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Interaction of FACTS devices with loads dynamics in the transport networks and interconnection

Kamal Mohammed Saleh Al-Azzawi[1], Muntadher Ali Abd[2]
[1]Diyala's General Directorate of Education, Baquba, Iraq
[2]Baghdad Al-Karkh Directorate of Education, Baghdad, Iraq

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ABSTRACT

This paper introduced analysis and improvement of power networks stability. It focused on the impact of flexible AC transmission systems (FACTS) device interaction with the other components of the network. It investigated the impact of dynamic charges on the ability of FACTS to eliminate power oscillations problems. A small-signal analysis, frequency analysis and non-linear time simulations using EUROSTAG made it possible to study these problems. Other, research has shown that the damping loops of the power oscillations effects using classical techniques of sensibility are not robust in relation to the variations of load models. Thus, this paper proposed a method based on the sensitivity of the eigenvalues and it takes into account the variations of the load models. The method calculates an optimal phase compensator based on a weighted average of the sensitivity of the target mode. It considers the variations of sensitivity as a function of the uncertainty in the load model. According to the obtained results, this method is effective in most stability problems.

Corresponding Author:

Kamal Mohammed Saleh Al-Azzawi
Diyala's General Directorate of Education
Baquba, Diyala Province, Iraq
Email: kms01424@gmail.com

1. INTRODUCTION

The power system, it is the set of all components that can provide energy to a consumer and therefore includes the transport network with the detail of all its components (production plants and distribution network). The management of such a system is very complex and poses many problems, the weak link in the chain being the transport network. It must be ensured at all times that the transport network fulfills its role as best as possible considering that it is easier to distribute quality energy downstream (to consumers) if its upstream transport is satisfactorily achieved.

Regulations are of vital importance for safe, reliable operation, and economic modern energy systems. To improve the quality of energy electrical engineers, they are inventing and exploiting more and more new devices and new advanced regulations for various applications. This is the case of the devices flexible AC transmission systems (FACTS) that truly constitute a new technology in the field of networks electric. It is an inevitable development, especially in the new context liberalization of the electricity market, but it should be recalled that, as in all areas, evolution is often accompanied by certain risks.

2. THE FACTS CONCEPT

The problems of the above-mentioned networks becoming more present from year to year, Electric Power Research Institute (EPRI), which represents a consortium dedicated to the research in the electric networks and gathering American electric companies, launched in 1988 the flexible AC transmission system (FACTS) concept. It is a long-term project that aims to make networks more flexible. FACTS technology uses power electronics and more particularly thyristor or (GTO thyristors) which allow control speeds to be significantly higher than mechanical systems which are still widely used, and a much lower level of maintenance because mechanical systems wear out much faster than static systems [1], [2].

The objectives of the FACTS project are to be able to control the power transits in the networks and to increase their load capacity up to their maximum thermal limit. To fix ideas, we can take a simple example. As shown in Figure 1 the AC transport line, Let's consider the power transit on an AC line. This line is shown the losses being assumed to be zero. The transmitted power P is a function of the amplitudes of the voltages E_1 and E_2 at the ends of the line, the phase shift d_{12} between these two voltages and the impedance X of the line, as shown in (1).

$$P = E\frac{E_1 E_2}{x}\sin\delta_{12} \tag{1}$$

From (1), the power transit can be controlled by adjusting one, two or even three of the equation parameters. Moreover, thanks to their short response time to changes in the networks, FACTS devices have appeared as elements that can contribute to the damping of very oscillations. Low frequency to replace or supplement traditional power stabilizers or "PSS" [3]–[5].

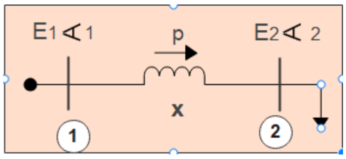

Figure 1. AC transmission line

2.1. Types FACTS devices [6]

The group of FACTS devices is vast in count. Among these, we can say:

- Thyristor controlled series compensators (TCSC), the TCSC, allowing to modify the line impedance with great flexibility [7]–[10].
- Static phase shifters (SPS), where thyristors are used on adjustable transformers, providing control of the transmission angle [11], [12].
- Static var compensators (SVC), where the compensation is of the shunt type, which allows the control of the reactive energy demand and the line voltage thanks to the synchronous switching of batteries. and inductors [13].
- The Advanced Static or STATIC Compensator Static-type reactive energy compensator, developed in recent years thanks to the development of high-performance high-power aperture thyristor (GTO) [14].
- The unified power flow controller (UPFC), whose concept is very recent. This compensator combines the functions of the shunt compensator, the series compensator and the phase shifter [15].

2.2. Concept of interactions

2.2.1. Harmonic interactions [16]–[18]

This type of interaction can come from the insertion of FACTS devices such as SVC, STATCOM, TCSC and/or the insertion of high voltage DC (HVDC) converters (high voltage DC rectifiers and high voltage inverters). It is characterized by generation or amplification harmonics in the voltage and current signals. HVDC converters are one of the major causes of harmonic generation in large power grids. Power electronics devices interact with regulations. The study of such phenomena requires a program of harmonic analysis or rapid transient time study that can be completed by the study of eigenvalues (small signal theory) [19].

