Study and Simulation of Voltage Profile Recovery on a 200 km Transmission Line Using Shunt Static Var Compensator (SVC)

Rennivan Simões Louzeiro
renivan1812@gmail.com
Centro Universitário FAMETRO – Manaus, Amazonas – Brasil

Livia da Silva Oliveira
oliveira.livia@gmail.com
Centro Universitário FAMETRO – Manaus, Amazonas – Brasil

David Barbosa de Alencar
david002870@hotmail.com
Galileo Institute of Technology and Education of the Amazon – ITEGAM

Roger Santos Koga
kogaroger@gmail.com
Coordenação de Engenharia da Universidade Nilton Lins – Brasil

Abstract

This article aims to clarify how Flexible Alternating Current Transmission Systems (FACTS) technology, for static operating devices, conditioned on application to long-distance transmission lines can solve problems related to voltage drop on paths known as "weak zones" of the power transmission system. Some technical aspects of the construction of the SVC Static Reactive Compensator in conjunction with thyristor switching devices such as TCR and TSC are described. The proposed scenario is similar to the Brazilian interconnected system, where much of the generator park is hundreds of miles from the country's major consumer centers, leading to the structure of this system longer transmission lines and consequently greater losses in the transmission paths. For the proposed simulations the MATLAB Simulink ® environment was used considering different voltage unbalance operating ranges caused by three-phase faults in the transmission lines. The conclusions show that the distance from the lines to the load has a great influence on the oscillatory effects of voltage, and the fact that the "loading" transmission lines can compensate for much of the path by generating wars through the circuit's natural capacitance. The allocation of capacitor and shunt reactor banks is a reliable option for the transmission system and can act as a support mechanism for voltage control maneuvers to circumvent abrupt changes in reactive demand. From the simulations output comparison, the transient effects showed greater stability in the voltage signal recovery in the stretches where the compensation blocks were located near the lowering substation bus, thus demonstrating the capacity of the applied technology.

Key words: voltage regulation; facts; transmission lines; reactive power;

1. Introduction

Demand loads in electrical power systems are mostly nonlinear, meaning that much of the time demand characteristics change as different types of loads are driven by consumers. This natural behavior of the grid often implies close control by the system operator, because the operational safety of the system coupled with the guarantee of continuous supply of electricity. It is legally guarded by the government that failure to comply with the specifications established for the operation of the guidelines within the minimum grid frequency and system stability standards can cause significant harm to consumers of all voltage levels it meets.

This study addresses the three layers, with greater emphasis on the primary (generation plants) and secondary (transmission lines) spheres. The Brazilian scenario is home to great geographical diversity and has what is considered one of the largest interconnected energy supply systems in the world. The challenges of expansion are constant because the geography of each region of the country is different and requires large studies for the implementation of transmission network infrastructure for the transportation of energy to the major consumer centers of the country. But while the country has an essentially diverse energy matrix, taking advantage of the intermittence of each power source in its territory, this system faces a problem attributed to the extension of this transmission grid network. Since most generation plants are built far from large urban centers, the high cost of installing new power systems and the fact that the farther these power plants are located, the greater the electrical losses, there is a growing problem of financial and economic magnitude. Flexible Alternating Current Transmission Systems (FACTS) technology, which has been devised for more than two decades and has been increasingly highlighted by the advanced technology capability in the electrical systems segment, reflects its revolutionary potential in a scenario where electricity has become an increasingly scarce good to all humanity.

2. Theoretical Reference

2.1 Electric Power Transmission Overhead Lines

Used to transmit electricity from generation sites to consumer centers by means of conductive cables, overhead power transmission lines are constructed so that an interconnected sine-wave operation system is achieved. [1].Throughout the consolidation cycle of technologies for more efficient and quality transmission of electricity, there is an increasing demand for flexible systems based on power electronics in which they are used for the control of electrical losses and voltage stability on transmission lines. Its implementation is mainly due to the scenario of the current power generation plants, which concentrated in most of the urban centers, implies longer routes for the transport of energy, which consequently substantially increases the electrical losses linked to the extension of the lines. of transmission [2] [9].

Transmission lines have four important characteristics to consider: series resistance, parallel conductance, series inductance, and parallel capacitance. And for the study of this paper we use the model π for transmission lines with medium extension (80 to 240 Km) in which the parallel admittance in two equal parts is considered [1].

