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Coordinated control by fuzzy logic between PSS and STATCOM to improve the stability of the electricity network of the Republic of Congo

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Summary - Power stabilizers (PSS) are one of the most common ways to improve the stability of electrical networks. In addition, FACTS control devices, thanks to their flexibility and their fast response times, can be used in addition to power stabilizers. This article is devoted to the study of the stability of the electricity network of the Republic of Congo using initially the first method of Lyapunov based on the analysis of the eigenvalues of the matrix of the state variables of the electricity network. of the Congo in the presence of the PSS-STATCOM control devices.

Keywords: fuzzy logic, power stabilizers, facts, Congo.

1. INTRODUCTION

Faced with the saturation of power networks, electric power companies are increasingly operating their networks close to safety limits (driving at limits). This situation creates operational problems, in particular for the control of power flows, the maintenance of an acceptable voltage profile, etc. To this end, the safety aspect takes on The development of FACTS (Flexible AC Transmission System) devices opens up new perspectives for denser network operation by continuous and rapid action on the various network parameters (phase shift, voltage, impedance) [1,2]. Thus, the power transits will be better controlled and the voltages better held, which will make it possible to increase the stability margins or tend towards the thermal limits of the lines. Moreover, thanks to their short response time to changes in power networks, FACTS devices have emerged as effective tools for the damping of electromechanical oscillations or as a complement to power stabilizers (PSS). These power stabilizers detect variations in rotor speed or electrical power from the generator and apply a suitable signal to the input of the voltage regulator (AVR). The generator can thus produce an additional damping torque which compensates for the negative effect of the excitation system on the oscillations [3,4]. They are an effective and economical means of improving the dynamic stability of an electrical system. However, the insertion of several PSS-STATCOM controllers can cause an interaction phenomenon that can lead to dynamic instability. To remedy this phenomenon, several coordination methods can be used, we have used in this article the method based on fuzzy logic. This article is organized as follows: section 2 describes the FACTS compensator model (STATCOM), section 3 describes the power stabilizer (PSS), section 4 describes the coordination method based on fuzzy logic. Section 5 is devoted to the description and modeling of the RC electrical network. Section 6 is reserved for the results and section 7 concludes the article. we have used in this article the method based on fuzzy logic. This article is organized as follows: section 2 describes the FACTS compensator model (STATCOM), section 3 describes the power stabilizer (PSS), section 4 describes the coordination method based on fuzzy logic. Section 5 is devoted to the description and modeling of the RC electrical network. Section 6 is reserved for the results and section 7 concludes the article. we have used in this article the method based on fuzzy logic. This article is organized as follows: section 2 describes the FACTS compensator model (STATCOM), section 3 describes the power stabilizer (PSS), section 4 describes the coordination method based on fuzzy logic. Section 5 is devoted to the description and modeling of the RC electrical network. Section 6 is reserved for the results and section 7 concludes the article.

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2. FACTS STATCOM DEVICES

Advanced Static Reactive Power Compensator (STATCOM) is a reactive power compensation device connected in parallel with the system, which is capable of generating and/or sinking reactive power, and in which the output can be changed to control the specific parameters of a power supply system. It is a controlled reactive power source. It provides the reactive power generation and desired absorption entirely by means of electronically processing the voltage and current waveforms in a voltage source converter (VSC). Fig.1, illustrates the statcom compensator [9].

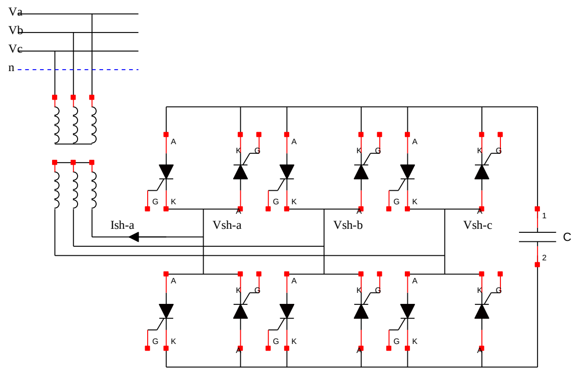

Fig.1: block diagram of a statcom [5]

The current injected by the statcom is given by [5,6]:

$$\bar{I}_{sh} = \frac{\bar{V}_{sh}.\bar{V}_k}{jX_K} \quad (1)$$

The power injected into the connection busbar is given by the following equation:

$$\bar{S} = \bar{I}^*_{sh}.\bar{V}_k = \frac{\bar{V}_k(\bar{V}^*_k.\bar{V}^*_{sh})}{-jX_K} = \frac{\bar{V}_k(\bar{V}^*_k.\bar{V}^*_{sh}.V^2_k)}{-jX_K} \quad (2)$$

