the Pointe Noire (Kouilou) department, and node (34) at the Imboulou power plant in the Pool department.

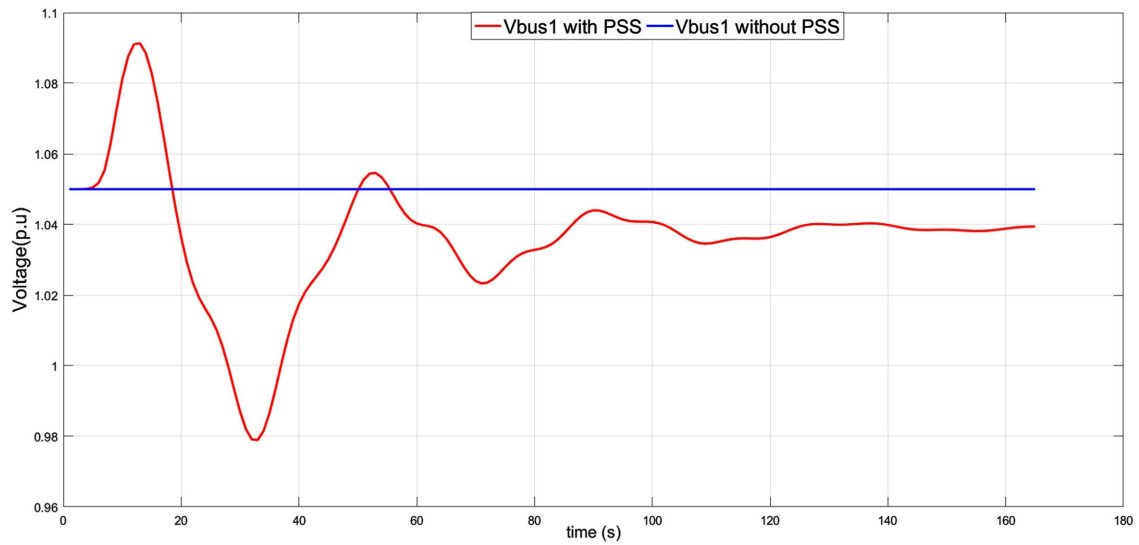
6.2.1. Dynamic Evolution of Various Parameters of the Power Grid with PSS

Following the same approach as in the case of the network without regulators, we will analyze the voltage at the generator nodes and the rotor angles of the generators.

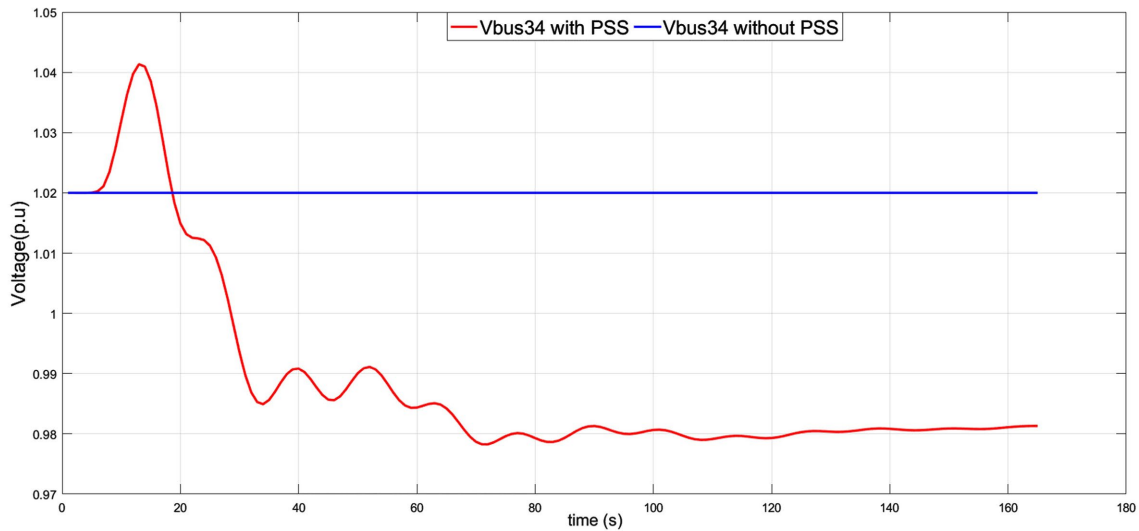
- Voltages at Generator Nodes

In this section, we focus on the evolution of the voltages at the machine nodes over time. The dynamic simulation of the Republic of the Congo's power grid with PSS was performed using the PSAT software.

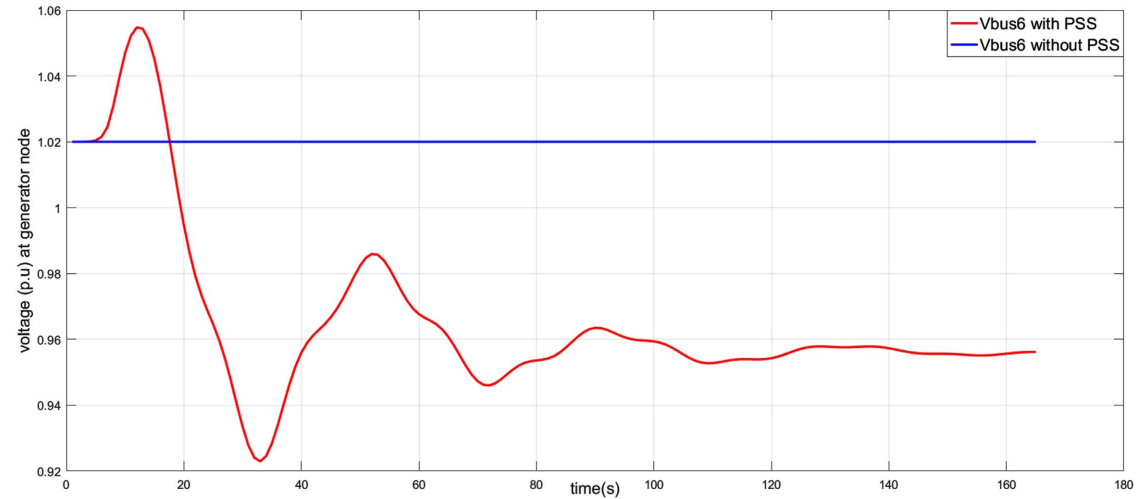
Figure 6 shows the evolution of the simulated voltages at the nodes with and without PSS at the Djeno power plant, Congo Power Plant, and Imboulou power plant.



