AUTOMATION STRATEGIES FOR THE HIGH VOLTAGE ELECTRICAL TRANSMISSION SYSTEM IN COLOMBIA

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Abstract: - This paper presents the technical impact that new technologies for automation and control connected at high voltage networks, i.e. 230 and 500 kV, would cause in the Electrical Transmission System in Colombia (ETSC). It is shown why there is a need for the automation of such high voltage networks, what is the possible equipment for automation and what are the chances for the recent power electronic based equipment HVDC and FACTS. According to expansion plans, international power exchanges opportunities and future challenges of the ETSC, digital simulation models that involve power electronics, automation and control systems have been developed using several world recognized software programs. The results have been compared against solutions based on conventional equipment. The advantages for the automation of the ETSC with recent technology are shown.

Key-Words: - Automation of high voltage networks, control systems, power electronics, HVDC, FACTS.

1 Introduction

The deregulation of the electrical networks requires new challenges that the companies have to meet in order to be competitive and supply a high level in the quality of the service. More than ever, the utilities and transmission systems must compete with high levels of reliability and avoid technical problems like bottle-necks, power closed loops, instabilities, shut downs and power swings. Such requirements are sometimes difficult goals to reach with conventional equipment like transmission lines. The solution is also difficult taking into account that nowadays there are environmental laws that control the growing of transmission lines. In the recent years, the growing of the power electronic and control systems have allowed the development of high capacity commutation systems. These systems connected in the high voltage networks allow automated solutions not available with conventional equipment until now. Now, the high voltage transmission systems could be automated and have controllable conditions. These equipments are the Flexible AC Transmission Systems (FACTS) and the High Voltage Direct Current transmission (HVDC). The application of these solutions has been slowly increasing in the world with excellent results. Anyway, since it is a new technology and it is composed of new elements and configurations, and since each country network has its particularities, there is always an uncertainty of which could be the results or the response of the networks once new automation or controlling equipment is installed.

In Colombia a theoretical exploration and analysis study with recent technology has already been initiated, while a first generation controller called SVC (Static VAR Compensator) has been installed [1], but it is a must to give definitive steps towards generic automation of the Electrical Transmission System in Colombia (ETSC). In this work, in Section 2 the ETSC is briefly described and some technical typical solutions, for problems that lead to new projects are mentioned. In Section 3, specific problems of the ETSC will be described and using digital models, developed with different world recognized programs, the operation of the networks without and with recent automated solutions will be simulated. Each automated solution will be explained. Finally, conclusions about the technical feasibility of the automation in the ETSC will be stated.

2 The ETSC

The Electrical Transmission System of Colombia (ETSC) is composed of more than 11,000 km of networks operating at high voltage levels at 220 and 500 kV. The total amount of power available is 13.000 MW. Colombia has international interconnections with Venezuela and Ecuador. And for year 2006 is projected one interconnection of about 250 MW with Panama and Central America. Also, for the future is expected to exchange through Colombia high amounts of power across The Region Andina (Bolivia, Ecuador, Peru, Colombia, Venezuela).

In Colombia, the entity in charge of planning the growing of the ETSC, the Unidad de Planeacion Mineroenergetica – UPME, has to deal with the most efficient solutions while taking care to the best cost-effective relations. Many times, the solutions for the ETSC are new conventional equipment like transmission lines, reactive compensation and new substations.

In the ETSC, it is common that the target for building a new line could be to gain an electrical balance in which more power can be shared between identified generation centers and its loads. This is how the unwanted power loops and bottle-necks are avoided. The problem is that for relative impedances, some existent lines stay with low amounts of load. Another reason for new lines could be the objective of increasing the electrical stability of the system, so that high amounts of power can be safely transferred.

Other conditions that lead to the reinforcement of power networks are the transient behaviors during strong conditions, i.e. short circuits. A short circuit could impact not only the faulted equipment but also neighboring important loads.

3 Automated solutions with FACTS and HVDC

3.1 The FACTS TCSC

FACTS are a set of new devices for the automation and control of electrical power systems [2]. These devices are mainly composed of electrical equipment (i.e. lines, capacitors, inductors, transformers), Power Converters (i.e. Thyristors, GTO's, IGBT's) and a Central Control System. According to the needs of the electrical systems different topologies of FACTS have been investigated and developed. The dynamic control and operation of a FACTS is a new possibility for today's needs in power networks.