This results in the active and reactive powers injected by the statcom into the connection busbar expressed by the following formulas:

$$\bar{S} = P_{sh} + jQ_{sh} \quad (3)$$

If (the angle at the connection busbar), then the active power is negligible.$\theta_{sh} = \theta$

$$\bar{S} \approx jQ_{sh} = j\frac{V_k[V_{sh}.\cos(\theta_k-\theta_{sh})}{X_K} \quad (4)$$

3. POWER STABILIZER (PSS)

3.1. Generic Power System Stabilizer

The general power system stabilization block can be used for the oscillation of the rotor of the synchronous machine by controlling its excitation. Disturbances occurring in an electrical system induce electromechanical oscillations of electrical generators. These oscillations, also called "power swing", must be effectively damped to maintain the stability of the system [9,10]. The PSS output signal is used as an additional input (vstab) to the excitation system block. The PSS input signal can be either the machine speed deviationdω, or the acceleration power (difference between mechanical power and electrical power) [1,7,8]. Fig.2, illustrates the generic Power System Stabilizer (PSS) diagram, which can be modeled using the transfer function below:$P_a = P_m - P_{e0}$

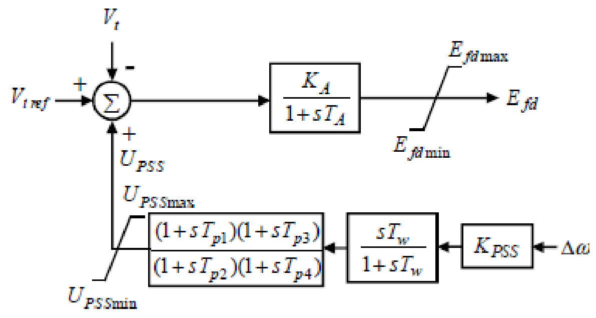

Fig.2: Generic Power System Stabilizer Diagram

4. Fuzzy logic

Thanks to fuzzy logic, it will be possible to integrate intelligence into the control of the speed and power of each generator. In fact, this type of reasoning is perfectly suitable here for adapting to each level of power and rotational speed measured, the setpoints of the speed adapted to the scenario. The controller is able to change these setpoint values, correlatively to the operating regime [15].

4.1. Fuzzy Controller Settings

4.1.1. Fuzzification of inputs

This first step allows us to express the numerical values of the input signals in fuzzy values, that is to say that these parameters will no longer be defined numerically, but "linguistically". It consists in defining an interval of maximum variation authorized for the input variables, in our case, these are the production limits and the limits of the rotation speed of a generator.

4.1.2. Membership functions

Let us define the membership functions for the fuzzification of the values of the active power measurement and the rotational speed. We will choose the membership functions for the fuzzification of the values of the reactive power measurement and the voltage [15,16].

Seven triangular membership functions are used for the active power. These functions are: large negative (NG), medium negative (NM), small negative (NP), null (NU), small positive (PP), medium positive (PM), large positive (PG). Fig.3 shows the fuzzy definition of active power according to these functions.

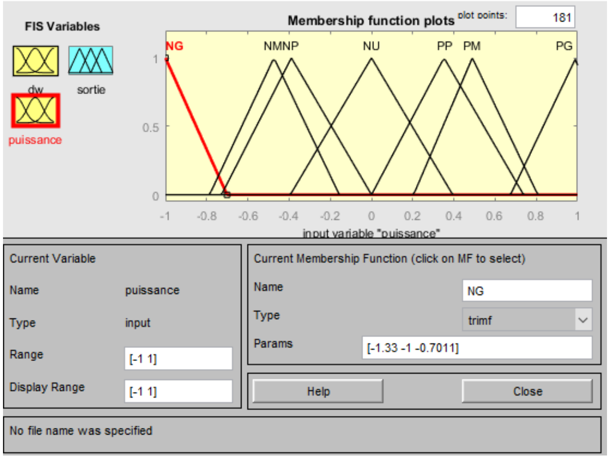

Fig.3: membership functions for active power

Seven membership functions are used for velocity are:large negative (NG), medium negative (NM), small negative (NP), null (NU), small positive (PP), medium positive (PM), large positive (PG). Fig.4 shows the fuzzy definition of active power according to these functions.