(a)



(b)



(c)

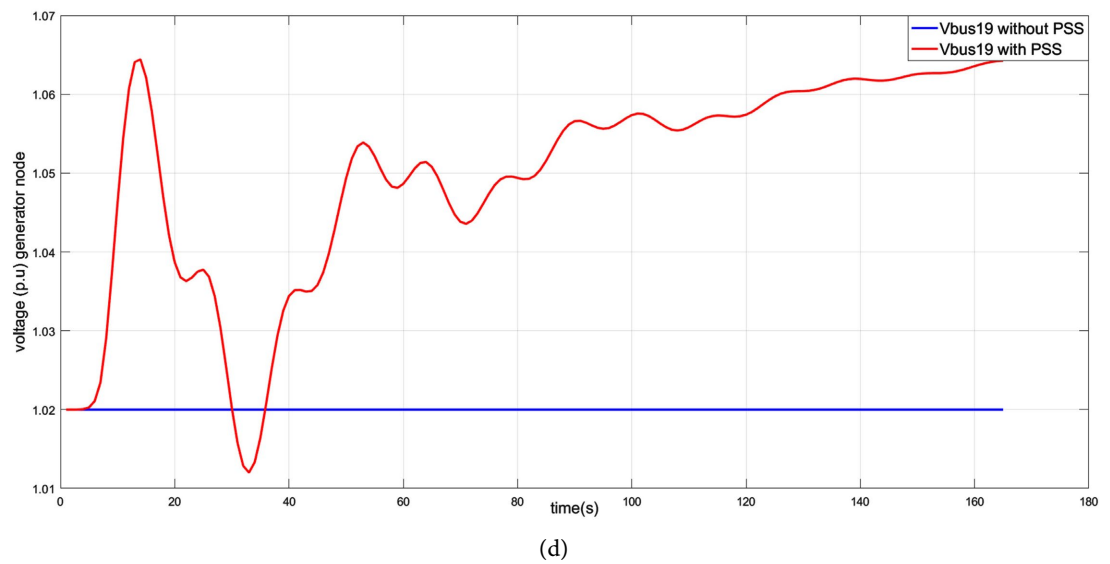
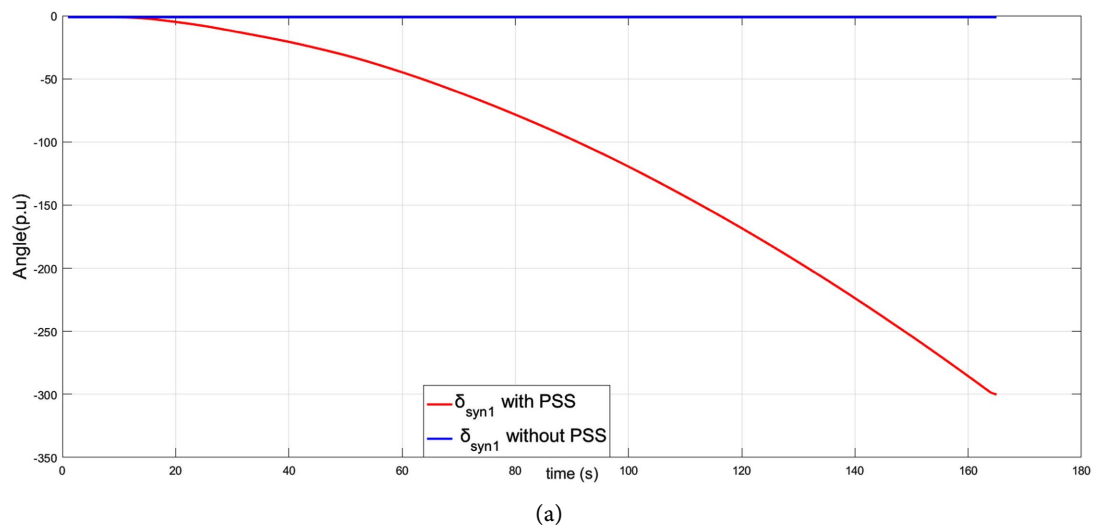
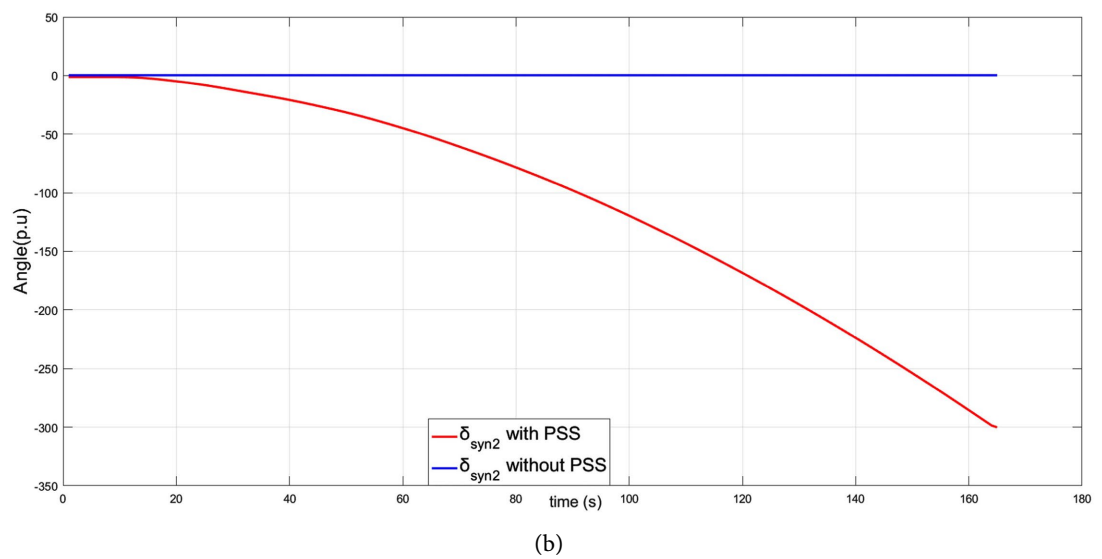


Figure 6. Voltage at the generator nodes. (a) CEC; (b) Imboulou; (c) Djeno; (d) Moukoukoulou.