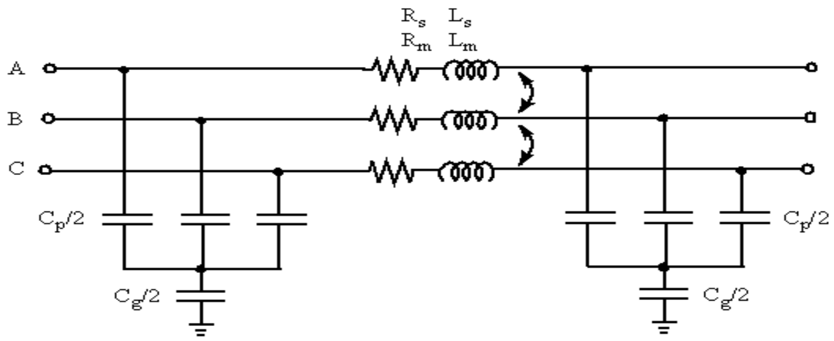

Figure 1: Pi (π) model for transmission lines.

2.2 Equation for Load Flow in Transmission Lines Model π

The representations of the π model used follow three fixed parameters: r_{km} series resistance; the X_{km} series reactance; and the shunt b_{km}^{sh} susceptibility, so that we have between bus k and m the impedance Z_{km} which according to [2] is described by:

$$Z_{km} = r_{km} + Jx_{km} \tag{2.1}$$

The transmission line given to the inductive component, makes the elements conductance and susceptibility positive. Since the shunt element is capacitive then, b_{km}^{sh} is positive. The terminal and parameter voltages of the model π used have the current I_{km} and I_{mk} formed by a series component and a shunt component that are calculated from them. Therefore, E_k e E_m are the tensions in bars k and m as below:

$$I_{km} = y_{km}(E_k - E_m) + jb_{km}^{sh}E_k \tag{2.2}$$

$$I_{mk} = y_{km}(E_m + E_k) + jb_{km}^{sh}E_m \tag{2.3}$$

$$E_k = V_k e^{j\theta_k}; \; E_m = V_m e^{j\theta_m} \tag{2.4}$$

2.3 Voltage Profile Recovery in Electricity Transmission Networks

The distortion effects of the voltage profile are mainly caused by the inductive and capacitive elements inherent to the equipment that make up the Electric Power System (EPS). Inductive reactive loads are very common in these systems and have as their main consumer destination industrial motor groups that are naturally large consumers of inductive reactive power. The electromagnetic fields of these motors require the circulation of inductive reactive elements to maintain their operation (when designed in the EPS model), which disables part of the capacity of the transmission lines and generate losses in active power transport due to the inability to generate effective work. by the reactive power [3].

2.4 Flexible Alternating Current Transmission Systems - FACTS

Flexible Alternating Current Transmission Systems (FACTS) belong to the family of power electronics-based controlled devices developed for the purpose of increasing control and power transmission capability, unlike the family of switched and advanced FACTS. Reactive power control in so-called SEP “Weak Zones” increases the degree of voltage stability resulting in lower losses along power transmission paths and greater control flexibility of electrical systems. [4] [8].

2.5 Static Var Compensator (SVC)

Static Compensation (SVC) devices use reactive elements (capacitors and / or inductors) which, depending on the need for implementation, are adjusted to achieve the desired compensation. Another important feature of these devices is that their Shunt connections give them the ability to generate or absorb reactive power where they are connected and are perfect elements for varying and controlling certain quantities such as voltage [5] [10].

2.6 Thyristor Switched Capacitor – (TSC)

It consists of a capacitor bank assembly in which thyristors form a switch whose circuit is used to connect or disconnect from the power system. In this way reactive power is injected into the system discontinuously through the keyed seat. Resonance effects associated with switching transients are mitigated with the inductor connection which also provides safe damping of the magnetization currents of the circuit. Since the switching performed is low frequency, there are no problems related to harmonic disturbances and are therefore irrelevant to the system [3] [6].

2.7Thyristor Controlled Reactor - (TCR)

The basic building block of the TCR is an inductor connected in series to a switch consisting of two bidirectionally connected thyristors. The tripping angle α determines at each half cycle of the fundamental frequency its conduction alternately when the voltage level crosses its zero value, the zero of the voltage. Through its bidirectional switching capability, you have control of the thyristor firing angle where it becomes possible to control the current as well as the driving time for each half cycle of the fundamental wave. Within the limits of the device's trigger angle control, continuous current adjustment is obtained which gives greater variability in terms of absorption control or reactive power injection within the nominal TCR values [6] [7].

3. Applied Methodology

For this study was used the MATLAB Software version R2017b that offers parameters for problem solving and analysis for different conditions and scenarios to the academic and professional. From the Simulink ® environment, whose space is intended for the simulation of scientific problems based on the configuration of mathematical base parameters, it also has a vast collection of complementary libraries for which one was used in this work called *Simscape Power Systems*, this library. allows you to set parameters of electrical systems and electrical and electronic devices for linear or nonlinear optimization, with time domain and frequency domain modeling. The models shown (Figures 2 and 3) represent the bases used for the construction of simulations that start from values where it is expected to achieve a high level of performance of capacitor banks, considering that their allocation is in derivation with transmission line and thus establish capacitive gain conditions in the critical sections between the transmission lines.

