

Application of static reactive compensation for voltage optimization and control

Aplicación de la compensación reactiva estática para la optimización y el control de la tensión

Joseph Sosapanta Salas¹

¹<https://orcid.org/0000-0002-2035-9323>. Institución Universitaria Pascual Bravo, Medellín, Colombia, j.sosapantasa@pascualbravo.edu.co

Date of receipt: 15/11/2025
Date of acceptance: 15/12/2025



This work is licensed under a Creative Commons Attribution-NonCommercial-NoDerivatives 4.0 International License.

DOI: <https://doi.org/10.18041/1794-4953/avances.2.13232>

J. Sosapanta Salas, "Application of static reactive compensation for voltage optimization and control", *Avances*, vol. 22, no. 2 (julio-diciembre), Dic. 2025, doi: <https://doi.org/10.18041/1794-4953/avances.2.13232>.

Abstract

The growth in electricity demand implies an expansion of the National Interconnected System (NIS) or the optimization of the actual power system components, which is achieved through the implementation of technologies such as the Flexible Alternating Current Transmission System (FACTS). One of them is the Static VAR Compensator (SVC), which mitigates the losses in transmission lines and also controls the bus voltages. Simulations are performed using the software DlgSILENT PowerFactory and from the results, the SVC reduces power system losses from 15% to 29%.

Keywords: Flexible AC transmission systems, power system modeling, power transmission, reactive power control, static VAR compensators.

Resumen

El crecimiento de la demanda eléctrica implica una ampliación del Sistema Interconectado Nacional (SIN) o la optimización de los componentes del sistema eléctrico actual, lo que se logra mediante la implementación de tecnologías como el Sistema de Transmisión de Corriente Alterna Flexible (FACTS). Una de ellas es el Compensador Estático VAR (SVC), que mitiga las pérdidas en las líneas de transmisión y también controla los voltajes de las barras. Las simulaciones se realizan utilizando el software DlgSILENT PowerFactory y a partir de los resultados, el SVC reduce las pérdidas del sistema eléctrico de 15% a 29%.

Palabras clave: Sistemas de transmisión de CA flexibles, modelado de sistemas de potencia, transmisión de potencia, control de potencia reactiva, compensadores de VAR estáticos.

1. Introduction

The continuous growth in population, technological advances, and the creation of new industries, bring with them increased demand for electrical energy, and in addition changes in power flow, reactive power consumption, generation of harmonics, and voltage drops. The power system expansion is the traditional solution to face this scenario and considering environmental restrictions to develop new projects, the implementation of FACTS devices emerges as an alternative to improve the loadability of transmission lines. In particular, SVC controls bus voltage with the absorption or injection of reactive power and thereby mitigating losses in transmission lines [1]–[4].

The SVC is selected for this study because of its highlighted features, which include: improvement of voltage profile, reduction of reactive losses, increase the transmission capacity, damping of disturbances and power oscillations, and enhanced voltage stability.

The implementation of SVC has been previously analyzed by other authors with different approaches. The authors in [5] examined the relief of transmission lines, and focused on optimizing the active power by controlling the power factor. The authors in [6] analyzed the improvement in power quality with the implementation of static compensators that regulate voltage levels in ideal conditions by absorbing or injecting reactive power into the grid. The authors in [2] studied the voltage profiles in distribution systems with reactive control, installing static compensators at strategic points to mitigate voltage drops. The authors in [7] examined the reduction of harmonics in power systems through static compensators that become wave traps, improving the stability margins.

This document can serve as a basis for studies of dynamic analysis of the SVC and studies of the sensitivity of the stress profile according to the bus location of the SVC, which are topics not covered in other investigations.

This paper is organized as follows. Section II describes the main characteristics of the SVC and its respective modeling. Section III indicates the SVC installed in the Colombian

NIS. Section IV presents the test model and the simulation scenarios. Section V exposes the results analysis and finally, section VI presents the main conclusions.