2.2.2. Regulatory interactions

The regulations associated with many devices that are encountered in large power grids, that is to say the regulations FACTS devices, HVDC converters, Adjustable series capacitors, voltage regulators (AVR) and power generators and power stabilizers (PSS), have natural oscillation modes at sub-synchronous frequencies (typically from 1 Hz to 35 Hz) [20], [21]. Depending on the "electrical distances" between the devices, these regulations can interact with each other, sustaining oscillations or even causing dynamic instability [22]. Another type of regulatory interaction is the interaction between a regulation and a natural oscillation mode of a network element. For example, the introduction of one FACTS device near another could degrade the damping of a natural oscillation mode of the latter. This may result in the appearance of a new oscillation mode related to the interaction of two FACTS device regulations. In addition, a regulatory interaction may also have an effect different from the two effects mentioned above. Indeed, the introduction of a system based on power electronics can cause the amplification of a resonance effect via a regulatory interaction. For example, the presence of a TCSC near a series capacitance can cause a resonance effect [23], so that the introduction of a SVC near a TCSC accentuates this resonance effect [24], via an interaction of regulation between these two devices FACTS. It can be noted here a certain ambiguity as for the type of interaction which comes into play, which accentuates the complexity of the study of the phenomena involved. Finally, interactions between the FACTS device regulations between them or interactions between the FACTS device and the machine power stabilizer regulations can lead to a degradation of the power oscillation damping [25], [26]. This is especially true when these FACTS devices are used precisely to dampen inter-region oscillation modes. This problem of regulation interaction is attracting more and more attention with increasing the number of power electronics-based devices in power grids and associated controls; increase which is only beginning. Above all, the complexity of these phenomena makes the study delicate. If the phenomena 'torsional or harmonic interactions and resonance phenomena are known for a long time, they take a new dimension today with the insertion of FACTS devices. Thus, we will be interested here more closely in this last type of interaction. The following sub-sections introduce some cases of interaction that took place in real power grids or that were identified in stability studies.

2.2.3. Interactions between PSS and other generator regulators

Interactions occurred between PSSs and turbine controls at the Reece hydropower plant in Tasmania (Australia). The power station has two generators with a nominal power of 120 MVA each. PSSs, with electrical power as an input signal, were installed in 1994. The commissioning tests, for different load conditions, showed no major problems. A few days later, the two generators found themselves with a saturation of reagent and very close to their maximum production. This caused oscillations on the reactive powers of the two generators between 5 and 45 MVAR. The frequency of the network oscillated between 48 and 52 Hz which required the triggering of the two generators.

2.2.4. Interaction between transformers with load controllers

In many power grids, transformers connecting different levels of voltage in the transmission network are equipped with load controllers known in the Anglo-Saxon terminology under the name of load tap changers (LTCs), as shown in Figure 2. These devices help increase network transfer capacity and voltage adjustment e ~disconnecting the generation of the load. Regulator transformers in charge, devices whose dynamics are sometimes neglected in some studies of dynamic stability or voltage of electrical networks, can interact with each other at different levels causing oscillations. The example following illustrates such a phenomenon (CUT98). Consider the simple radial network of Figure 3. When the transformation ratio r1 of HTB/HTA transformer decreases, high voltage controlled V_H and medium voltage V_M increase.

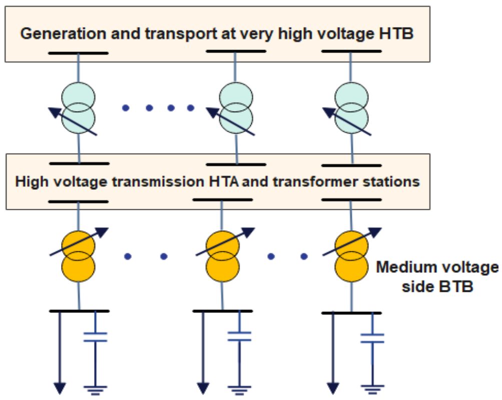

Figure 2. LTCs two-level network

However, when the transformation ratio r_2 of the transformer HTB/BTB decreases in the purpose of supporting the voltage V_M, the voltage V_H on the HTB side also decreases. In addition, when V_H increases, the current in the HTB line decreases by the same power, reducing hence the reactive losses due to the reactance of the line X_l. For these reasons, the coordination of the two LTCs must ensure that the LTC HTB/HTA is faster than the HTB / BTA level. This will ensure a better setting with a minimum of switching possible.