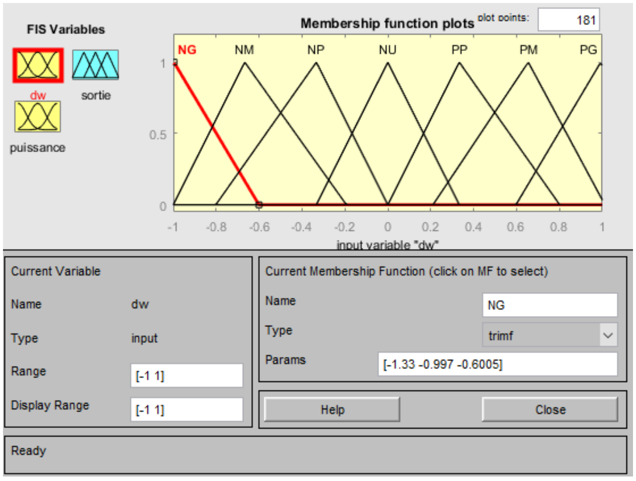

Fig.4: rotation speed membership functions

4.1.3. Ireference of the adaptation block

As explained in the previous chapter, the inference step is the decision-making step of our adaptation block based on the input data. In addition, we have treated case by case the variations of the inputs and the evolution of the setpoint of the output signal according to the state of these inputs. Thus, fuzzy logic facilitates this decision-making, since the inputs are qualified by quantitative terms. Table 1 summarizes all the possible output states according to the inputs.

Table 1: rules of inference

	ΔP						
Δω	NG	NM	NP	NU	PP	PM	PG
NG	SNG	SNG	SNG	SNG	SNP	SNP	SNU
NM	SNG	SNG	SNM	SNM	SNP	SNU	SPP
NP	SNG	SNM	SNM	SNP	SNU	SPP	SMP
NU	SNG	SNM	SNP	SNU	SPP	SPM	SPG
PP	SNM	SNP	SNU	SPP	SPM	SPM	SPG
PM	SNP	SNU	SPP	SPM	SPM	SPG	SPG
PG	SNU	SPM	SPM	SPG	SPM	SPG	SPG

The output of this stage is expressed in seven membership functions, these functions are: large negative (NG), medium negative (NM), small negative (NP), null (NU), small positive (PP), medium positive (PM), large positive (PG).

5. Description of the electricity network of the Republic of Congo

The single-line representation of the network and a geographical and schematic representation of the electrical transmission network of the Republic of Congo. Heconsists of 5 generating stations, 22 numbered loads, 24 lines and 35 nodes, as shown in Fig. 5.

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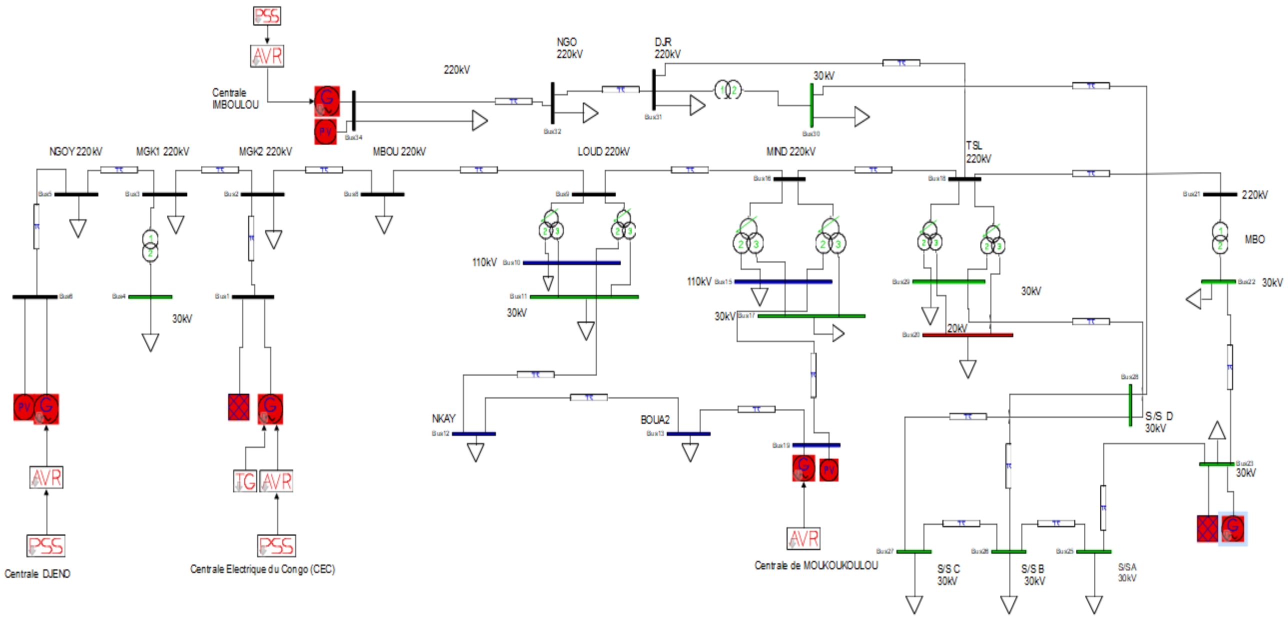