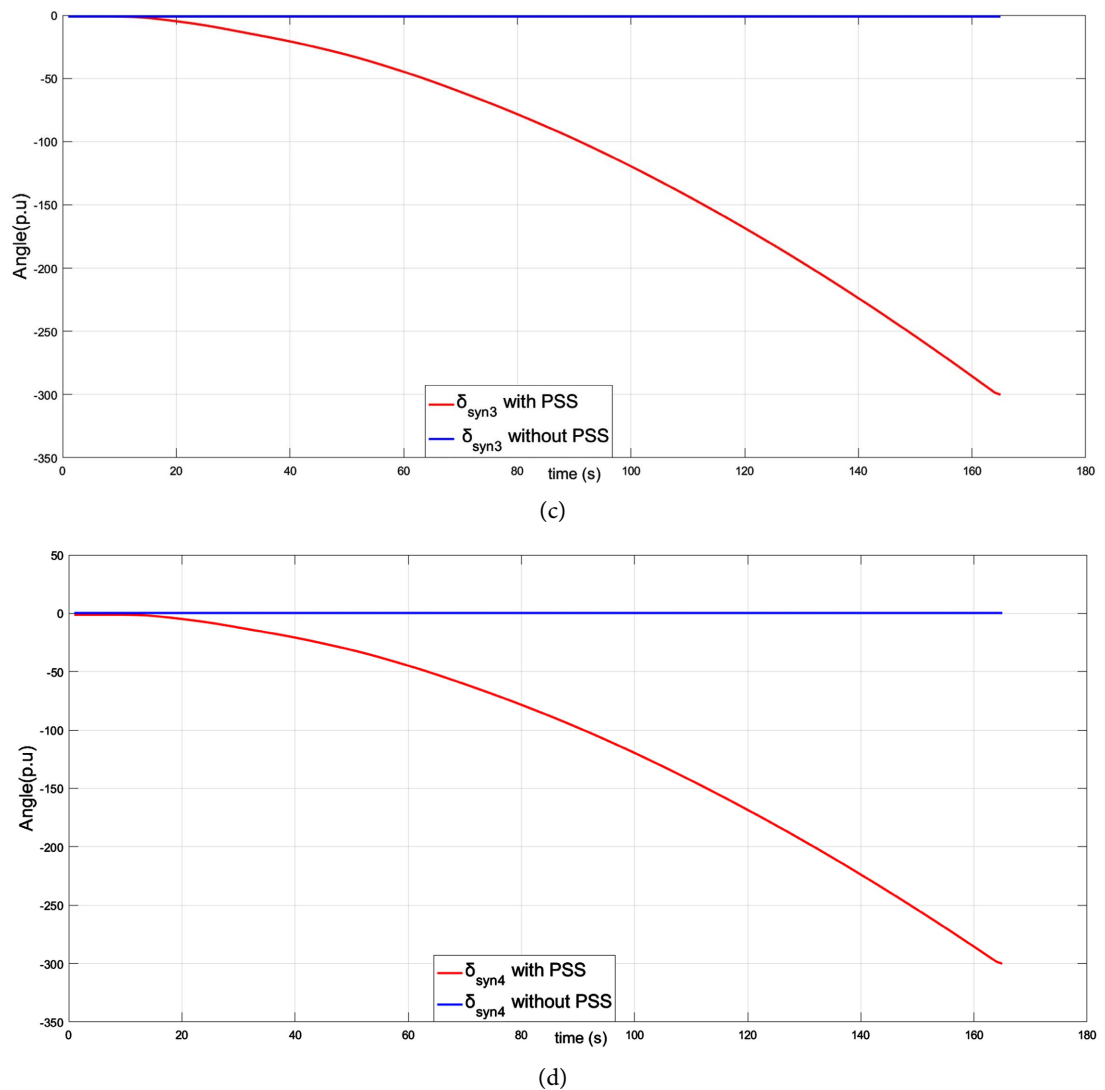


Figure 7. Rotor angles of the generators. (a) CEC; (b) Imboulou; (c) Djeno; (d) Moukoukoulou.

The generator bus voltages oscillate for a period of $t = 100$ s. After this time, they become practically stable. The effect of the insertion of the PSS is noticeable; in fact, in all four cases, a low-amplitude fluctuation of the voltages is observed around 1.1 p.u. and 0.96 p.u., corresponding respectively to 242 kV and 211 kV. Consequently, these voltages remain within the admissible range.

- Rotor Angles of the Generators

We also focused on the rotor angles. The evolution of the rotor angles for each generator with the PSS is shown in **Figure 7**.

The graph shows that the rotor angle with the PSS gradually decreases. Since the eigenvalue analysis does not reveal any unstable mode, this behavior does not correspond to linear instability. It is likely a poorly damped transient response or the result of an excessive PSS gain, which alters the rotor trajectory without causing growing oscillations.

- Oscillation Modes with PSS

Here, we apply the first Lyapunov method to determine the eigenvalues of the electrical network equipped with three PSS at nodes 1, 34, and 6. As before, we aim to determine the eigenvalues of the state matrix of the electrical network. The results obtained are presented in **Table 2** below.

Table 2. Eigenvalues of the system with PSS.

Department/Power Plants	λ	Real Part	Damping Ratio
Pointe Noire (Power Plant Djeno). Pool (Power Plant Imboulou)	λ_1	-0.5643 ± 0.7827	0.5848
Pointe Noire (Power Plant Djeno)	λ_2	-0.2335 ± 0.8806	0.2565
Bouenza (Power Plant Moukoulou)	λ_3	-0.1502 ± 0.7875	0.1874
Pool (Power Plant Imboulou)	λ_4	-0.8948 ± 0.3440	0.933
Pointe Noire (Power Plant Djeno)	λ_5	-0.8615 ± 0.2017	0.9742
Bouenza (Power Plant Moukoulou)	λ_6	-0.8846 ± 0.0858	0.9956
Pointe Noire (Power Plant CEC). Bouenza (Power Plant Moukoulou)	λ_7	-0.9114 ± 0.0162	1
Pointe Noire (Power Plant Djeno)	λ_8	-1	
Pool (Power Plant d'Imboulou)	λ_9	-0.1512	
Pointe Noire (Power Plant Djeno)	λ_{10}	-0.0144	
Pointe Noire (Power Plant CEC)	λ_{11}	-0.0140	
Pool (Power Plant Imboulou)	λ_{12}	-0.1632	
Pointe Noire (Power Plant Djeno)	λ_{13}	-0.2346	
Pointe Noire (Power Plant CEC)	λ_{14}	-0.2650	
Pool (Power Plant Imboulou)	λ_{15}	-0.5318	
Pointe Noire (Power Plant CEC)	λ_{16}	-0.5425	
Pointe Noire (Power Plant Djeno)	λ_{17}	-0.5626	
Bouenza (Power Plant Moukoulou)	λ_{18}	-0.6342	
Pool (Power Plant Imboulou)	λ_{19}	-0.698	

All oscillation modes have a damping ratio greater than zero, indicating good damping of the oscillations. However, two modes are weakly damped, namely λ_2 with a damping ratio of 0.2565, and λ_3 with a ratio of 0.1874.

- Improvement of Voltage Profile

Although the installation of Power System Stabilizers (PSS) significantly improved the network's performance in terms of power stability, the voltage profile, particularly in Brazzaville, remained below the permissible range of $-10\% U_n$ [IEC 60,038, 2009]. To further enhance voltage stability across the Congolese power network, two STATCOM devices were added: one at node 25, representing substation (A) in the 2nd district (Baongo), and another at node 29, corresponding to the Tsielampo substation in the 7th district (Mfilou). The placement of the PSS was guided by the identification of the most heavily loaded generators, namely

CEC, Djéno, and Imboulou. The STATCOM locations were determined based on the most heavily loaded nodes with the lowest voltages, 12.318 kV at node 25 and 12.204 kV at node 29, while the nominal voltage of these nodes is 30 kV. Following the previous methodology, the network was then characterized with a total of five regulation devices, comprising three PSS and two STATCOMs. The results of the thermal voltage profile for all network nodes are shown in **Figure 8**.