2. Theoretical framework / Background

Within the FACTS classification illustrated in Fig. 1, the SVC is a first-generation thyristor control switch, whose objective is to maintain the voltage profiles within a defined range of operation by continuously injecting or absorbing reactive power. When the voltage drops below the threshold given in p.u. values, the SVC injects capacitive reactive power into the network, on the other hand, when the voltage increases, the SVC absorbs inductive reactive power. These two cases are handled by regulating the firing angles of the thyristors in the different models or classes of SVC [8]–[11].

A fundamental part of an SVC is the thyristors. Thyristors are high-speed power semiconductors that function as switches, that is, the thyristor is the element that, when switched, allows the delivery of reactive power or the absorption of inductive power according to the voltage levels of the network [12].

2.1. SVC configuration

The most common configurations of SVC are described below [1], [14]–[16],

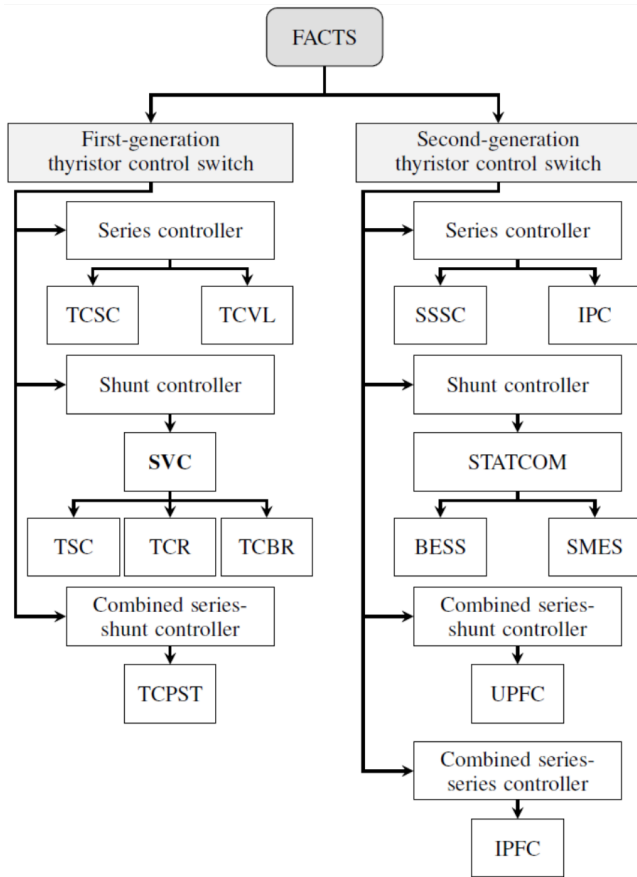


Figure 1. FACTS classification [13].

1) *Thyristor Switched Capacitor (TSC)*: This is the simplest reactive control configuration, made up of a solidstate switch in series with a capacitor or capacitor batteries, as shown in Fig. 2. TSC is made up of two thyristors, which are in charge of connecting the capacitor to the network when there is a voltage drop.

2) *Thyristor Controlled Reactor (TCR)*: This maintains a continuous regulation of the power consumed by the coil, which is connected in series with two thyristors that are responsible for controlling the opening of the coil and the reactive injection according to the firing angle.

3) *Thyristor Switched Reactor (TSR)*: This is made up of a set of coils connected in series to the thyristors. This configuration has the same purpose as the TCR with the difference that the coil connection control is given by means of a thyristor commutation.

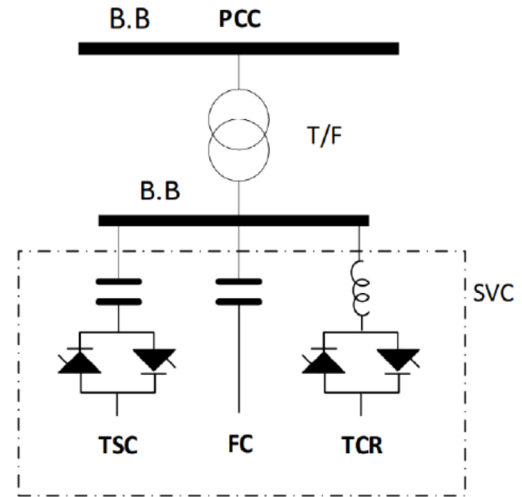


Figure 2. SVC configurations [9].