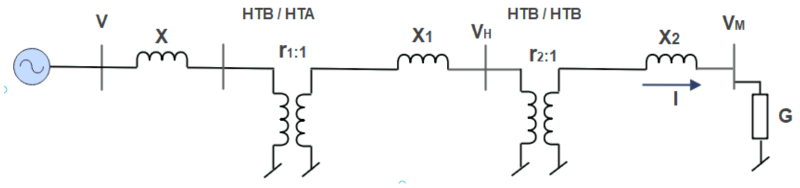

Figure 3. Radial network with two on-load regulator transformers

2.2.5. Interaction FACTS-PSS-charge dynamic

Some solutions are starting to appear in order to address in this sense, which proposes coordination techniques for regulations based on theories of optimization and mathematical programming as well as on the methods of optimal control. Another factor, which seems interesting to us to take into account in the study of these phenomena of regulatory interactions, is that concerning the influence of the models of load on dynamic stability analysis of electrical networks. The loads is a combination of different static or dynamic devices and a composite load model combining static–dynamic. Dynamic loads exhibit time-dependent responses which are determined by the previous conditions of both the system and the load itself.

2.3. Influence indices

The insertion of a FACTS device in a power system must not therefore lead to a degradation of its performance (or at least as little as possible). The sensitivity indices allow us to select the insertion node of the FACTS device in order to avoid these interaction phenomena as much as possible. However, the FACTS device will be active in the power system, and the insertion of another FACTS device (or other elements of the power systems) into the network may lead to interaction phenomena. In order to guard against these phenomena, we propose to delimit zones according to the influence of STATCOM in the power system. An area under strong influence will then be declared “inviolable”. In addition, in some cases, the insertion of a FACTS device into a given node of the network can be unavoidable. A good adjustment can make it possible to limit the importance of the phenomena of interaction, or even to bring about phenomena of beneficial interaction. The application of the indices of influence would then make it possible to clear zones where one will refrain from positioning any other new element of network under penalty of seeing the phenomena of interaction to be amplified and possibly, to see them take a harmful aspect.

- Definition of influence indices

The purpose of this part is to find an influence index of the FACTS device on the network nodes. Such an index must therefore be calculated for each node of the network. A strong index would indicate that the node would be in an area under strong influence of the FACTS device. The insertion of another FACTS device encode would then involve phenomena of interaction between the two devices. On the contrary, a null index would mean that the FACTS device has no influence on the node. The insertion of a new FACTS device on this node would therefore not result in interaction phenomena between the two devices. The influence indices must therefore be calculated at each node of the network. But the phenomena of interaction are “conveyed” by the modes of the system. Also, if a mode is observable at a node, then a STATCOM inserted in this node will be able to interact with network devices via this mode [27]. It is therefore necessary to characterize each node of the network.

2.4. Literature review

In the literature dealing with electrical energy systems, many situations where network regulations have had unexpected behavior as a result of interaction with other regulations or simply with the network itself and its various components (generators, charges,) have been processed. The phenomenon of interaction of FACTS devices regulations, little discussed a few years ago, is of increasing interest to researchers and industrialists in the field of networks. Electric, indeed, these devices were little used, especially in Europe, for reasons related to the costs of installation and maintenance. They are now starting to gain ground in the context of the opening of the electricity market with all that this could lead to new network architectures as we mentioned in the introduction.

One of the first studies dates from 1989 and was presented by Ramos and Tyll [28]. It presents the dynamic performance of a Brazilian radial network on which three SVCs were to be implemented. This study has shown that instability can occur if there is no coordination between the regulations of these SVCs. Another study was conducted as part of a project to implement SVCs in the US Southwester Network. It made it possible to highlight the potentiality of a negative interaction between the SVCs regulations and those of the HVDC converters relatives.

2.5. Aims and objectives of the study

Environmental concerns and trade pressures have led the trend of energy networks of growth towards quality objectives. This resulted in the increase in the number of regulations involved in the networks and by a better exploitation of conventional and unconventional devices in networks. Indeed, generators are increasingly equipped with power damping loops as well regulators of FACTS devices whose fields of action develop from day to day. However, these regulators, although often effective, are not immune to possible interactions with each other but also with other elements of the network. In this chapter, we put the focus on this phenomenon, through some examples of studies but also real cases, where interactions between regulators had a negative impact on dynamic performance electrical networks.

These phenomena can come inter alia from the interaction of FACTS devices with each other, but also with other elements such as, for example, voltage regulation of machines, and the power stabilizers that may be associated with them. Other elements that can interact with FACTS are dynamic loads. Through an illustrative example, we demonstrated the importance of the load model in the analysis dynamic performance of electricity networks. Very few studies have been conducted in that sense in the past. As a result, we have set ourselves the goal in this research work to study the interactions that may result from the insertion of FACTS devices into networks in the presence of dynamic loads.

3. RESULTS AND DISCUSSION

3.1. Analysis of interaction phenomena

When inserting a FACTS device into a power network in the presence of PSS, or when simultaneously inserting several FACTS devices into a single network, it is possible to see the interaction phenomena altering the network stability. The objective of this paper is to highlight phenomena of interaction between FACTS device and network elements including the PSS, as well as between FACTS devices between them, then to analyses them. For this, we will use the test one network zone 2 machines.