In this scenario of simulations, it was considered to represent the various disturbances and failures in the transmission network through the illustrative block called Three Phase Fault, which represents, among other situations, the occurrence of voltage dips or dips along the transmission paths transmission of electricity over long distances.

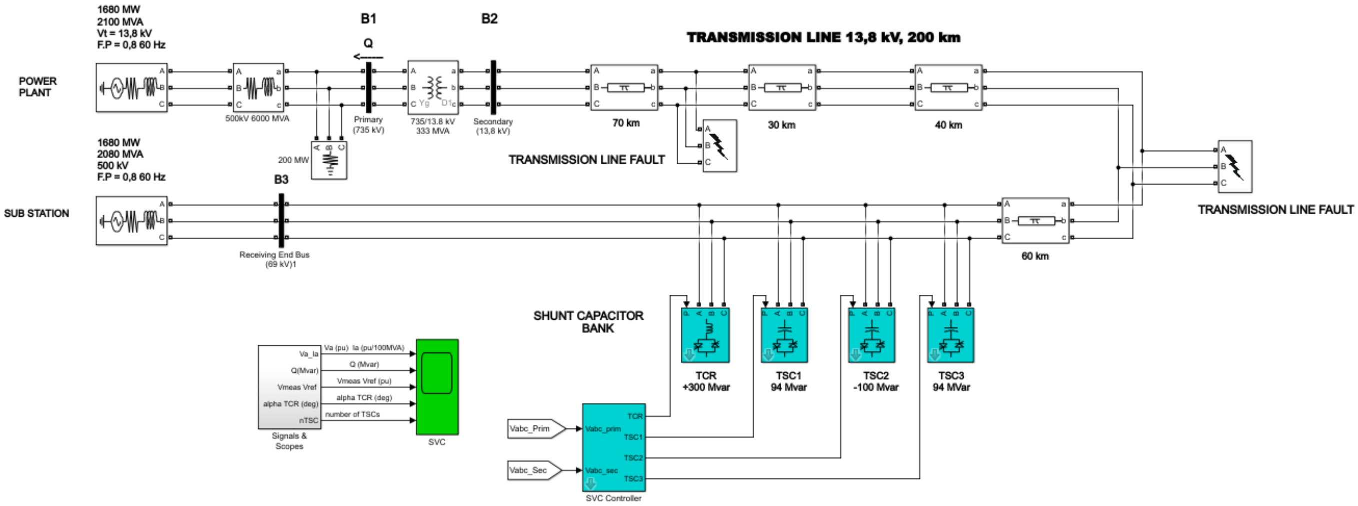

Figure 2: HVAC Receiving Bus Shunt Compensation.