Fig. 5: transmission grid of the Republic of the Congo

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6. RC network simulation results

6.1. RC network results without fuzzy control

In this section, we present the results of the dynamic operation of the electricity network of the Republic of Congo in the presence of power stabilizers (PSS) and static compensators (STATCOM). We have inserted two (02) STATCOMs, in particular at node 26 which represents the substation (B) located in Mpila in the district (02) Oeunzé, in the center of Brazzaville, at node 29 which represents the Tsielampo substation located in the district (07) Mfilou. The operating voltage of these two nodes is 30kV.

6.1.1. Power flow

Figure 6 illustrates the results of the voltage profile of all the nodes of the electricity network of the Republic of Congo with PSS-STATCOM without coordinated control.

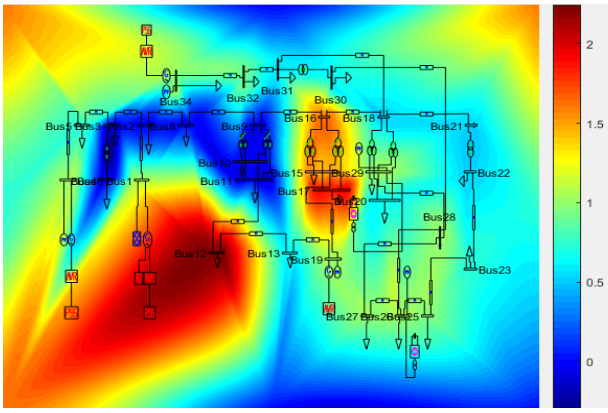

Fig.6 : thermal profile of the voltage of the nodes of the electrical network of the RC with PSS-STATCOM without CF

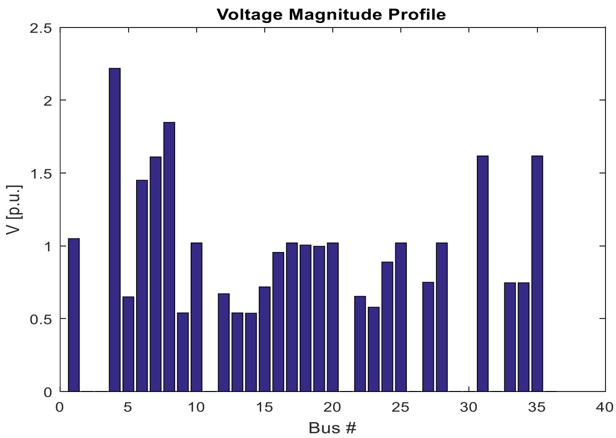

Fig.7: Voltage histogram of RC power grid nodes with PSS-STATCOM without CF

Fig.6 and Fig.7 after inserting the STATCOMs, show that the voltages in Brazzaville are within the allowable limit. STATCOMs act not only on the connecting node, but the effect of the latter is felt on neighboring nodes. However, in the Pointe Noire area starting from Loudima until reaching Mongokamba 1, there is a drop in voltage compared to the case where the RC electrical network operates without STATCOM. In the department of Bouenza, a peak is observed in the locality of Nkayi, i.e. a value above 2pu.

6.1.2. Evolution over time of the different quantities

- Voltages at generator nodes

We present the voltages at the nodes of the generators of the electricity network of the Republic of Congo with PSS-STATCOM without fuzzy control, as shown in Fig.8 below:

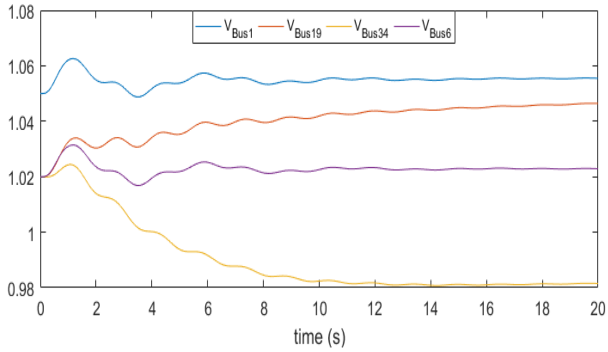

Fig.8: voltage at generator nodes without CF

V_{b1}: Centrale électrique du Congo; ;
;V_{b34}: Imboulou V_{b8}: Djeno V_{b19}: Moukoukoulou

We observe in fig.8 that the voltages at the nodes of the generators after a few oscillations stabilize at t = 14s. The evolution of the angle of the rotor of each generator is presented in fig.9.