3.2. STATCOM (a static synchronous compensator) interactions-network elements

To determine the influence of the insertion of a STATCOM according to its positioning, the two parallel interconnection lines have been replaced by a single equivalent interconnection line. In addition, we have “moved” the STATCOM along this line, the latter being divided into 4 sections of the same impedance, as shown in Figure 4. Of course, such a division of the line has no physical meaning since it is difficult in practice to create new facilities solely for the purpose of installing a FACTS device. However, by this study, we seek to highlight the influence of the distance between the elements participating in interaction phenomena.

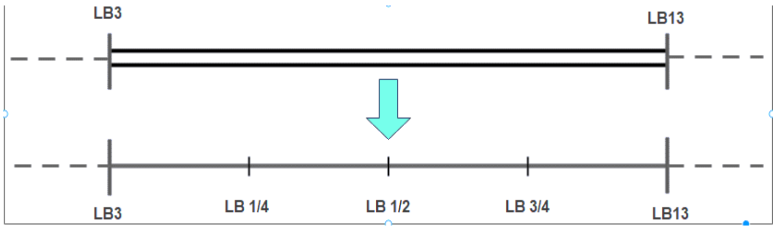

Figure 4. Substitution of interconnection lines by an equivalent line

For each positioning of the STATCOM, we have noted the damping rate of the only mode of oscillation between regions. Figure 5 shows the values of these damping rates for the insertion of a single STATCOM in the network and the insertion of two STATCOMs. In both cases, depreciation rates were determined for the five STATCOM positions. The abscissa '0' corresponds to the STATCOM on LB3, the abscissa '0.25' to the STATCOM on LB1/4. With the observation of this figure, it appears that, when the STATCOM is connected to the node LB3 or LB 13, the rate of damping of the mode inter-regions undergoes a clear degradation by the phenomena of interaction between the STATCOM and the machine regulations. On the other hand, when the STATCOM is in the middle of the line, there is no significant degradation. Figure 6 shows the voltage at the STATCOM connection node when it is installed at node LB3. The tension support appears very clearly. At the same time, there is an oscillation on the voltage which persists longer in the presence of the STATCOM. Figure 7 shows the degradation of the inter-region mode damping when this STATCOM is inserted on the node LB3. After the short circuit, the stable state is found after more than 150 seconds in the presence of STATCOM against less than 60 seconds for the network without STATCOM.

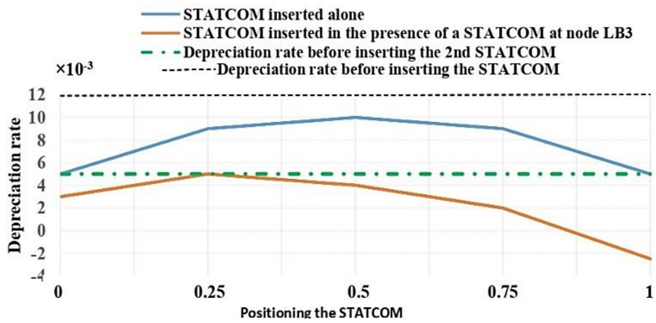

Figure 5. Cross-region depreciation rate following the positioning of the STATCOM

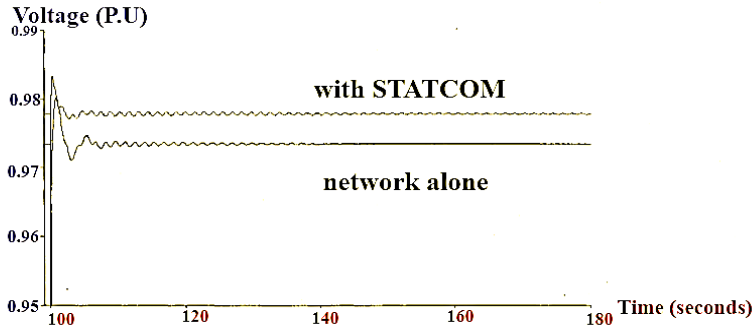

Figure 6. Voltage at the STATCOM connection node as a function of time

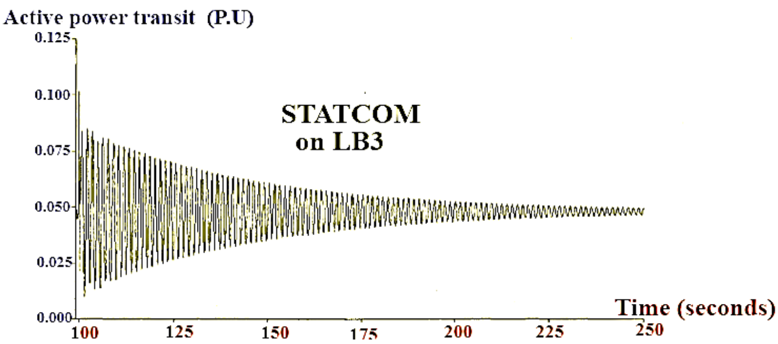

Figure 7. Active power transit between LB 13 and LB3 nodes as a function of time

3.3. Use of FACTS devices in damping power oscillations

After highlighting interaction phenomena when using STATCOMs in support of voltage, we will focus here on the use of these devices to dampen the inter-region oscillation mode of our test network, and no longer in tension support. We will return first to the influence of the insertion of STATCOM in the network alone before analyzing the interaction of a STATCOM with a PSS, then two STATCOMs. So the results depend of type of FACTS devices and position and Influence and interaction with each other in the network.