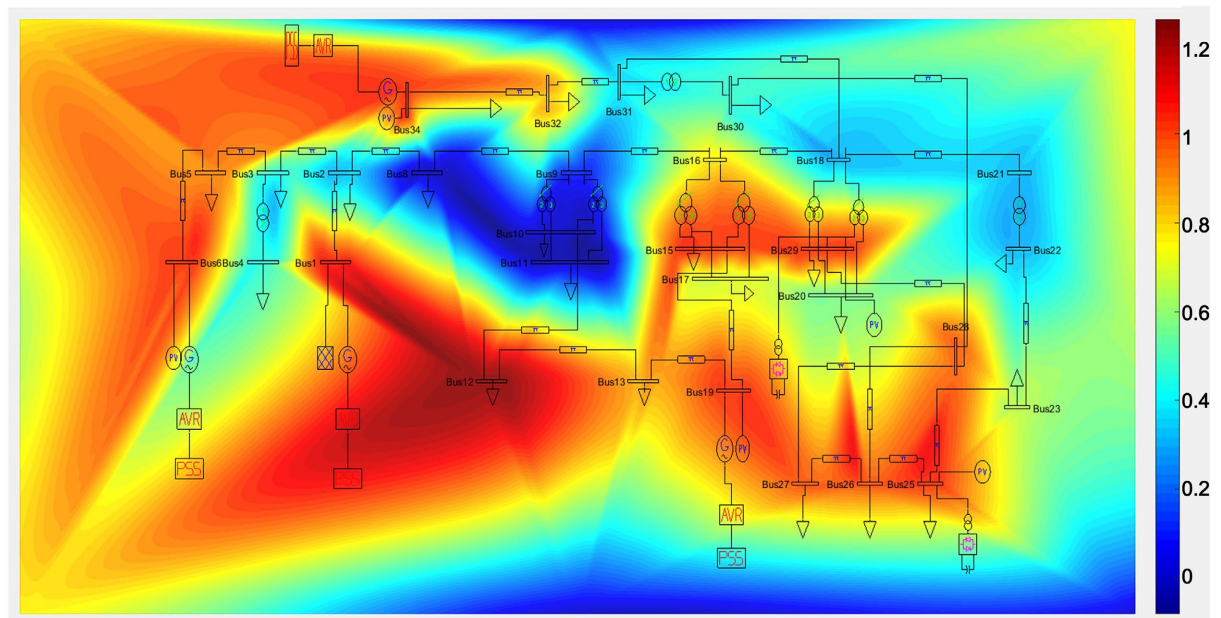


Figure 8. Thermal voltage profile of the nodes in the electrical network of the Republic of the Congo with PSS-STATCOM.

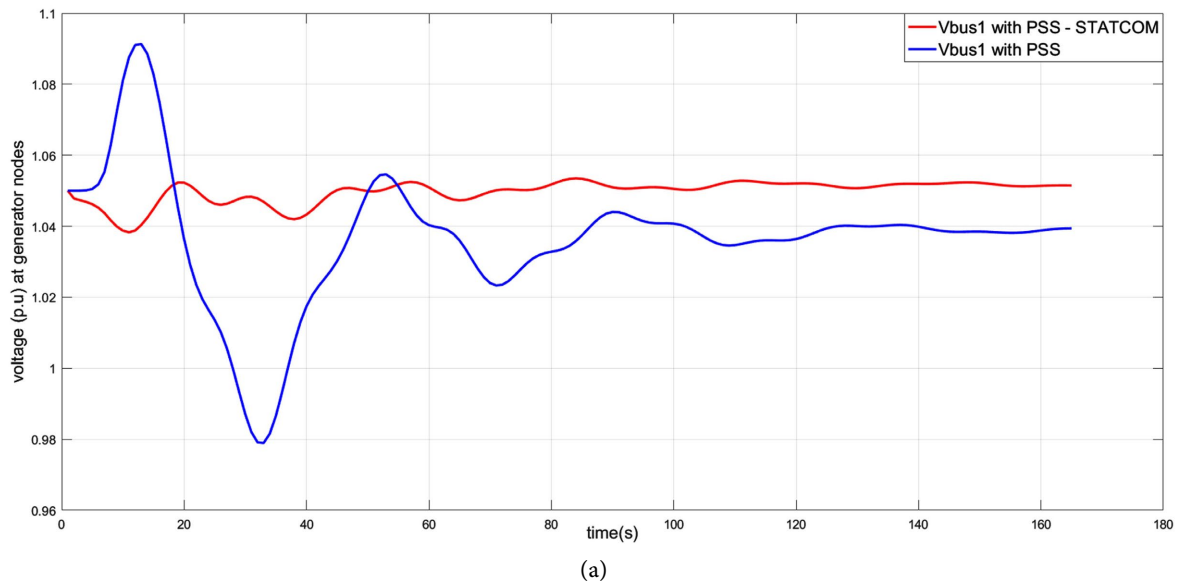
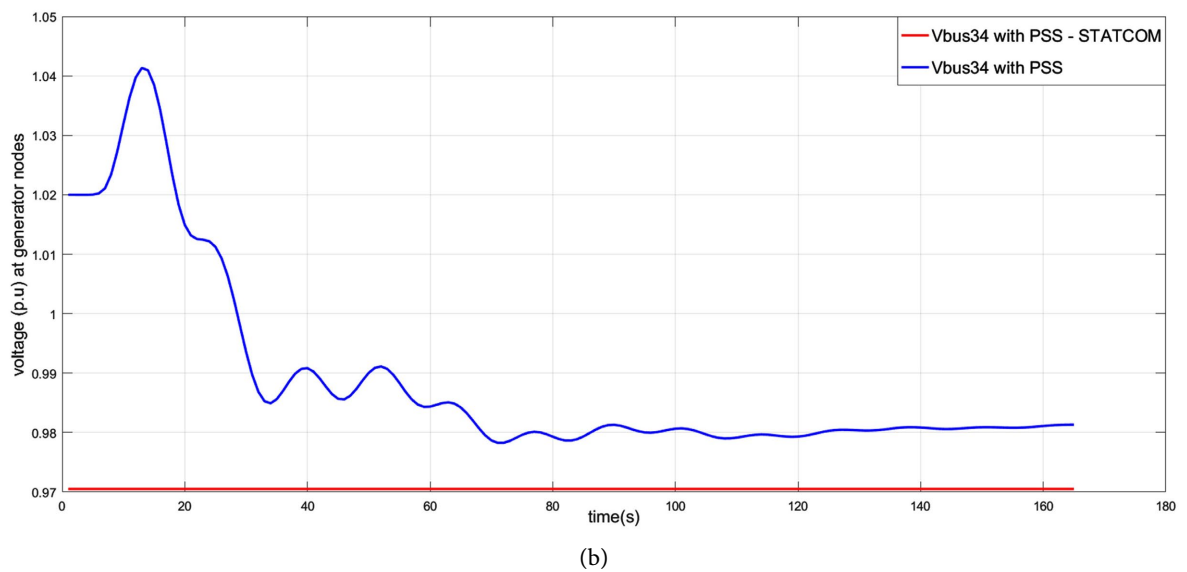
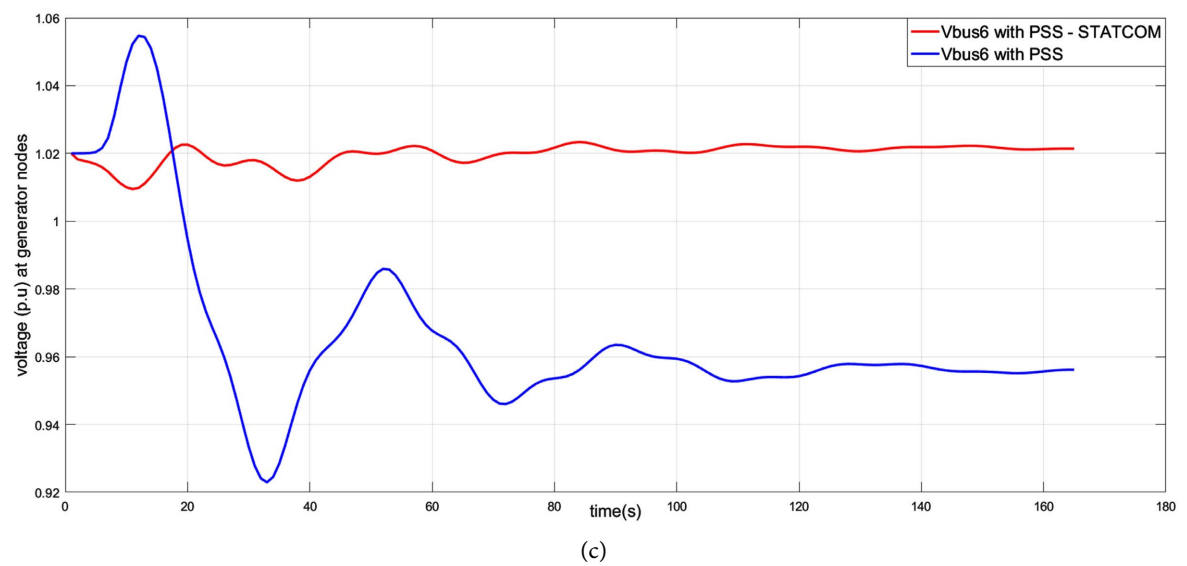
Figure 8 shows that the voltages in the Brazzaville area, supplied at 30 kV, now display a thermal profile characterized by bright colors (yellow, red, orange). This coloring indicates that voltages remain within the admissible $\pm 10\%$ U_n range relative to the nominal voltage of 30 kV.