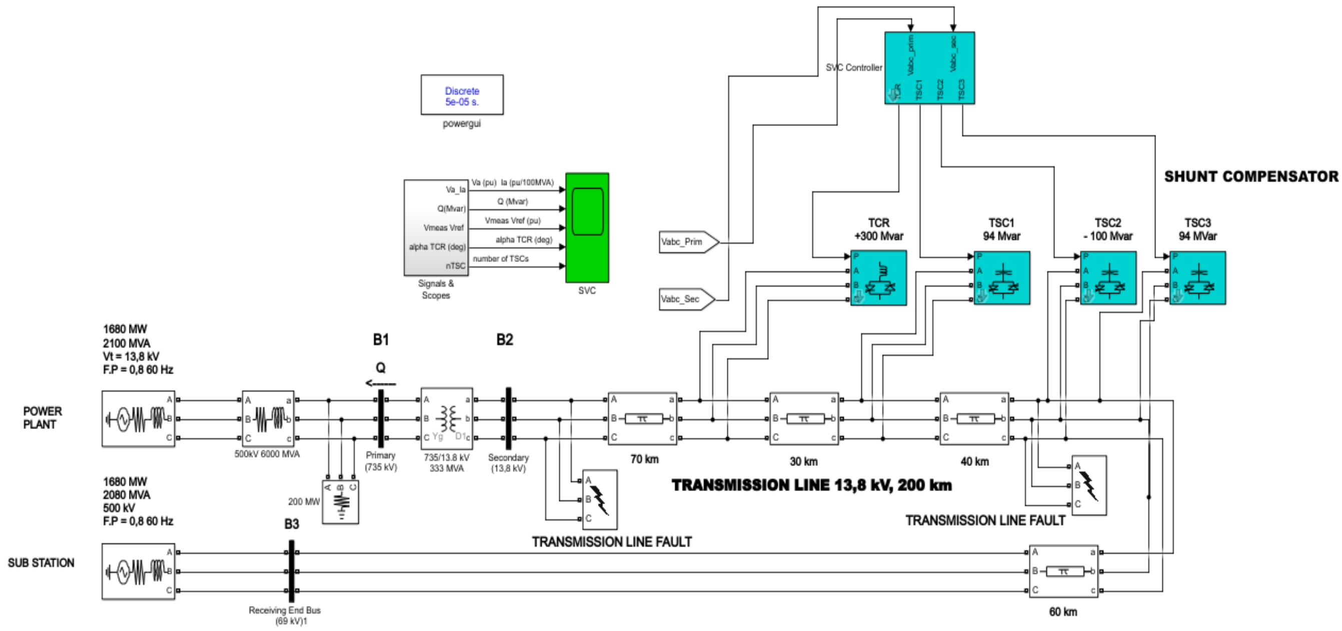

Figure 3: Shunt Compensation at Intervals in an HVAC System.

The proposed modeling uses equal values for the two reactive zone compensation scenarios that are prone to voltage drops. The data resulting from the voltage and power values (inductive reactive and capacitive reactive) were obtained from the Matpower library together with the same Simulink interface. Thus, some samples of the voltage profile during the energy transport path of the generation plant to the load feeding substation. It was necessary to note in this article the voltage transmission pattern of the large energy blocks, like the Brazilian context, values that vary according to the location of the generation plants and the availability conditions of the transmission circuits. Between the regions connected by the Brazilian Interconnected Electrical System - BIES. Thus, the values 500 kV, 735 kV and 13.8 kV are the most common values of electric current transmission in the country. The highest value (13.8 kV) determined the condition of voltage rise from the isolating bus B2 (secondary of the transformer elevator) from the generating plant.

The representation model for the transmission lines used (model π) emerged as the least expensive option for the mathematical simplifications related to the division of parallel susceptibilities and capacitive and inductive line reactance. The transformer used is a delta three-phase three-winding model whose rated operating frequency in the grid is $336e^{6}$ at 60 Hz. For transformer bars B1 and B2, the substation in B3 was of the magnitude measurements of phase-to-ground faults in B1 on the primary bus, while in B2 (secondary) the occurrence of phase-to-phase faults was measured. Under "normal" conditions of full-load operation this transmission system would be able to establish self-charging line conditions compared to a capacitor that charges slowly over time.

Therefore, the objective behind the high values of capacitive reactive power and inductive reactive power used in devices comprising capacitor banks sought to reach the maximum operating range of the transmission line circuits. The more critical the demand for supply line reactive supply or substation load supply became, the more these instruments were required to intervene so that the voltage values would not sink or increase uncontrollably. For the initial load conditions, 1680 MW of active power to be transmitted by the grid was established, with an ideal power factor FP = 0.8 at 60 Hz. Reactive compensation is required by the grid to regulate and maintain the voltage profile. So that the transmission pattern does not show too much loss or abrupt voltage drops. Rapid maneuvering of the system to maintain this balance requires continuous monitoring as demand does not follow a standard curve throughout the system. Values of + 300 / -100 Mvar are used in shunt capacitor bank controllers for power factor conditions closer to optimal operation for voltage stability over much of the transmission path.

The Thyristor-TCR Controlled Reactor (Figure 4) provides inductive characteristics to the voltage waveforms. Given this fact, in the proposed power system we tried to establish load parameters in which the values of the angle α most closely approximated the value. Optimal for power factor FP in power per unit p.u.

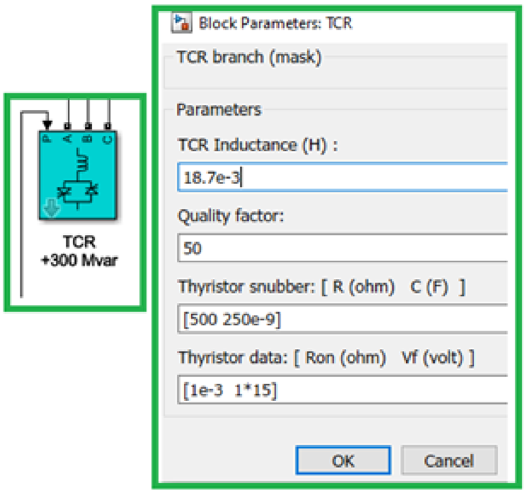

Figure 4: TCR Controller Parameterization.