3.3.1. Interactions STATCOM-PSS

After being interested in the interactions between the STATCOM and the machine protocols. We will analyze here the interaction of a PSS and a STATCOM. The latter will successively be placed on the node LB 13 and the node LB3.

3.3.2. Insert STATCOM on the node LB 13

The results obtained in this case in the form of eigenvalues and depreciation rates and the results obtained in the presence of the only PSS and the only STATCOM in order to highlight possible interaction phenomena. Only oscillation modes undergoing significant modifications are reported in this table. It appears here that the inter-region mode l3 is significantly less depreciated than for the STATCOM alone (0.16 against

0.31). It is not surprising to see a phenomenon of harmful interaction between PSS and STATCOM leading to a modification of the eigenvalues associated with the inter-region mode since these two devices have been adjusted in order to dampen this mode.

The l1 mode is more damped than for the PSS alone (0.55 against 0.47), although the STATCOM has, in principle, little action on this mode. The mode lsta4 linked to STATCOM sees, meanwhile, its depreciation rate increase (0.61 against 0.51). Finally, the depreciation rate of the PSS2 mode linked to the PSS is slightly improved (0.16 against 0.14). However, the examination of the factors participation teaches us that STATCOM and PSS both take art to these three modes of oscillation. Thus, the variations in the eigenvalues associated with these three modes are the result of the PSS-STATCOM interaction which, if the latter was detrimental in the case of the interregional mode, shows a positive effect for these three modes.

Figure 8(a) illustrates the degradation of the inter-region mode. The degradation of the damping of the inter-region oscillation mode with respect to that obtained in the presence of the STATCOM alone appears clearly. This longer oscillatory response is found on the voltage as shown in Figure 8(b).

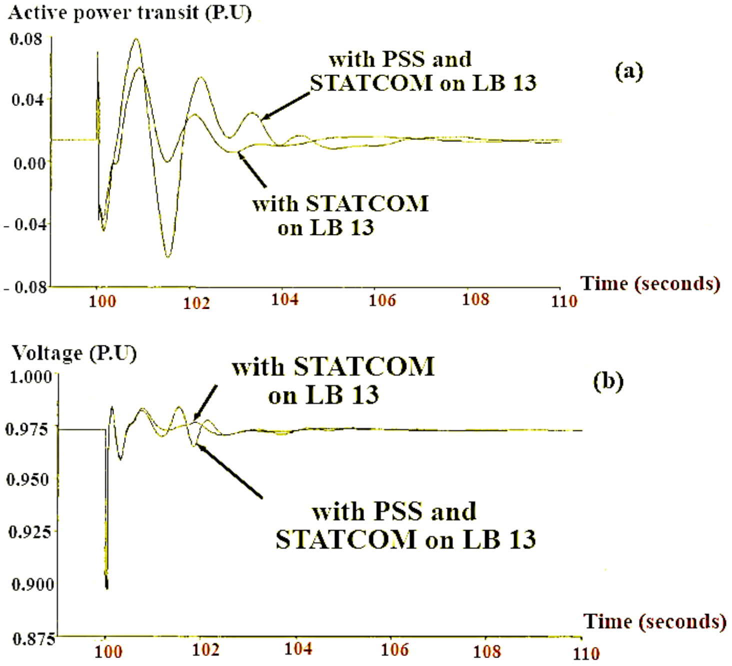

Figure 8. The effect of STATCOM and PSS-STATCOM on active power transfer and voltage: (a) transit of active power between LB 13 and LB3 nodes and (b) voltage at node LB 13 as a function of time