After the insertion of the STATCOM devices, the extreme voltages in this area range from 0.891 p.u. (26.7 kV) at node 30 in Djiri to 1.02 p.u. (30.6 kV) at node 25 at substation A. These results demonstrate a significant improvement in voltage, bringing it closer to the levels required for optimal power supply. The STATCOM devices not only stabilize the connection node but also have an effect on neighboring nodes.

However, in the Pointe Noire area, from Loudima at node 9 to Mongokamba 1 at node 3, a voltage drop is observed compared to the case without STATCOM integration. In the Bouenza department, a voltage peak was observed at Nkayi, node 12, where the voltage reaches 1.227 p.u. (135 kV) on a network with a nominal voltage of 110 kV.

6.2.2. Dynamic Evolution of Various Parameters with PSS-STATCOM

Using the same approach as for the network without control devices, we will analyze the voltage at the generator nodes and the rotor angles of the generators.



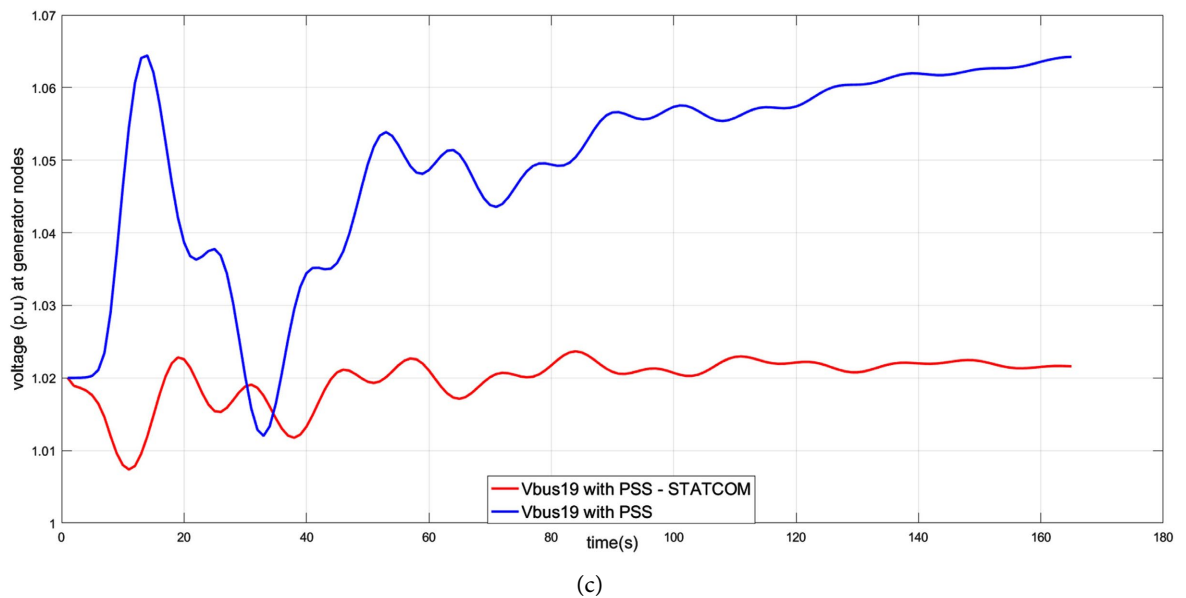
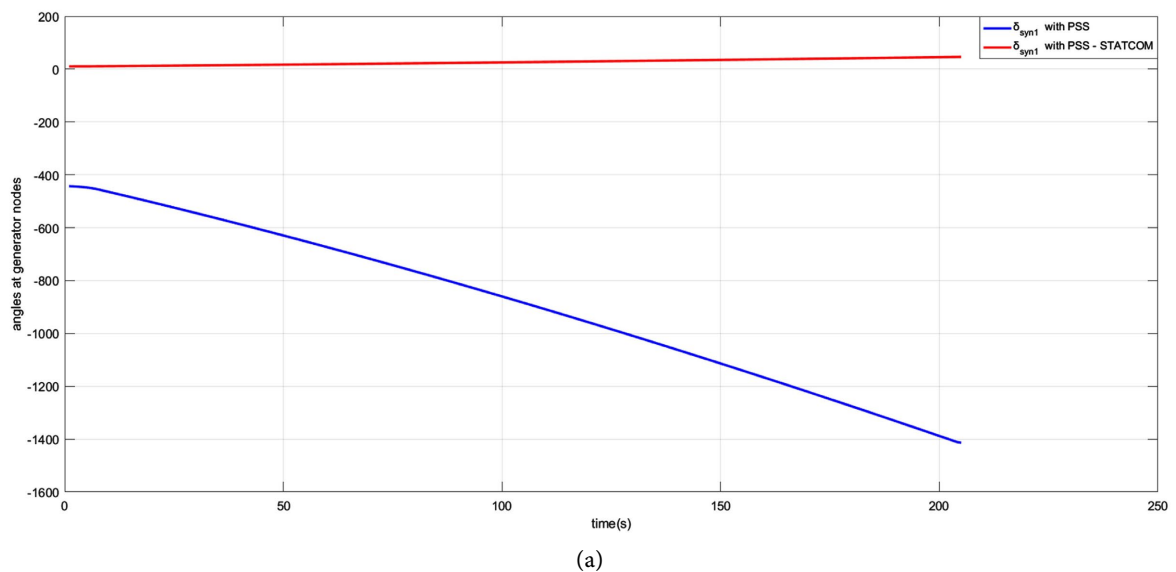