The parameterization of the TSC 1 Thyristor Switched Capacitor Arrangement (Figure 5) operates in conjunction with the reactive static compensator. The pre-set parameters had values above 30 Mvar for the "shortening" of the transmission line and increased the gains upon application. These devices were associated in a group of 3 subdivided into 94 MVar value for absorption or shunt compensation in conservative controlled operating mode.

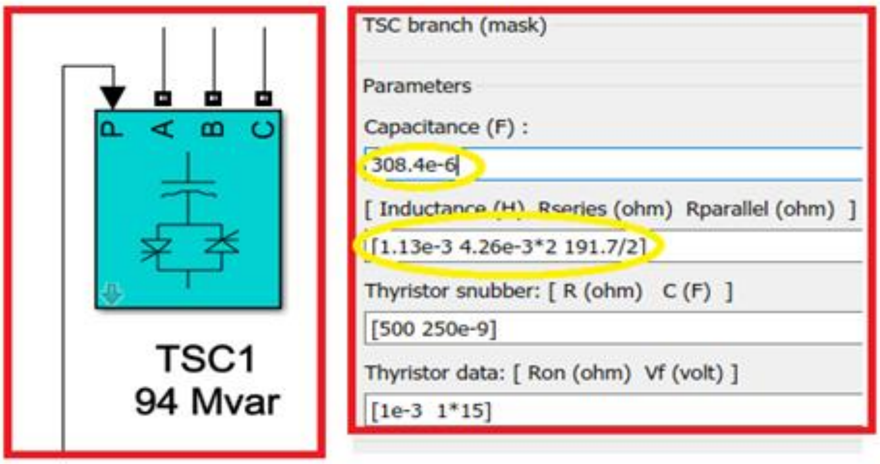

Figure 5: Thyristor Switched Capacitor.

According to the operating characteristic of the thyristor switches, the number 3 TCS will operate with a 3% cut-off factor when the previous ones are triggered, so it must be placed in a ready response condition for line reactance compensation transmission (Figure 6):

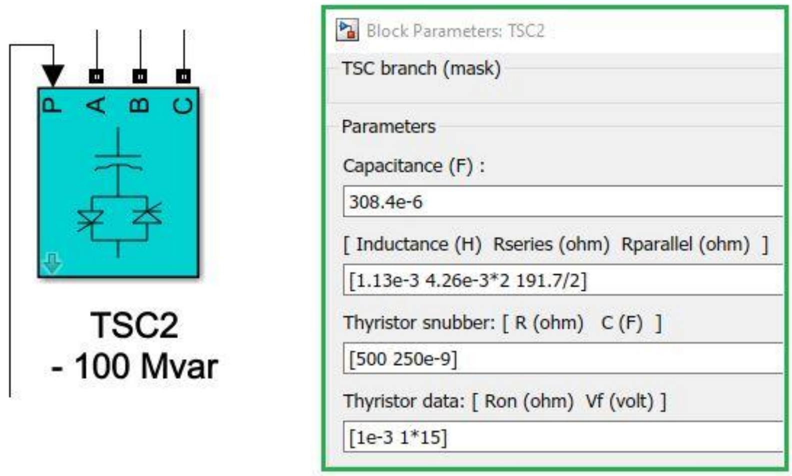

Figure 6: Thyristor Switching Capacitor 2

For the set three of thyristor keys the same values were established as in the previous figure:

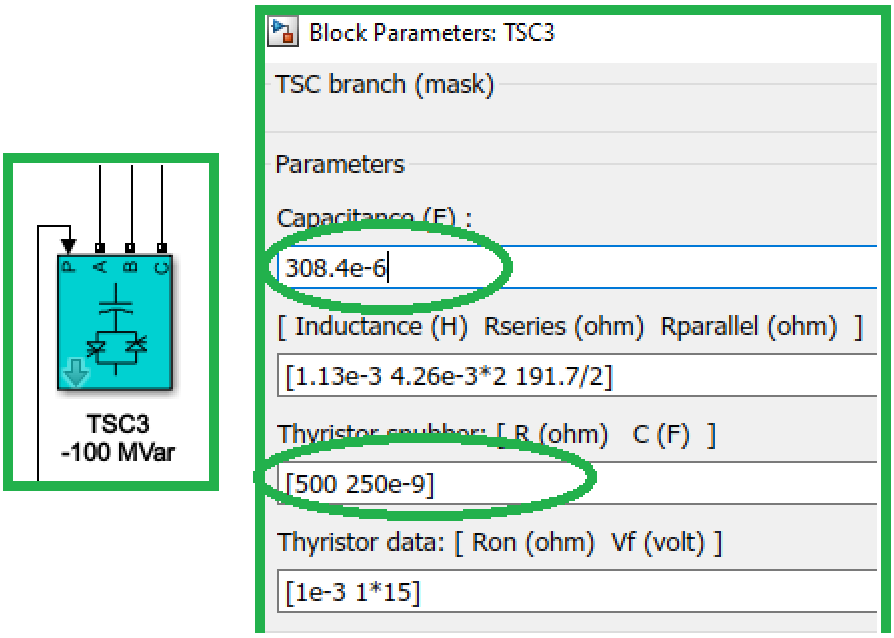

Figure 7: Parameterization of the Thyristor Switched Capacitor

The arrangement parameters of this device (Figure 7) aimed to retain the maximum reactive power consumption in the final feeder bus (B3) aiming to establish higher quality and stability in the wave signal received at the substation.

4. Analysis and Discussion of Results

As the system requires periodic injection of reactive power to bus B1 it is noted that the voltage profile is distorted in the switching interval between 0.5 s and 1 s of tripping of the controller switches, being characteristic of the capacitors connected in bypass to delay the effects of currents on bidirectional circuit switching.

Simulation 1

For case 1 it was observed that the voltage signals especially in the execution of control techniques 2 and 3 with the switches in the on / off mode (Figure 8) made the same high distortion rates with the experiment on the transmission bar B1.

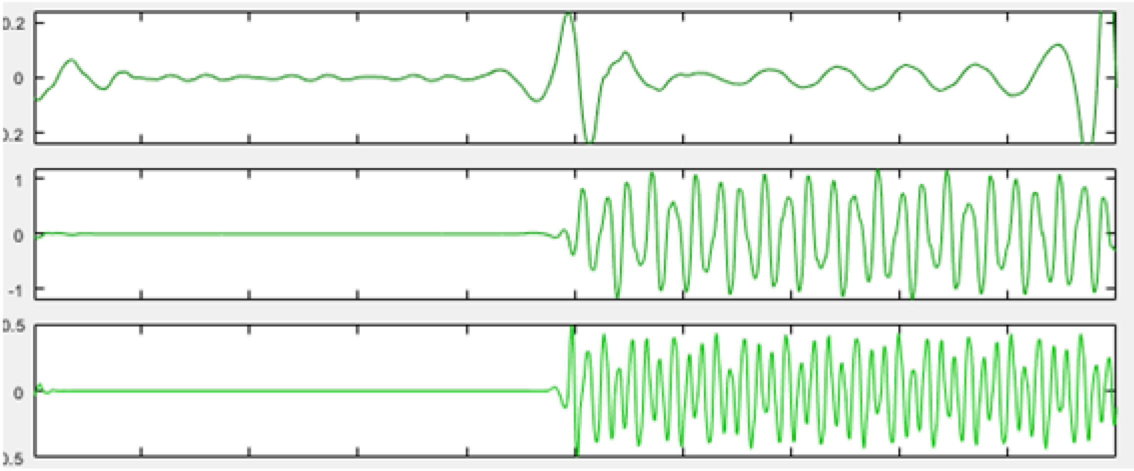

Figure. 8: Effect of Static Control on Bus 1 and Bus 2

The histogram of the switched circuit bus frequency B1 of the transfer circuit exemplifies that under conditions of continuous reactive power supply in the system, the estimated time between the TSC and TCR switch keys is respectively 1,025 for switching over the analyzed frequency range, which is 60 Hz. The need to transmit large blocks of energy has caused the transmission networks to work very close to their thermal capacity, which often places extra stress on the transmission tower structures and cables that wear out faster due to the Joule effect and suffer from it. Consequent losses even if they mean little at first, causes such as: corona effect, ambient temperature wear and air ionization, the Ferranti effect between the lines are some of the many problems that may be inserted in this same context.

Simulation 2

For case 2 it was installed in the same parameters of the first example with the change of control time of the switches in the period T = 0.1 according to the system requests for reactive power injection in bars B2 and B3, which meant in this case high levels of voltage signal disturbance in simulations for B1 and B3 (Figure 9). Case 3 showed some stability but with large fluctuations in the interspersed pathways.