3.3.3. Insert the STATCOM on the node LB3

We then did the same job by connecting the STATCOM to the LB3 node. Here again, we find that the damping of the inter-region mode is significantly degraded (0.15 against 0.31 in the case of STATCOM alone). As for the local mode l1, it is this time also a significant decrease in its depreciation rate (0.23 against 0.47 for the network with PSS). The interaction that had proved beneficial for this mode when connecting the STATCOM on the node LB 13 appears harmful here. The same goes for the mode lpss2, which sees its depreciation rate fall from 0.14 for the network with PSS to 0.08 in the presence of the STATCOM. Whereas we had only noticed a weak interaction phenomenon, which is more positive, in the case of the STATCOM on the node LB13, we are here in the presence of a phenomenon of interaction between PSS and STATCOM causing a very net depreciation of this mode. The lsta4 mode, meanwhile, sees a very significant improvement in its depreciation rate (0.75 against 0.50 for the STATCOM inserted alone in the network). As before, the PSS-STATCOM interaction is positive for this mode of oscillation. However, we can note that this interaction phenomenon is more "violent" than for the STATCOM connection to the LB13 node. Finally, the oscillation mode l4, which was not concerned with an interaction phenomenon when the STATCOM is connected to the node LB13, is this time subject to a PSS STATCOM interaction phenomenon whose action is beneficial since its depreciation rate reaches 0.57 against 0.35 for the network with PSS and 0.30 for the network with STATCOM. The PSS-STATCOM interaction phenomena are therefore more "virulent" for the STATCOM connected to the node LB3 with respect to the STATCOM connected to the node LB13.

Figure 9(a) shows the degradation of inter-region damping during the simultaneous insertion of PSS and STATCOM. The degradation of the damping mode lpss2 can be observed on the excitation voltage of the generator G1, which generator accommodates the PSS. Thus, from Figure 9(b), we can notice, in comparing the excitation voltages of the machine G1 in the case of the network with PSS and in the case of the network with PSS and STATCOM the presence of the oscillation linked to this mode.

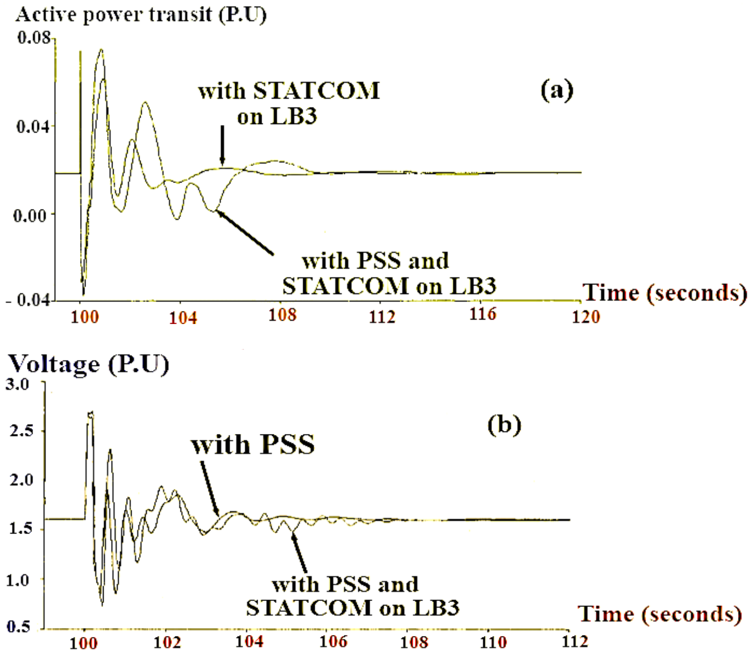

Figure 9. The effect of STATCOM and PSS-STATCOM on active power transfer and voltage (a) transit of active power between nodes LB 13 and LB3 as a function of time and (b) machine excitation voltage G1 according to time

3.3.4. STATCOM-STATCOM interactions

Finally, we inserted the two STATCOMs together in the network. One is connected to node LB3, the other to node LB13. The results obtained by the small-signal study indicates the inter-regions mode undergoes a modification of its damping rate (0.23 against 0.31 for STATCOMs inserted alone in the network). Indeed, the FACTS devices both acting on this mode, it makes sense to note a STATCOM-STATCOM interaction resulting in an evolution of the eigenvalues associated with this mode. Finally, it should be noted that, although its damping ratio is constant, the lsta4 mode, a mode related to STATCOM regulation, is subject to a phenomenon of interaction between the two FACTS devices since the eigenvalues associated with that see a strong evolution.

In large electrical networks, electromechanical oscillations of low frequency persist over long periods of time and, therefore, limit the transit of power. We distinguish local modes, which see the participation of a few machines close to each other, and inter-regional modes, which correspond to exchanges of power across lines interconnection between groups of machines. With the growing interconnection of power systems, the potential for very weakly damped inter-regional oscillations has greatly increased. FACTS devices have the advantage of responding quickly to changes in networks and can be located near the interconnection lines. However, their insertion causes phenomena interaction with network elements (machine regulations, PSSs, and other FACTS devices), whether these FACTS devices are used conventionally or to dampen power oscillations. These interactions can degrade the damping of certain modes of oscillation and even lead to instability, or to reveal new modes of oscillation. It therefore appears necessary to coordinate the various FACTS schemes and certain elements of the network such as PSSs.

3.4. Application of influence indices

Influence indices were applied for the 2 networks already used for the study of sensitivity indices. It is therefore the test network 4 machines 2 zones and the real network 29 machines. We will focus on three configurations of this test network: insertion of a STATCOM in the network alone, in the network with PSS and in the network in the presence of another STATCOM.