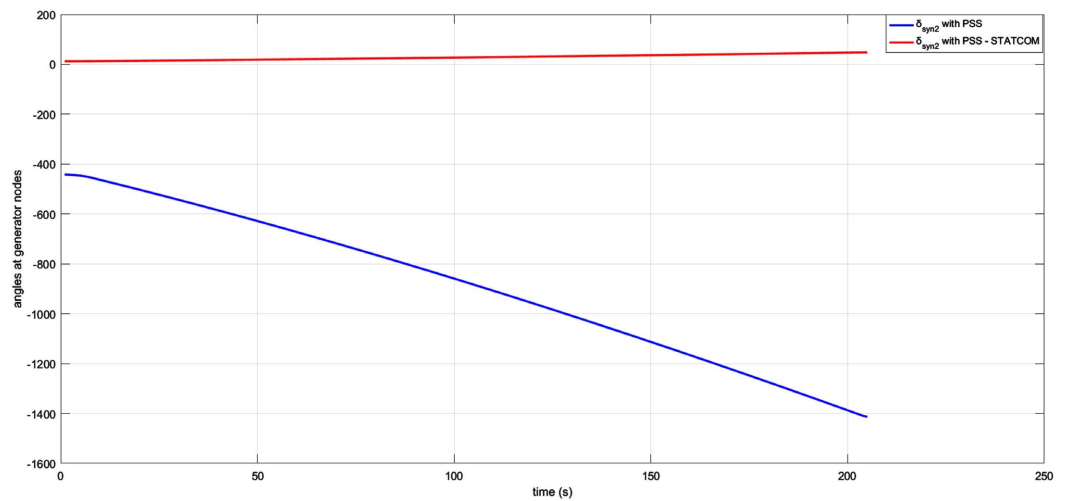
Figure 9. Voltages at the generator nodes with PSS-STATCOM. (a) CEC; (b) Imboulou; (c) Djeno; (d) Moukouloulou.

- Voltage at the Generator Nodes

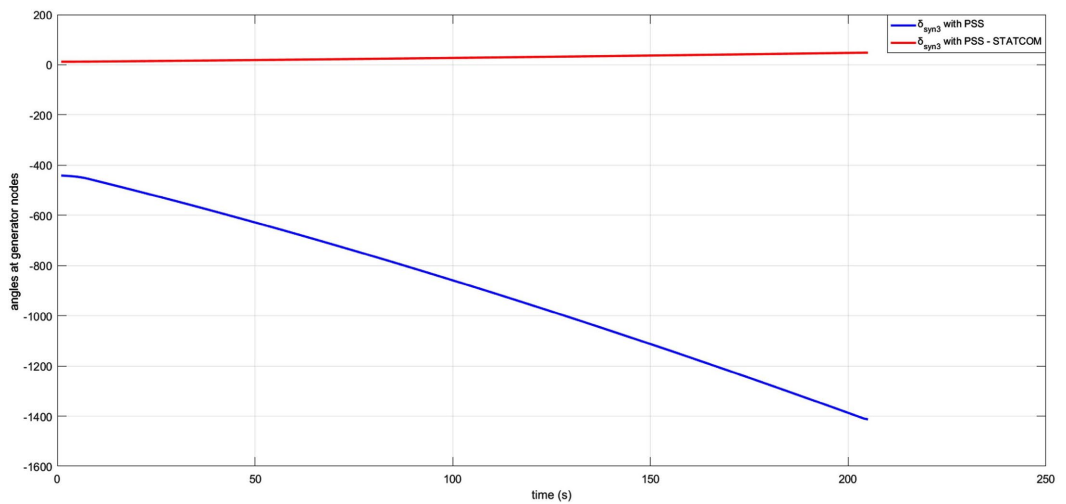
In this section, we focus on the evolution of the voltage at the generator nodes over time. The dynamic simulation of the electrical network of the Republic of the Congo with PSS-STATCOM was performed using the PSAT software.

In **Figure 9**, the generator bus voltages with the combined PSS-STATCOM configuration are presented. It can be observed that the voltages at these generator nodes are stable and remain nearly constant. The effect of the STATCOM devices is clearly noticeable. In all four cases, voltage stabilization occurs around 1.05057 p.u. (231.13 kV) for the Congo Power Plant (CEC), 1.02027 p.u. (224.46 kV) for Imboulou, 0.97051 p.u. (213.51 kV) for Djeno, and 1.02051 p.u. (112.26 kV) for Moukouloulou.

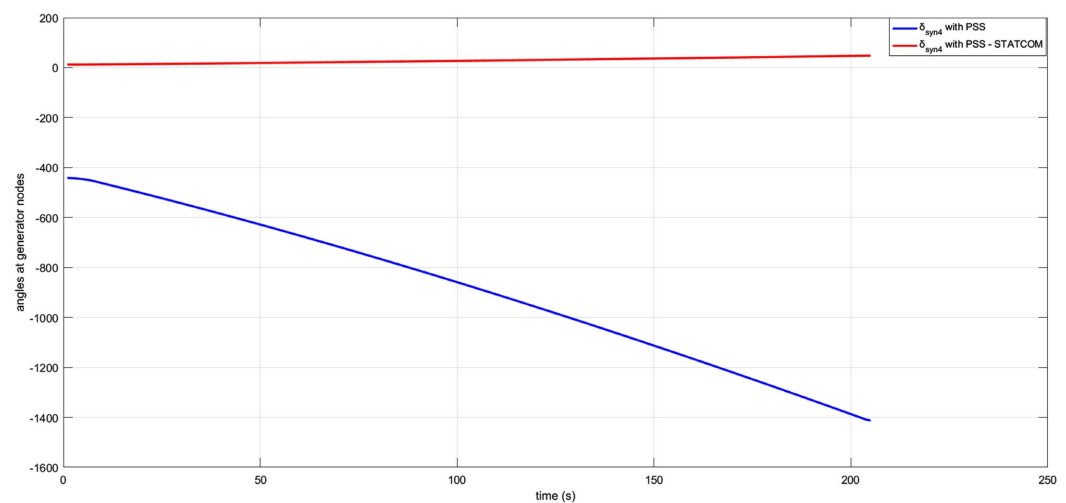




(b)



(c)



(d)

Figure 10. Rotor angles at the generator nodes with PSS-STATCOM. (a) CEC; (b) Imboulou; (c) Djeno; (d) Moukoulou.

- Rotor Angles of the Generators

The evolution of the rotor angles for each generator is shown in **Figure 10**.

Figure 10 shows that the rotor angles at the generator nodes are nearly identical and decrease similarly in the presence of only the PSS devices. However, they remain practically constant when the STATCOM devices are added. This is likely because FACTS STATCOM devices influence the rotor angles of synchronous generators by regulating voltage, reducing the reactive power load on the generators, and modifying the dynamic characteristics of the power network.

- Modes of Oscillation with PSS-STATCOM

As previously, we propose to determine the eigenvalues of the state matrix of the electrical network as well as the participation factors. To do this, we will follow the same approach used for the network with PSS to determine the eigenvalue modes of the electrical network equipped with three PSS at nodes 1, 34, and 6, as well as two STATCOMs at nodes 26 and 29. By simulating the electrical network equipped with three PSS and two STATCOMs using the PSAT software, we obtained the results presented in the following **Table 3**.