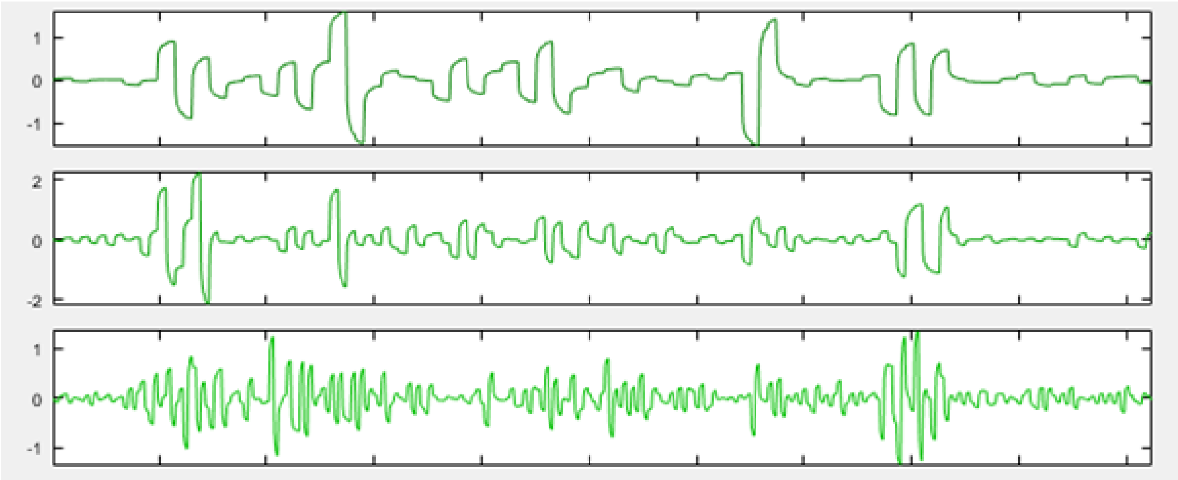

Figure 9: Controllers Acting on Bus B1 and B2

Similarly, case three represented gains in signal quality, unlike case one and two, the transmitted frequency signal showed higher positive fractions, which means greater control capacity at bus B2 terminals resulting in fast recovery capability (Figure10).

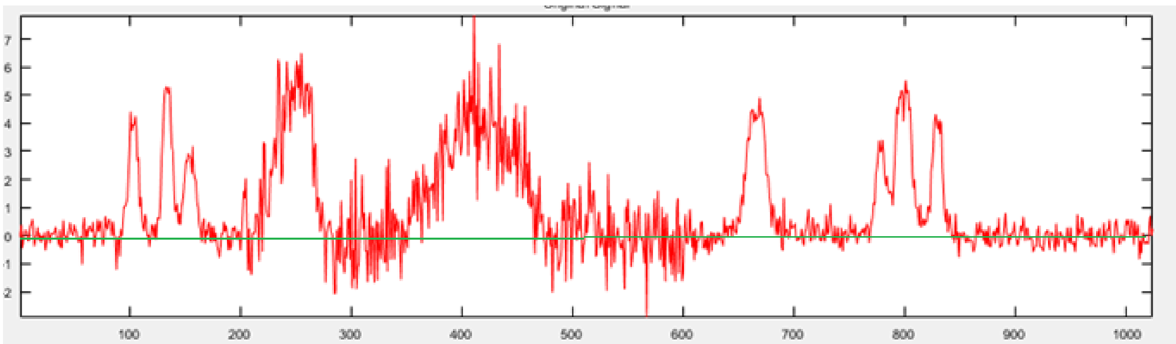

Figure 10: Positive Sequence of Capacitor Bank Operating Range

As the substation buses achieve a good level of inductive reactive power continuously throughout full load operation, this is because the power factor generated satisfactory gains on the real side of the power triangle.

Simulation 3

Case 3 was with the compensation device operating in linear regime, without control interventions for the analyzed section, in this case the bus B4 (substation), the receiving bus meant among the previous cases the best response in time since the inductive reactive power parameters to be injected / absorbed on transmission bus B2 allowed the system greater absolute gain capacities in power per unit p.u.

The voltage signal showed strong variations in the stretch, but from the moment when bus B2 received reactive power compensation via bus B3, the line quickly drained its inductive reactive state to more capacitive reactive, thus contributing to the input voltage stability. Without much impact on substation control devices. The signal behavior and its stability trend are gradually recovered at the end of each controller trip (Figure 11).