The TCSC (Thyristor Controlled Series Capacitor) is a series FACTS employed for the control of the power flow in high voltage networks. In Fig. 1, the reactance X_{TCSC} is connected in series with the power flow through a transmission line. According to the expected behavior of the system, and known i.e., the actual power and current, the controller can dynamically modify the reactance X_{TCSC}. The modification is done by means of variation in the triggering angle of the converter thyristors. Now, the power system can accommodate itself to several desired operation points.

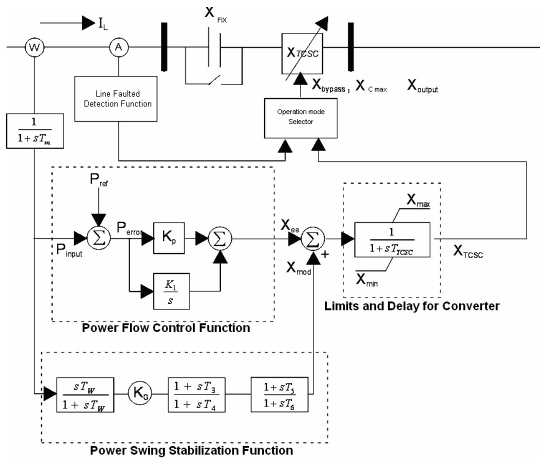

Fig. 1. The FACTS TCSC

A main application for which the TCSC was simulated in the ETSC was for the Power Flow Control Function, in which the line having the TCSC, forces the power flow to keep a reference. This allows other lines to have an adequate load transfer, avoiding overload conditions limiting the transfer capacity in certain regions of the ETSC.

For the purpose of the study of the impact of the TCSC, a digital model was built using the software DIgSILENT Power Factory ver 12. The model was included in a ETSC model having more than one thousand busbars.

According to the expected needs stablished by UPME in [3], a large 500 kV new network has to be built around 2006. The intention is to eliminate or decrease the restrictions of the region called Oriental. A main restriction is that under certain load conditions and topologies, the transmission lines Purnio – Noroeste (Fig.2) are overloaded, decreasing the possibilities of a power transit towards Oriental region, and so more power has to be generated inside this region allowing some generator utilities increase their energy costs. According to Table 1, with the 500 kV system alternative: El Sol – Primavera – Ocaña – Copey – Ternera, the lines Purnio – Noroeste are discharged in 133.84 MW. Instead of the last alternative, and after installing the TCSC in several places, it was found very advantageous to propose a new line Primavera – Noroeste with an Hybrid TCSC (composed of fixed and variable reactance) regulating the power through the line at 600 MW, see Fig. 3. According to Table 1, with this alternative the lines Purnio – Noroeste are discharged in 149.36 MW; more than the value reached with the 500 kV alternative. In the Base Case, without any new alternative, the lines Purnio Noroeste are at 84.4% of their load capacity.

TABLE 1.
ELECTRICAL RESULTS ACCORDING TO CONVENTIONAL AND FACTS ALTERNATIVES

Case/Alternative	Total charge in Purnio-Noroeste lines [MW]	Load Capacity [%]
Base	298.68	84.4
500 kV	231.76	65.5
Hybrid TCSC	224	63.3

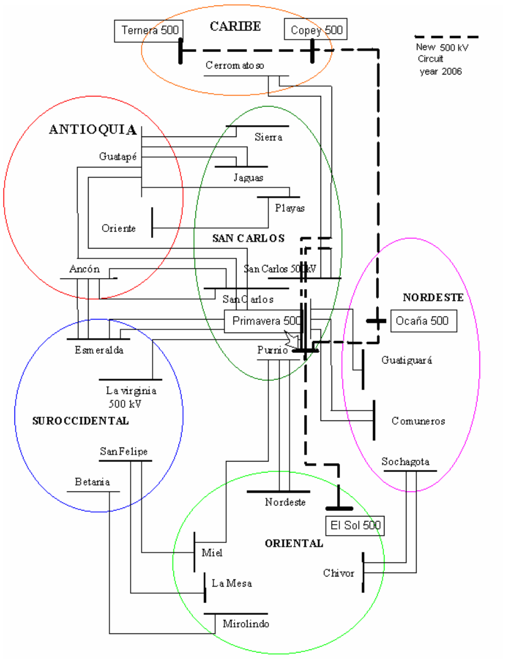

Fig. 2. Equivalent of the ETSC showing interconnection between Regions and proposed 500 kV expansion.