Table 3. Eigenvalues of the system with PSS-STATCOM.

Department/Power Plants	λ	Eigenvalues	Damping
Pointe Noire (Power Plant Djeno)	λ_1	-50	
Pointe Noire (Power Plant CEC)	λ_2	-50	
Pointe Noire (Power Plant CEC)	λ_3	-0.1	
Pointe Noire (Power Plant Djeno)	λ_4	-50	
Pointe Noire (Power Plant Djeno)	λ_5	-0.1	
Pool (Substation B)	λ_6	-61.8012	
Pool (Power Plant Imboulou)	λ_7	-32.0303	
Bouenza (Power Plant Moukoulou)	λ_8	-48.2206	
Pool (Power Plant Imboulou)	λ_9	-186.584	
Pool (Power Plant Imboulou)	λ_{10}	-47.4372 ± 6.5514	0.99
Bouenza (Power Plant Moukoulou)	λ_{11}	-42.7882	
Pointe Noire (Power Plant Djeno)	λ_{12}	-44.4346	
Pool (Substation Tsielampo). Pointe Noire (Power Plant CEC)	λ_{13}	-27.0381 ± 1.0147	0.99
Pool (Power Plant Imboulou)	λ_{14}	-8.9968	
Pointe Noire (Power Plant Djeno)	λ_{15}	-20.1851	
Pointe Noire (Power Plant CEC)	λ_{16}	-13.7822	
Pointe Noire (Power Plant Djeno)	λ_{17}	-8.8896	
Pointe Noire (Power Plant CEC)	λ_{18}	-8.3479	
Pointe Noire (Power Plant CEC). Pointe Noire (Power Plant Djeno)	λ_{19}	3.2115	-1
Pointe Noire (Power Plant Djeno)	λ_{20}	-2.6434	

Continued

Pointe Noire (Power Plant CEC)	λ_{21}	-0.2545 ± 1.63279	0.153
Pool (Power Plant Imboulou)	λ_{22}	-0.7372	
Pointe Noire (Power Plant Djeno)	λ_{23}	-1.4716	
Pointe Noire (Power Plant CEC)	λ_{24}	-0.95976	
Bouenza (Power Plant Moukoulou)	λ_{25}	-0.3911	
Pointe Noire (Power Plant Djeno)	λ_{26}	-0.15291	
Pointe Noire (Power Plant CEC)	λ_{27}	-0.19425	
Pointe Noire (Power Plant CEC)	λ_{28}	-0.0074	

The characteristics of these power plants and parameters of the regulation systems are presented in **Table A1** and **Table A2** in **Appendix**.

Table 3 above shows the eigenvalues of the state matrix of the electrical network of the Republic of the Congo in the presence of Power System Stabilizers (PSS) and FACTS STATCOM devices. It can be observed that there is an unstable oscillation mode $\lambda_{19} = 3.2115$ and a weakly damped mode, namely $\lambda_{21} = -0.2545 \pm 1.63279$.

7. Discussion

Results show that, without control devices, several nodes exhibit significant voltage deficits: 10.97 kV at node 20 (Tsielampo) and 14.55 kV at node 30 (Djiri) for a nominal voltage of 30 kV, with an unstable mode at the Moukoulou generator (node 19). The addition of PSS at nodes 1, 6, and 34 reduces fluctuations, with voltages around 242 kV and 211 kV and lightly damped modes (damping ratios of 0.256 at Djéno and 0.187 at Moukoulou), confirming their effectiveness, in line with Alkhatib [12]. The combined integration of PSS and two STATCOM devices at nodes 25 and 29 further stabilizes the network: Brazzaville voltages are within $\pm 10\%$ of 30 kV, ranging from 26.7 kV at node 30 (Djiri) to 30.6 kV at node 25 (substation A), while Nkayi in Bouenza shows a voltage peak of 135 kV for a node with a nominal voltage of 110 kV. Generator voltages stabilize around 231.13 kV (CEC), 224.46 kV (Imboulou), 213.51 kV (Djéno), and 112.26 kV (Moukoulou). The unstable mode ($\lambda_{19} = 3.2115$) only appears after the joint addition of the PSS and STATCOM, suggesting that it arises from their interaction ($\lambda_{19} = 3.2115$, damping ratio -1), as observed by Passelergue [12]. From a practical perspective, the appearance of this unstable mode indicates that the electrical system may experience growing oscillations when subjected to certain disturbances, even after the installation of stabilization devices such as the PSS and STATCOM. This can compromise network stability, causing voltages and currents to become unstable and potentially disrupting service continuity, while also increasing mechanical or electrical stress on generators and other connected equipment. To mitigate these risks, it is essential to perform coordinated tuning of the PSS and STATCOM parameters using methods such as Fuzzy Logic, Genetic Algorithms, etc., to pre-

vent mutual interference, and to carefully review the placement and configuration of these devices to minimize the emergence of unstable modes.

8. Conclusion

Our work, conducted within the framework of power system stability analysis, focused on the impact of FACTS devices on voltage stability in the electrical network. We specifically examined the influence of integrating STATCOM devices into the power network of the Republic of the Congo. The main objective was to analyze the effects of STATCOM FACTS devices in the presence of Power System Stabilizers (PSS) within the operation of the Congolese electrical network. To achieve this, we performed a stability analysis of the network using the first Lyapunov method, based on the eigenvalue analysis of the network's admittance matrix. This method proved effective in studying the characteristics of the Republic of the Congo's electrical network.

Author Contributions

Mavie Grâce Mimiesse: Conceived and wrote the manuscript, conducted the data collection, and developed the model, including its modeling and simulation.

Rostand Martialy Davy Loembe Souamy: Translated the manuscript into English.

Smaël Magloire Elombo Motoula: Contributed to the review and revision of the manuscript, particularly by checking and correcting the mathematical equations and verifying their consistency with the proposed model.

Désiré Lilonga-Boynga: As the scientific supervisor, coordinated the research activities, provided scientific guidance and research directions, and supervised the overall development of the study. All authors reviewed and approved the final version of the manuscript.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

- [1] Hassan, H.A., Osman, Z.H. and Lasheen, A.E. (2014) Sizing of STATCOM to Enhance Voltage Stability of Power Systems for Normal and Contingency Cases. *Smart Grid and Renewable Energy*, **5**, 8-18. <https://doi.org/10.4236/sgre.2014.51002>
- [2] Naganathan, A. and Ranganathan, V. (2016) Improving Voltage Stability of Power System by Optimal Location of FACTS Devices Using Bio-Inspired Algorithms. *Circuits and Systems*, **7**, 805-813. <https://doi.org/10.4236/cs.2016.76069>
- [3] Kaxramon Raximovich, A. and Tokhir Farkhadovich, M. (2018) Analysis of Small Oscillations in Complex Electric Power Systems. *Engineering*, **10**, 253-261. <https://doi.org/10.4236/eng.2018.105017>
- [4] Ramasamy, K. (2016) Comparison and Performance Analysis of FACTs Controller in System Stability. *Circuits and Systems*, **7**, 2948-2958. <https://doi.org/10.4236/cs.2016.710253>