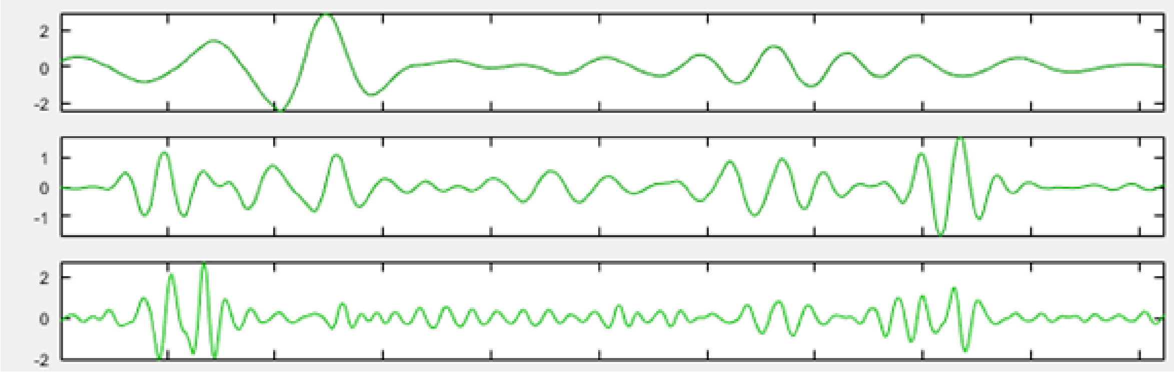

Figure 11: Recovery of transient voltage stability in B3

The switched frequency signal on bus B3 denotes greater stability of the voltage signal absorbed by the substation bars (Figure 11). It was noticeable that, being farther from the inductive reactive power absorption site in this case of the B1 bus, there was a slight decrease of the grid frequencies, which eventually also contributes to the reduction of the power factor for that moment at T = 0.10 s. This effect on bus B3, which can be considered the final stage of successive control strategies and / or recovery of voltage rises on critical transmission line paths (Figure 12).

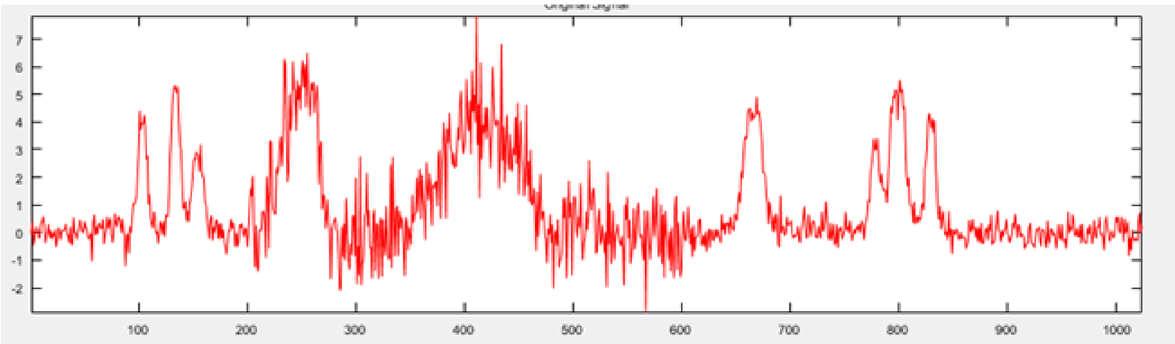

Figure 12: Voltage profile recovery at the end of the path B3 - positive range of the receiving bus (substation).

The values obtained in the final bus (substation) suggest that the positive sequence of the voltage signal after the capacitor banks actuation is effective. Signals observed on the secondary bus of the generating plant do not require shunt maneuvers.

Generation		Load		Losses	
MW	Mvar	MW	Mvar	MW	Mvar
273.9	113	259	73.5	14.9	39.5

Figure 13: Load balance and loss due to control delays.
Source: Adapted Matpower

As the load flow values suggest, losses tend to accumulate as the transmission lines reach their maximum transport capacity, this is due to the gain tendency that the disconnecting buses which in this case boils down to B3 maximum reactive values for voltage stabilization.

Flow			Losses	
MW	Mvar	MVA	MW	Mvar
159.1	-21	153.6	4.55	8.21
74.8	16.3	73.2	2.94	7.12
-154.6	29.2	152.7	4.55	8.21

Figure 14: Accumulated power flow and losses in the transmission bus of the plant.
Source: Adapted Matpower

5. Conclusion

Simulation results demonstrate the effectiveness of using reactive compensation in transmission lines. Stability margins require close control by the electrical system operator, and this is the exercise of continuous control of the balanced operating ranges of the electrical system. Especially when one can identify the behavior of demand throughout the day at times of higher energy consumption, the control technique enabled by FACTS device technology is an excellent long-term investment proposition.

The problem discussed in this paper can be distinguished mathematically as a midsize nonlinear programming problem, and there may be several variables and constraints. Having observed that the scenario modeling makes the criteria restricted to the study of this article itself. It is also evident that, in the Brazilian context of large urban centers, there is much to develop for the implementation of advanced technologies in the large Brazilian territory. Transmission system integration requires complex regional operators that operate with minimal electrical noise in the regional interconnection sections, the operation of the circuit routes behind the loss maximization and this study can serve as a basis for future developments to be applied in this context.

6. Acknowledgment

To the Engineering Coordination of the FAMETRO University Center and Professor M.Sc. Livia da Silva Oliveira, for their support in the development of this work.

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