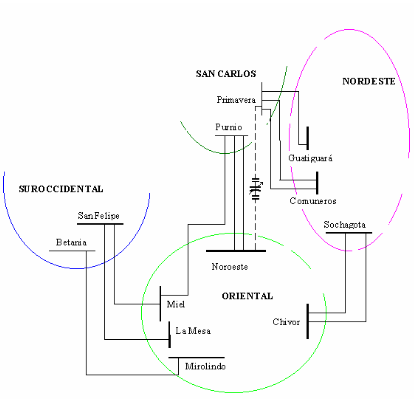

Fig. 3. Proposed TCSC alternative

With the automated solution the power transit can be fixed at 600 MW through the mentioned line. In case of a strong system dynamic contingency, i.e. the opening of one of the lines Purnio - Noroeste, it must be expected little consequences through the controlled line. The Fig. 4 shows the Power reference of 600 MW as a percentage value per unit as the horizontal line. It can be seen that the contingency indicated occurring at 5 s and removed at 30 s, does not de-stabilize the reference wanted around 600 MW.

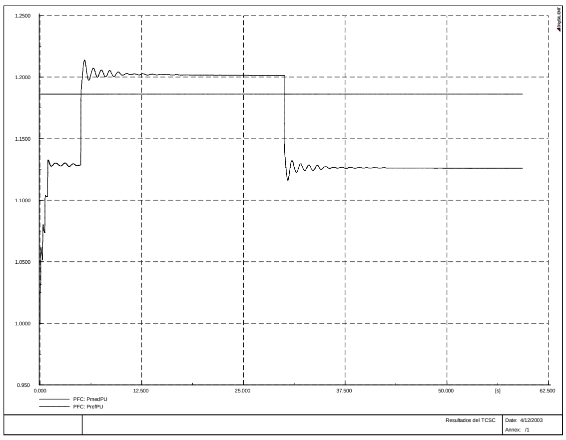

Fig. 4. Dynamical behavior of the TCSC when one of the lines Purnio – Noroeste is abruptly opened.

It is necessary to leave clear that the final decision to define the installation of a novel solution, depends on the economical studios, in which it is also taken into account some other factors like the main intention of certain Project. The aim of this work, is just to give ideas to the expansion studies entities, of how could impact the ETSC an automation solution like TCSC.

It is also necessary to say that the TCSC is a world proven technology, i.e. see [4] and that it helps to decrease the environmental impact caused by new lines.

3.2 The FACTS STATCOM

Previous studies and simulations addressed the STATCOM (Static VAR Compensator based on Voltage Source Inverters) as a skilled device for distribution applications [5]. For the application In Colombia it has been intended for transmission solutions. In distribution systems the STATCOM damps the bad effects of the voltage falls or increases called SAG's and SWELL's in terms of Power Quality theory. The latter affect very negatively the sensible equipment of customer's loads and manufacturing processes.

The SAG is defined as a decrease of the voltage when it falls in a range between 10 to 90% of the nominal voltage, with duration within 0.5 cycles to 1 minute. The SWELL is an increase of the voltage between 110 to 180% of the nominal voltage and with the same duration as SAG's.

One of the main objectives of the STATCOM is to mitigate the effects of system variations regulating the voltage over the transmission lines through the injection (at a SAG condition) or absorption (at a SWELL condition) of reactive power in its installation place.

This device is composed of a Gate Turn Off Thyristor (GTO) three phase converter, by means of Power Width Modulation (PWM) and a proper central control system the convenient DC/CA conversion is achieved. It is connected in parallel with the line by means a coupling transformer and uses a capacitor that stores energy for the proper operation of the inverter (see Fig 5.).

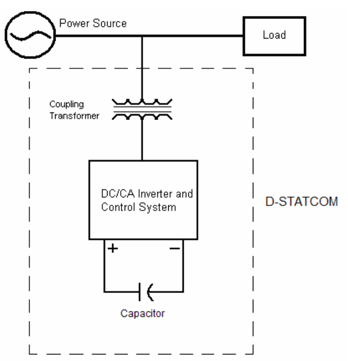

Fig. 5. Diagram of a STATCOM

The D-STATCOM can also be provided with a device able to store energy (battery, capacitor, SMES, flywheel, etc) to supply active energy without interruption in case of temporary outages of the power supply.