3.4.1. Inserting the STATCOM into the network alone

The influence indices were determined in this test network for the STATCOM inserted successively on each node of the network. For each positioning of the device FACTS, the indices were calculated for all the nodes of the network. We will present here only the zones of influence determined after insertion of a STATCOM on the node LB1.

3.4.2. STATCOM connected to node LB1

The index is very high at the STATCOM connection node Figure 10. The STATCOM is very influential on its node of connection because it interacts with the regulations of the machines. In addition, we find high indices for the LB2 and LB3 nodes which are the most proximal nodes of the STATCOM. Finally, the influence decreases with the electric distance.

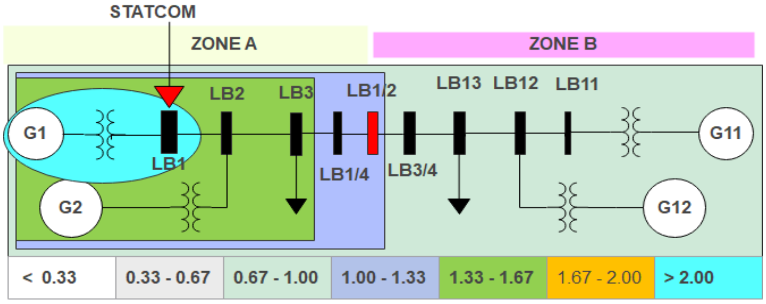

Figure 10. Areas of influence of STATCOM connected to node LB1 into the network alone

3.4.3. Insertion of the STATCOM in the presence of a PSS

We will focus here on the influence of STATCOM when it is inserted in the network with PSS. The PSS is added to the voltage regulation of the machine G1.

- Influence of the STATCOM; The determination of the influence indices was carried out for all the positions of the STATCOM. We will present here the influence zones determined for the STATCOM connected on node LB 1 and on node LB3/4.
- STATCOM connected to node LB1; Figure 11 shows the zones of influence of the STATCOM when it is connected to node LB1. At the STATCOM connection node, the influence index is maximum. Once again, the influence of STATCOM on the nodes of zone A is important. As soon as one moves away from node, the index of influence decreases very markedly. The results obtained are therefore logical.
- STATCOM connected to node LB3/4; The STATCOM is now connected to the LB3/4 node, i.e., to a node located on the interconnection line. Figure 12 gives the zones of influence of the FACTS device.

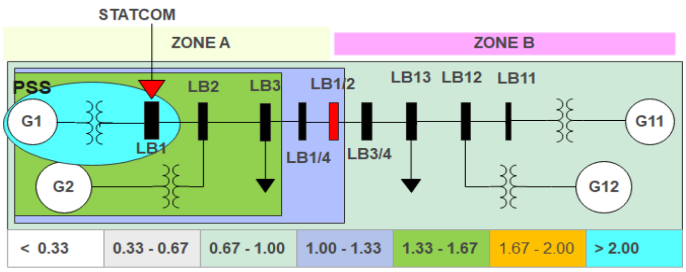

Figure 11. Areas of influence of STATCOM connected to node LB1 in the presence of a PSS

The STATCOM, deviating from the zone A, escapes little by little to the zone of action of the PSS. Also, the influence index is lower at the connection node than in the previous case. The interaction phenomena between the PSS and the FACTS device and between the machine controls and the FACTS device are less violent, and the influence of the latter lower on the disconnect node. On the other hand, because of its more "central" positioning, the STATCOM sees its influence on the distant nodes more important than in the previous case. Indeed, the electric distance between STATCOM and the most distant node (LB1) is weaker than between STATCOM and the node (LB I) in the previous case.

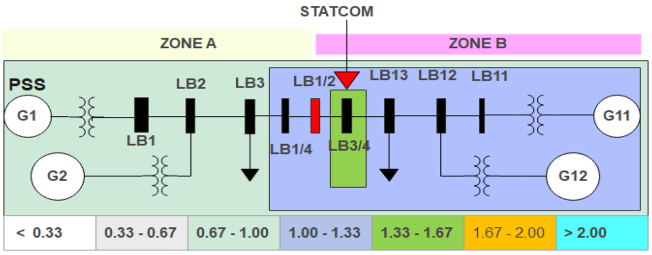

Figure 12. Areas of influence of STATCOM connected to node LB3/4 in the presence of a PSS

3.4.4. Insertion of the STATCOM in the presence of a first STATCOM

The network is now equipped with a first STATCOM. This one is connected to the node LB3. We will present here the results obtained for the connection of the STATCOM on the node LB1 and on the node LB3.

- STATCOM connected to node LB1; The influence zones of STATCOM are given in Figure 13. The influence is maximum for the node LB3 hosting the first STATCOM. Indeed, the interaction phenomena between the two FACTS devices are important. The influence is also high at the connection node of the second device FACTS. Finally, the influence is weaker for the distant nodes, namely those of zone B.
- STATCOM connected to node LB3; STATCOMs are now both connected to the LB3 node, as shown in Figure 14. The maximum influence is obtained at the connection node of the two STATCOMs, reflecting the interaction phenomena between the two FACTS devices. Moreover, we can observe that the influence is higher for the nodes LB1 and LB11 because we are presence of interactions between the regulations of the machines GI and G II and FACTS devices.