- [5] Zuniga-Haro, P. and Ramirez, J.M. (2010) Modeling of Multi-Pulse VSC Based SSSC and STATCOM. *Journal of Electromagnetic Analysis and Applications*, **2**, 145-161.
- [6] Badiane, M., Fall, W., Kouyate, M. and Barro, F.I. (2024) Study and Production of a Two-Stage DC/DC DC/AC Converter for Generating an Alternating Voltage from a Direct Voltage Supplied by a Photovoltaic Array. *Circuits and Systems*, **15**, 45-55. <https://doi.org/10.4236/cs.2024.154004>
- [7] Tehero, R. (2021) Determinants of the Access to Electricity: The Case of West African Power Pool Countries. *Open Access Library Journal*, **8**, 1-23. <https://doi.org/10.4236/oalib.1107223>
- [8] Benaissa, O.M., Hadjeri, S. and Zidi, S.A. (2016). Impact of PSS and SVC on the Power System Transient Stability. 2016 8th International Conference on Modelling, Identification and Control (ICMIC), Algeria, 15-17 November 2016, 303-307. <https://doi.org/10.1109/icmic.2016.7804127>
- [9] Lee, S.-D., Kim, C.-K., Kim, J.-Y. and Sim, E.-B. (2011) Stability Enhancement in HVDC System with STATCOM. *Engineering*, **3**, 1072-1081.
- [10] Callavik, M., Blomberg, A. and Leksell, M. (2012) The Hybrid STATCOM: An Innovation Breakthrough Realized. ABB Grid Systems Technical Paper.
- [11] Belhamidi, M., Lakdja, F., Guentri, H., Boumediene, L. and Yahiaoui, M. (2023) Reactive Power Control of D-STATCOM in a Power Grid with Integration of the Wind Power. *Journal of Electrical Engineering & Technology*, **18**, 205-212. <https://doi.org/10.1007/s42835-022-01215-y>
- [12] Mimiesse, M.G., Souamy Loembe, D.R., Motoula, S.M.E. and Lilongo-Boyenga, D. (2024) Coordination of Regulation Devices for Damping Power Oscillations in a Dynamic Disturbance Context: A Fuzzy Logic-Based Approach Applied to the Electrical Grid of the Republic of Congo. *Journal of Power and Energy Engineering*, **12**, 44-60. <https://doi.org/10.4236/jpee.2024.121004>
- [13] Sun, X.M. (2019) Analysis on Sensitivity of Power System Stability to Generator Parameters. *Journal of Power and Energy Engineering*, **7**, 165-182.
- [14] Kumar, S., Kumar, L. and Kumar, S. (2022) Voltage Profile Enhancement Using STATCOM in Power System Network. In: Gupta, O.H., Sood, V.K. and Malik, O.P., Eds., *Recent Advances in Power Systems: Select Proceedings of EPREC-2021*, Springer, 537-547. https://doi.org/10.1007/978-981-16-6970-5_39
- [15] Kerrouche, K.D.E., Lodhi, E., Kerrouche, M.B., Wang, L., Zhu, F. and Xiong, G. (2020) Modeling and Design of the Improved D-STATCOM Control for Power Distribution Grid. *SN Applied Sciences*, **2**, Article No. 1519. <https://doi.org/10.1007/s42452-020-03315-8>
- [16] Ansari, J., Abbasi, A.R., Heydari, M.H. and Avazzadeh, Z. (2022) Simultaneous Design of Fuzzy PSS and Fuzzy STATCOM Controllers for Power System Stability Enhancement. *Alexandria Engineering Journal*, **61**, 2841-2850. <https://doi.org/10.1016/j.aej.2021.08.007>

Appendix

Table A1. Data on power generators of the Republic of the Congo power grid.

Data on Power Generators							
Node Number	R_a	X_d	X'_d	T'_{d0}	X_q	H	D
1 (CEC)	0	2.42	0.238	10.8	2.253	5.09	0
34 (Imboulou)	0	1.004	0.294	4.5434	0.644	6	0
6 (Djéno)	0	2.02	0.198	6.9	1.9	5	0
19 (Moukouloulou)	0	1.149	0.283	5	0.8	6	0

Table A2. Parameters of the regulation systems.

Power System Stabilizers (PSS)	$K_{PSS} = 4$	$T_1 = 0.5$ s	$T_2 = 0.5$ s	$T_3 = 0.5$ s	$T_4 = 0.5$ s
Excitation System	$K_A = 200$	$T_A = 0.02$ s			
STATCOM	$K_P = 0.8$	$K_I = 50$	$T_1 = 0.2$ s	$T_2 = 0.1$ s	

The linear model of a multi-machine network without control devices is presented as follows.

$$\Delta \dot{\delta}_i = \Delta \omega_i \quad (3)$$

$$\Delta \dot{\omega}_i = \frac{1}{M_i} \Delta T_{Mi} - \frac{E'_{qi}}{M_i} \Delta I_{qi} + \frac{X'_{di} I_{di}}{M_i} \Delta I_{qi} + \frac{X'_{di} I_{di}}{M_i} \Delta I_{di} - \frac{I_{qi}}{M_i} \Delta E'_{qi} - \frac{X'_{qi} I_{di}}{M_i} \Delta I_{qi} - \frac{X'_{qi} I_{qi}}{M_i} \Delta I_{di} \quad (4)$$

$$\Delta \dot{E}'_{qi} = -\frac{\Delta E'_{qi}}{T'_{di}} - \frac{(X_{di} - X'_{di}) \Delta I_{di}}{T'_{di}} + \frac{\Delta E_{fdi}}{T'_{di}} \quad (5)$$

$$\Delta \dot{E}_{fdi} = \frac{1}{T_{Ai}} \left[-\Delta E_{fdi} + K_{Ai} V_{ref} - K_{Ai} \right] \quad (6)$$

The state variables of the multi-machine network model with PSS and a STATCOM controller are thus given by:

$$\Delta X_i = \left[\Delta \delta_i \quad \Delta \omega_i \quad \Delta E'_{qi} \quad \Delta E_{fdi} \quad \Delta V_{si} \quad \Delta X_{s1} \quad \Delta X_{s2} \quad \Delta V_{sc} \right]^T \quad (7)$$

with:

$$\begin{cases} \Delta \dot{V}_{si} = -\frac{1}{T_2} \Delta V_{si} + \frac{K_{PSS}}{T_2} \frac{\Delta \omega_i}{\omega_s} + \frac{K_{PSS} T_1}{T_2} \frac{\Delta \dot{\omega}_i}{\omega_s} \\ \Delta \dot{X}_{s1} = -\frac{1}{T_m} \Delta X_{s1} + \frac{K_\omega}{T_m} \Delta \omega - \frac{1}{T_m} \Delta V_{meas} \\ \Delta \dot{X}_{s2} = \left(-\frac{K_P}{T_m} + K_1 \right) \Delta X_{s1} + \frac{K_P K_\omega}{T_m} \Delta \omega - \frac{K_P}{T_m} \Delta V_{meas} \\ \Delta \dot{V}_{sc} = -\frac{1}{T_2} \Delta V_{sc} + \frac{1}{T_2} \Delta V_{s2} + \frac{T_1}{T_2} \Delta \dot{X}_{s2} \end{cases} \quad (8)$$