The Table 2 summarizes the Colombian network simulated. It belongs to an important circuit in which two industrial loads are connected to the ETSC in the Caribe area through a 230/11/11 kV transformer. The digital simulation required a model implemented with the program PSCAD/EMTDC ver 4.0.1. The STATCOM is connected in the tertiary side of the transformer.

TABLE 2.
ELECTRICAL SYSTEM STUDIED FOR THE AUTOMATION SOLUTION BY STATCOM

Power System	
AC Voltage	230 kV
Z thévenin	0.1Ω - 758 mH
Three windings Transformer	YΔY 230/11/11kV-100 MVA Xp = Xs = Xt = 10 %
Compensation Bank	1.5 µf per phase
Industrial Load A	14.1Ω - 200 mH
Industrial Load B	1.5 Ω - 5.9 mH

To make the study, the network with and without the STATCOM was perturbed in such a way that the connection and disconnection of loads, including the compensation bank, would cause SAG's and SWELL's. The response of the voltage at the loads terminals without the STATCOM is showed in Fig. 6. The Fig. 7 shows the effectiveness of the STATCOM as an automation solution as it preserves the voltage deviation in an universal accepted range of less than 5%. As stated, the STATCOM injects or absorbs reactive energy according to the voltage deviation.

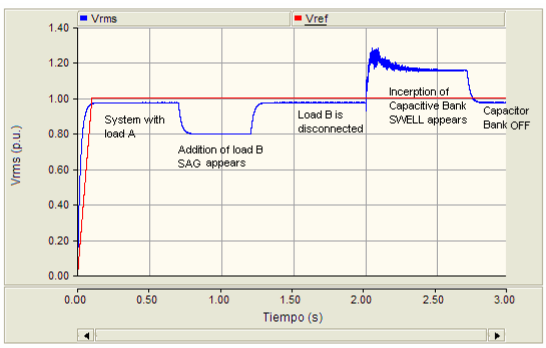

Fig. 6. Voltage at loads terminals without STATCOM

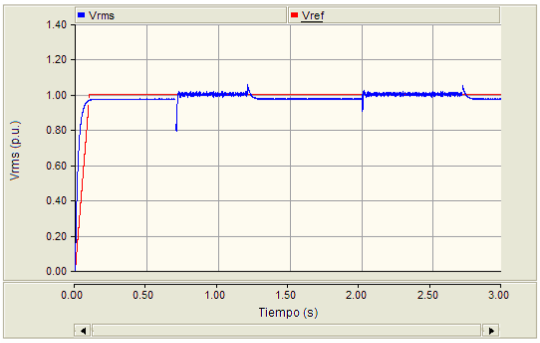

Fig. 7. Voltage at loads terminals with STATCOM for the same events of Fig. 6.

3.3 HVDC GPFC

A new concept of FACTS systems but included in the HVDC branch and widely studied and presented in [6], is the Grid Power Flow Controller (GPFC). This device shown in Fig. 8 is an economical solution when it is a desired to transport electrical energy between two or more AC systems. These systems could even share important differences like voltage, frequency or synchronization conditions.

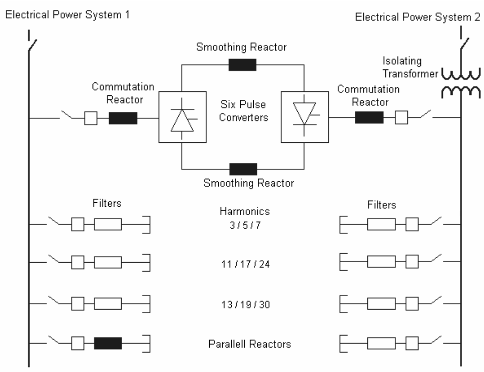

Fig. 8. Diagram of a GPFC

The characteristics of this device would offer very interesting advantages to the Colombian transmission system, especially for the next planned link Colombia – Panama 230 kV around 2006.

At this moment, this device is being deeply studied for the controls on voltage stability and power flow control (active and reactive power). Depending on control strategies, even with intelligent control theory (i.e. Fuzzy Logic, Artificial Neural Networks, Robust Control, adaptive control) devices like this could be the solution for complex operating waited conditions, never reached with conventional equipment.

The control system operates independently the triggering angles for the rectifier and inverter in Fig.8. In the HVDC systems the rectifier controls the reference current while the inverter the voltage reference. In some cases, according with the behavior, the control is interchanged.