- Generator Rotor Angles

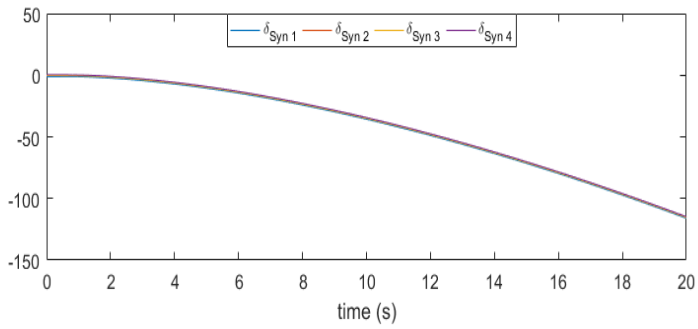

Fig.9: Rotor angle of machines without CF

It is noticed that the rotor angles of the generators have the same evolution of decrease.

- Active powers at generator nodes

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The electrical power produced by a plant is a function of the output voltage of the generator and the angle of the rotor. Fig.10 below illustrates the evolution over time of the transmission power at the nodes of each generator.

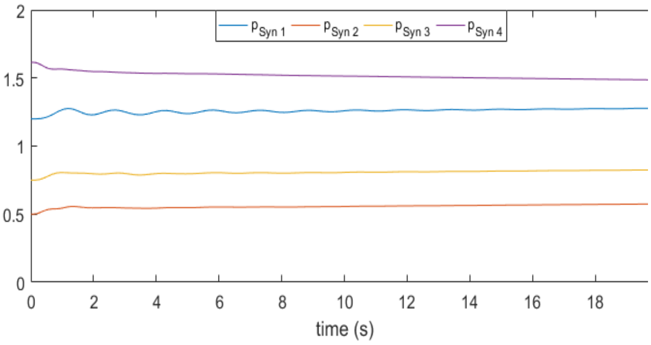

Fig.10: active powers at generator nodes without CF

Note that in fig.10, the evolution of the power at the nodes of the generators is substantially the same as that in the case where there is no STATCOM.

6.1.3. Eigenvalues without CF

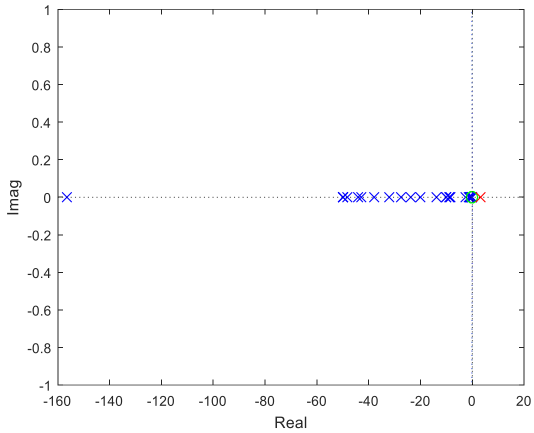

Fig.11:distribution of the eigenvalues of the electrical network with PSS-STATCOM in the complex plane

We see in fig.11 the presence of an unstable mode, represented in the figure in red color. Fig.12 below illustrates the rotation speed of each generator in the network.

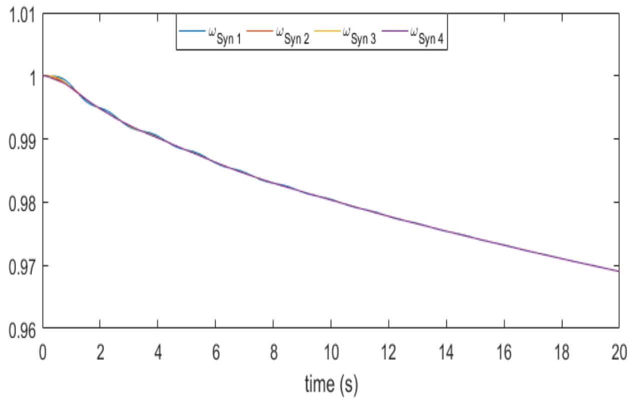

Fig.12: generator rotation speedswith PSS-STATCOM without CF

Fig.12 illustrates a speed of the generators which gradually decreases until it becomes constant. We can say that the addition of compensator FACTS (STATCOM) has had little influence on the speed of rotation of the generators.