2.2. SVC modelling

The equivalent reactance of the TCR depends on the firing angle, which establishes the reactive absorption and injection. The equivalent reactance of the TCR is given by,

$$X_{TCR} = \frac{\pi X_L}{\alpha - \sin \alpha} \quad (1)$$

where X_L : inductive reactance, α : firing angle. When $\alpha = \pi/2$, TCR fully conducts and the equivalent reactance is equal to X_L . On the other hand, when $\alpha = \pi$, TCR is fully blocked and the equivalent reactance becomes infinity.

The effective reactance of the SCV is determined by the parallel equivalence of capacitive reactance X_C and X_{TCR} ,

$$X_{SVC} = \frac{\pi X_L X_C}{2X_C(\pi - \alpha + \sin 2\alpha)} \quad (2)$$

Then, the reactive power is computed as follows,

$$Q_{SVC} = -V_{SVC}^2 \frac{2X_C(\pi - \alpha + \sin 2\alpha)}{2X_C X_L} \quad (3)$$

Depending on the ratio of the capacitive and inductive reactance, there is a trigger angle value and according to this it injects or absorbs reactive power.

3. Materials and methods

The national regulations associated with the FACTS are at the level of the resolutions created by the Comisión de Regulación de Energía y Gas (CREG) for the expansion of the NIS, which considers the use and under what criteria these elements can be urged when defining the expansion plan [17]. CREG’s resolution 22 of 2001 establishes that the installation of FACTS may be carried out as an expansion when the Unidad de Planeación Minero Energética (UPME) identifies those assets are necessary to avoid or mitigate scenarios with a high probability of unattended users. In addition, CREG’s resolution 18 of 2005 establishes the basis for reactive power flow management, types, and applications of FACTS [18].

The actual SVC systems installed in the Colombian NIS are listed in Table I and located in Fig. 3.

Table 1. SVC installed in Colombia [13].

Substation	Voltage
SVC installed in the Chinú substation	500 kV
SVC installed in the Caño Limon substation	230 kV
SVC installed in the Tunal substation	230 kV
SVC installed in the Oxy substation	34,5 kV

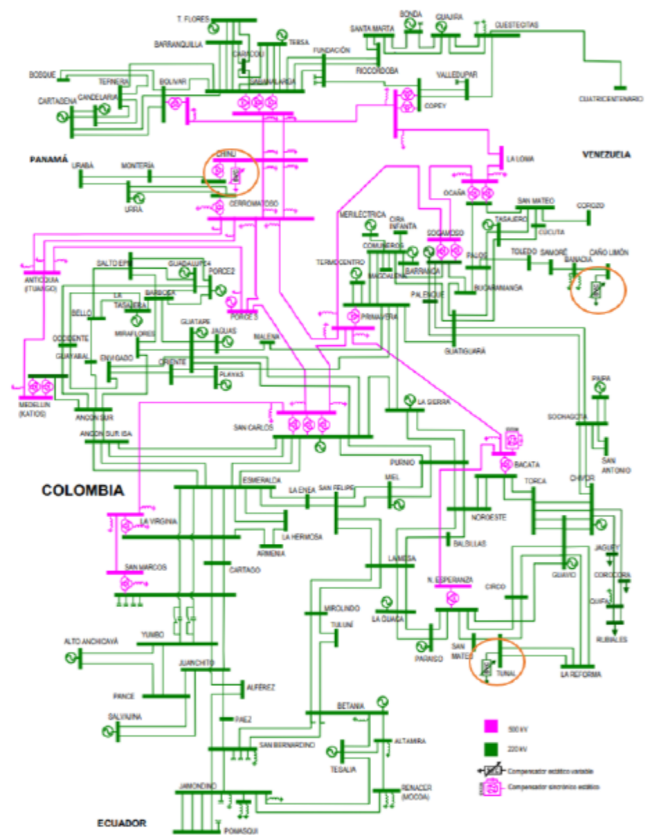


Figure 3. Colombian NIS 2022 [19].