The application in a Colombia network was for the interlink Colombia (ETSC) – Panama and setting an operation mode for the Power Flow control. In this control, and according to possible contracts, the objective is to establish different reference powers to be interchanged, taking care that the voltage does not deviate more than a ±10% according to National Regulation in Colombia.

A digital model was built using the program EMTP/atpdraw ver 3.7. The system parameters are presented in Table 3. The system voltages are stepped down to 33 kV. The ETCS is considered a strong Power System while Panama a weak terminal.

TABLE 3.
ELECTRICAL SYSTEM STUDIED FOR THE AUTOMATION SOLUTION BY HVDC - GPFC

	Power System 1	Power System 2
AC Voltage	33 kV	33 kV
Source X_1	1.85 mH	2.1397 mH
Source R_1	0.54 Ω	0.6293 Ω
Source X_0	1.85 mH	2.1397 mH
Source R_0	0.54 Ω	0.6293 Ω

From Fig. 9, it can be seen that at the first stage of the simulation, the two systems interconnected by the GPFC are programmed to share a power of 63 MW. A reduction to 30 MW is ordered. And a time after, the power is desired to come back to the initial value. It can be observed how the angles for the rectifier and inverter change. And also the changes in voltage and current references commanded by the control system of the GPFC.

To obtain this behavior with conventional equipment, previous studies and assisted preparation of system conditions have to be done, and so the operation responses would not be automated.

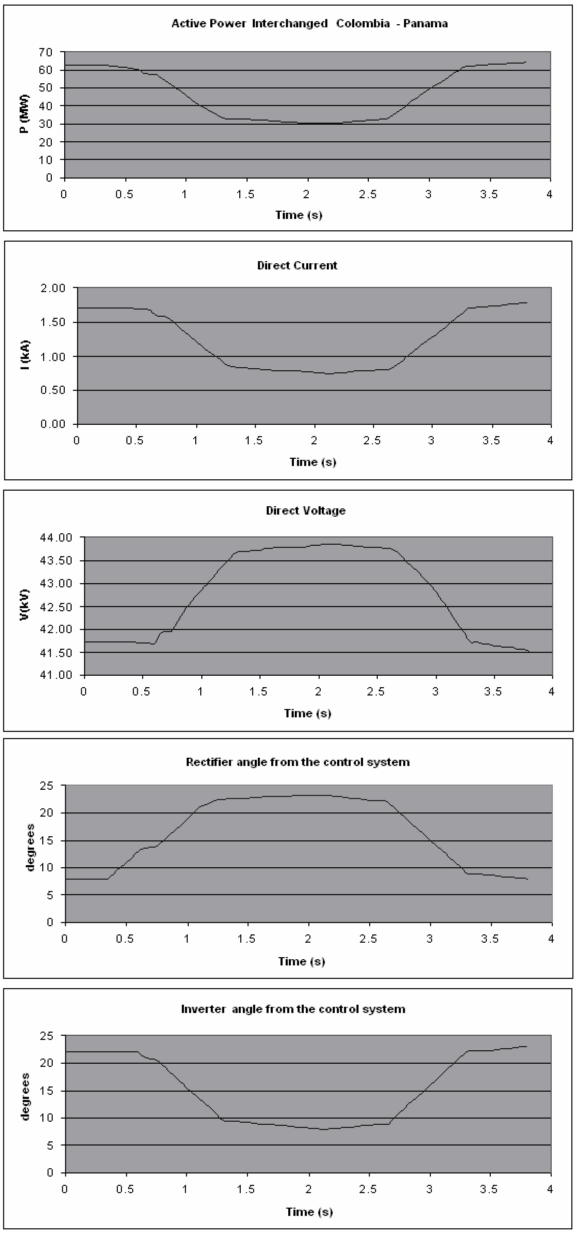

Fig.9. Simulation Results for the HVDC - GPFC

4 Conclusion

In this work, the impact of recent automation solutions for the Colombian Electric Transmission System (230 and 500 kV) has been studied. The idea was to break the uncertainty of how could operate or respond this large network with the inclusion of new non conventional solutions as alternatives for the typical expansion needs. The study was achieved using digital simulations and analysis of the responses of the system with and without automated solutions. The results with automated devices are very good and from the technical point of view provide more and new advantages and challenges for the future of the Colombian Transmission Network than with conventional equipment.

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