6.1.4. Variable participation factors

The determination of the participation factor allows us to determine the generators participating in each critical mode.The fig.13 shows the participation factors associated with the rotational speeds of the generators.

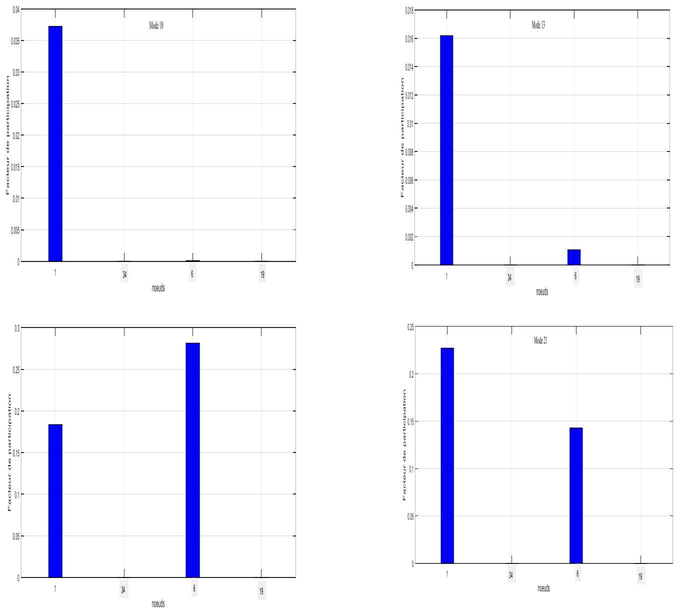

Fig.13: participation factors associated with generator speedswith PSS-STATCOM without CF

Note in Fig.13 that the Congo Power Plant (CEC) actively participates in all oscillation modes. However, the Imboulou plant has almost zero participation in all oscillation modes.

6.2. RC network results with fuzzy control

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In this section, we performed coordinated control of PSS-STATCOM control devices using fuzzy logic. Table 2 presents the different scenarios carried out to observe the behavior of this electrical network.

Table 2: list of scenarios

Scenario no.	Scenario configuration
1	15% decrease in active power of generator 1
2	20% increase in Active Power of Charge at Node 13

6.2.1. Analysis by temporal simulations

The variation in the speed of the generators which follows a 15% reduction in the power of the generator at the Congo power plant (node 1) and a 20% increase in the load at Bouenza on node 13 is presented in fig.14.

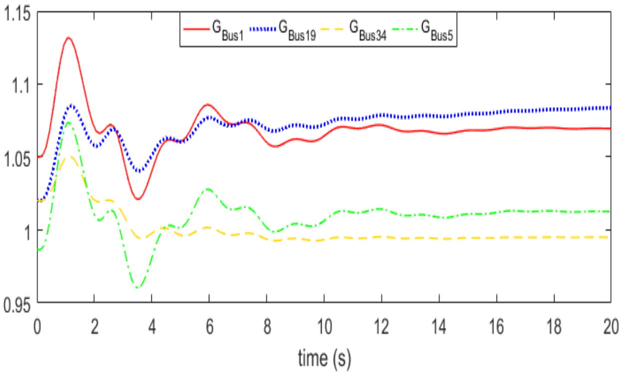

Fig.14: speed variation of the five generators with CF

It is observed that the coordination of the PSS-STATCOM regulation devices makes it possible to eliminate the oscillations in the first ten (10) seconds to finally regain normal operation. Fig.15 below shows the evolution over time of the power of the generators of the different power plants.

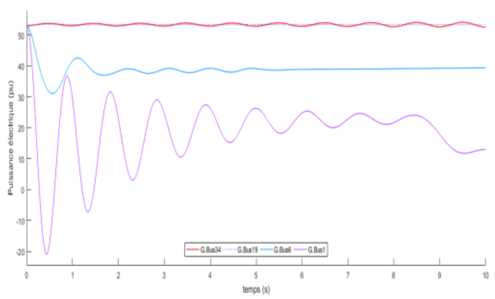

Fig.15: electrical power of the generatorswith FC

It can be seen that the powers of the Imboulou and Moukoukoulou power stations are not impacted by the various disturbances carried out. The Djéno plant returns to normal operation within the first five (5) seconds. On the other hand, the central power of the CEC is quite disturbed, but regains its stability after 10 seconds. Figure (16) gives the evolution of the voltages at the nodes of the various generators.