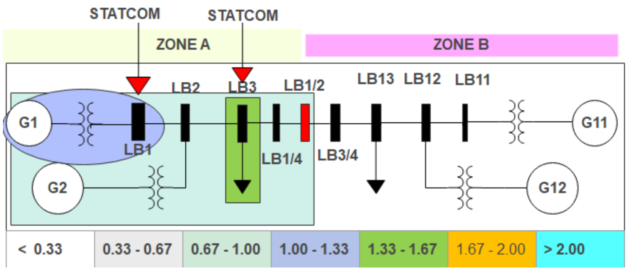

Figure 13. Areas of influence of the STATCOM connected to node LB3 in the presence of a first STATCOM

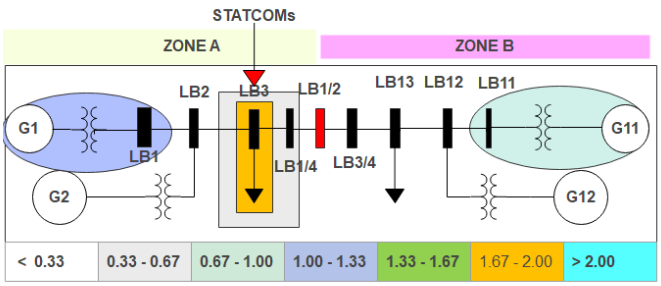

Figure 14. Areas of influence of the STATCOMs connected to node LB3

4. CONCLUSIONS

In the context of the insertion of FACTS devices in the transport and interconnection networks, we focused our work on the study of the regulatory interaction phenomena related to the insertion of FACTS devices. After highlighting these interaction phenomena FACTS-regulation machines, FACTS-PSS and FACTS-FACTS, we focused on coordinating the interacting devices through two optimization techniques: a method of the “minimax” type and a decentralized linear quadratic method. We have thus highlighted the limits linked to coordination. Indeed, if the interaction phenomena are very violent, a coordination of the interacting elements can result in the under-exploitation of these devices. We then developed sensitivity indices derived from the concepts of controllability and observability. These are calculated before insertion of the FACTS devices and make it possible to predict the importance of the interaction phenomena according to the positioning of the FACTS device.

As a result of this work, several areas of study can be identified: a) generalization of the use of sensitivity indices to all FACTS devices (FACTS series and universal), b) distinction between “harmful interaction” and “beneficial interaction”. It is a question of not rejecting by the application of the sensitivity indices a positioning of the device FACTS that would result in the improvement of the dynamic stability by a phenomenon of beneficial interaction, c) coordination by grammars. The coordination techniques envisaged in this paper call for a modal study which can be very cumbersome. So, we can consider realizing the coordination by using the concord of the controllability grammars by quantifying the minimum energy needed to recover the equilibrium state after the incident, d) setting of FACTS devices from the energy concept (energy dissipation function). The regulation structure based on this approach uses the Lyapunov principle, namely that each subsystem (FACTS, PSS, ...) must have the derivative of its energy function less than or equal to zero. Thus, the regulation structure is decentralized and does not require coordination. It does not depend on the structure of the network, nor the state of charge of the network, nor the place of the disturbance (default), e) setting of FACTS devices from Linear Matrix Inequality (LMI) techniques. The work to be done is so bulky, f) the degradation of inter-region damping during the simultaneous insertion of PSS and STATCOM, g) it necessary to coordinate the various FACTS schemes and certain elements of the network such as PSSs, h) the influence indices are very high at the STATCOM connection node, the influence decreases with the electric distance, i) the interaction phenomena between the PSS and the FACTS device and between the machine controls and the FACTS device are less violent, and the influence of the latter lower on the disconnect node.

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BIOGRAPHIES OF AUTHORS

Kamal Mohammed Saleh Al-Azzawi is currently a lecturer in Diyala's General Directorate of Education, Baquba, Diyala Province, Iraq. He received his BSc in Electrical Engineering from University of Technology, Baghdad, Iraq in 2000. He, also, received MTech. Power systems and control from Acharya Nagarjuna university, India in 2015. His research interests are in power system, control and Electronic Engineering. He can be contacted at email: kms01424@gmail.com.

Muntadher Ali Abd is currently a lecturer in Baghdad Al-Karkh Third Directorate of Education, Baghdad, Iraq. He received his BSc in Power Technology Engineering from Al-Mamoun University College, Baghdad, Iraq. He, also, received MTech. Power systems and control from Acharya Nagarjuna university, India in 2015. His research interests are in are in power technology and related fields. He can be contacted at email: aazzewvgf1234567809@gmail.com.