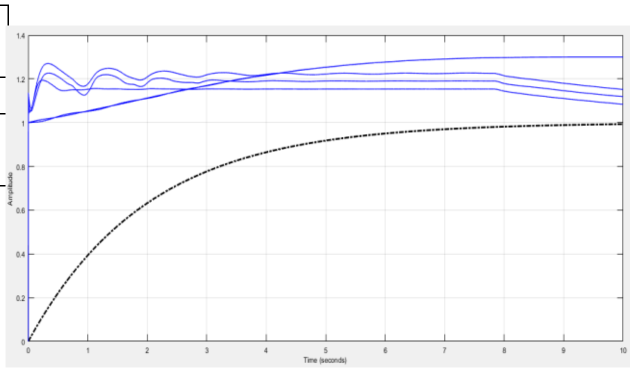

Fig.16: voltages at generator nodes with CF

Fig.16 shows the evolution of the voltages at the nodes of the generators of the different power plants. A voltage instability is observed, this during the response time does not exceed four seconds to bring the voltages gradually back to the reference voltage 1pu.

6.2.2. Eigenvalues with CF

We present in this section the distribution of eigenvalues in the complex plane with coordinated control using fuzzy logic.

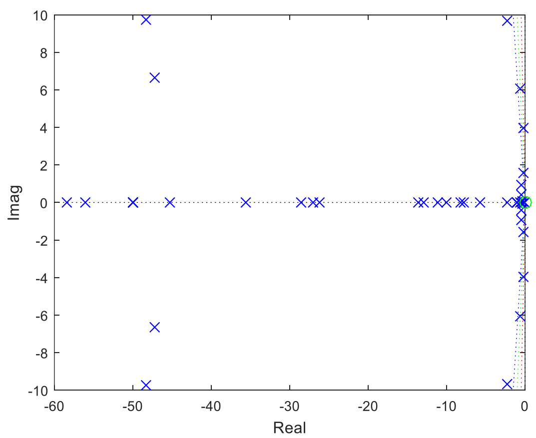

Fig.17: eigenvalues with PSS-STATCOM in the complex plane with CF

Fig.17, illustrates the different eigenvalues in the complex plane. One can easily note the absence of the unstable modes. This is explained by the simple fact that all modes have a negative real part.

6.2.3. Participation factors

The participation factor allows us to determine the generators participating in each mode.The fig.18 shows the participation factors associated with the speeds of each generator for the oscillation modes.

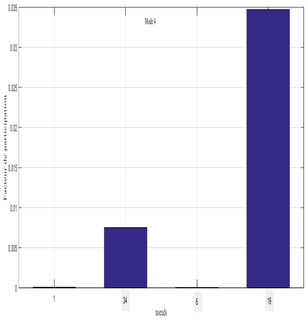
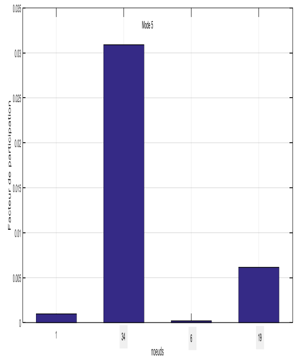
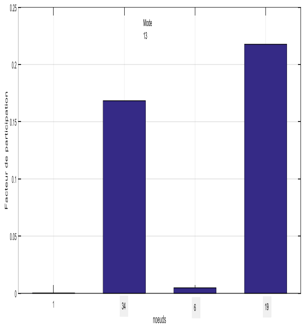
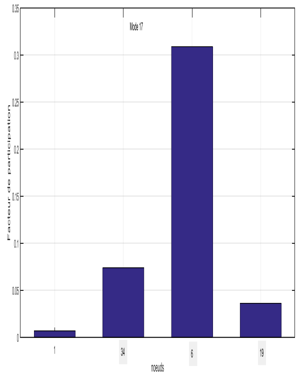
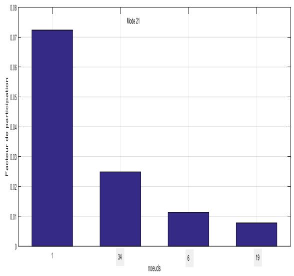
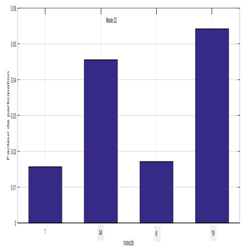
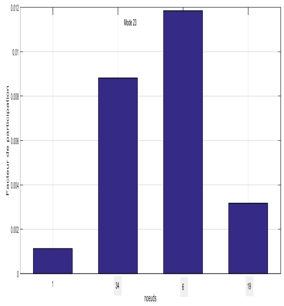
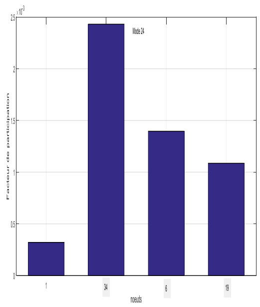
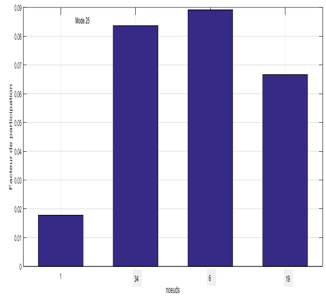

Fig.18: participation factors associated with generator speedswith FC

We notice in fig.18, that all the power stations participate in almost the oscillation modes. The Congo Power Plant (CEC) participates in only one mode namely the mode.λ_{21}

7. Conclusion

In this article, we have studied the stability of the electricity network of the Republic of Congo. At first, we observed the functioning of this network with the PSS-STATCOM control devices. This observation shed light on an interaction phenomenon due to the presence of an unstable oscillation mode. In the second time, we applied a method of coordination of control devices using fuzzy logic. This coordinated control of the PSS-STATCOM has made it possible to improve more effectively the stability of the electricity network of the Republic of Congo.

References

[1] HF Wang and FJ Swift, “A unified model for the analysis of FACTS devices in damping power system oscillations Part I: Single-machine infinite-bus power systems,” IEEE Trans. Power Delivery, vol. 12, p. 941–946, Apr. 1997.

[2] KR Padiyar. “Investigation on strong resonance in multimachine power systems with STATCOM supplementary modulation controller”. IEEE, transaction on power systems, vol. 21, No. 2, May 2006.

[3] Kundur P. Power system stability and control. New York: McGraw-Hill; 1994.

[4] Rodrigo A. Ramos," Stability analysis of power systems considering AVR and PSS output limiters", Electrical Power and Energy Systems 31 (2009) 153–159.

[5] L. Bougouffa, "Effects of FACTS Compensation Systems on Overcurrent Protection in Electrical Networks", doctoral thesis, University of Batna 2 Faculty of Technology, April 30, 2016.

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 12 Issue 05, May-2023

[6] S. Sasidharan, J. Tibin, J. Sebin, VC Chittesh, J. Vishnu, D. Vipin, " Power System Loading Margin Enhancement by Optimal STATCOM Integration- A Case Study", November 21, 2019.

[7] Bhargava B., Dishaw G. Application of an energy source power system stabilizer on the 10MW battery energy storage
system at Chino substation, IEEE Transaction on Power System 1998; 13(1): 145 – 151.

[8] Wu Chi-Jui, Hsu YuanYih, Design of self-tuning PID power system stabilizer for multimachine power systems. IEEE
Transactions on Power Systems.1998; 3(3):1059-1064.

[9] AS Tharani, TR Jyothsna, " Design of PSS for Small Signal Stability improvement", 16th NATIONAL POWER SYSTEMS CONFERENCE, 15th-17th DECEMBER, 2010. [10] KM Lin, WPL Swe, "Coordinated design of PSS and STATCOM for Power System Stability Improvement using Bacteria Foraging Algorithm", International Journal of Electrical, Computer, Electronics and Communication Engineering, Vol: 7, No:2, 2013.

[11] D. Mondal, A. Chakrabarti, A. Sengupta, " Power System Small Signal Stability Analysis and Control", Library of Congress Cataloging-in-Publication Data Application submitted, ISBN: 978-0-12-800572- 9.

[12] Akram F. Bati, "Optimal Interaction between PSS and FACTS Devices in damping power systems oscillations: part II", IEEE International Energy Conference 2010.

[13] Rajendraprasad Narne, PCPanda, "Optimal Coordinate Control of PSS with Series and Shunt FACTS Stabilizers for Damping Power Oscillations",IEEE International Conference on Power Electronics, Drives and Energy Systems December16-19, 2012, Bengaluru, India.

[14] Nesmat Abu-Tabak, "Dynamic stability of multi-machine electrical systems: modeling, control, observation and simulation", doctoral thesis, central school of Lyon, November 2008.

[15]Karuppiah N., Malathi V., Selvalakshmi G., "Transient stability enhancement using fuzzy controlled SVC and STATCOM", International Journal of Innovative Research in Science, Engineering and Technology, vol 3, special issue 3, March 2014.

[16] KM Passino, S. Yurkovich, and M. Reinfrank, "Fuzzy control," vol. 42: Addison Wesley, pp. 15-21, 1998.