The SVC projects to be developed in the next years are indicated in Table II.

Table 2. SVC to be installed in Colombia [19].

Installation of SVC Churuyaco - Orito - Mocoa 230 kV line corridor with static compensation at the Churuyaco substation
Due to the low voltages that are caused in the area due to the contingency of the Ocaña 500/230 kV - 450 MVA transformer, the next Plan studies the need for a new bank or the installation in the area of an SVC
Installation of an SVC in any of the 230 kV level substations in the area (Ocaña, San Mateo, Belén or Tasajero)
SVC in the Copey 500 KV substation

The need for 275 MVar of static capacitive compensation was established, distributed between the Bogotá and Meta operational sub-areas, as well as 440 MVar of dynamic compensation, installed in the Bacatá (SVC) and Nueva Esperanza (SVC) substations

The test system is a 15-bus circuit, with two generators and five transformers as illustrated in Fig. 4. The initial data will be taken from this system and the installation of the SVC is proposed in the 5 buses with lower and higher values for voltages in p.u. In this way, the impact on the buses and the loadability in the circuit is analyzed. The system has the parameters indicated in Table III, and has transmission lines at 220 kV and 132 kV, generators with installed capacities of 448 MVA and 100 MVA, one transformer of 500 MVA, and four transformers of 100 MVA. In addition to 15 buses where 11 loads are connected, the SVCs are installed on buses 3, 9, 10, 13 and 14.

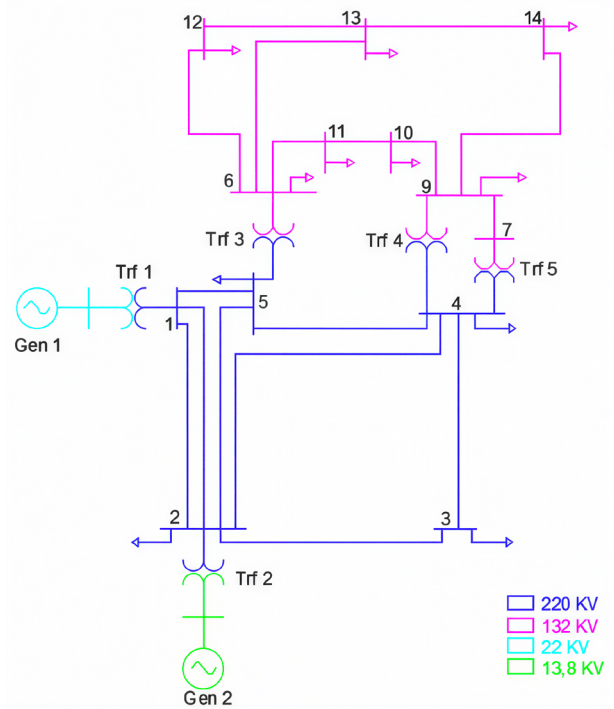


Figure 4. 15 bus test pattern DigSILENT.

Table 3. Line data.

Line	Distance [km]	Z1	R1	X1	Angle	Voltage
Line 0001-0002	1	30,13	9,38	28,64	71,86	220
Line 0001-0002	1	30,13	9,38	28,64	71,86	220
Line 0001-0005	1	111,07	26,15	107,95	76,38	220
Line 0002-0005	1	88,56	27,56	84,15	71,86	220
Line 0002-0004	1	89,85	28,12	85,33	71,75	220
Line 0002-0003	1	98,47	22,74	95,81	76,64	220
Line 0003-0004	1	88,9	32,43	82,77	68,6	220
Line 0005-0004	1	21,38	6,46	20,38	72,4	220
Line 0006-0012	1	49,45	21,41	44,57	64,33	132
Line 0006-0013	1	25,45	11,54	22,69	63	132
Line 0006-0011	1	38,4	16,54	34,65	64,47	132
Line 0007-0009	1	19,16	0	19,16	90	132
Line 0009-0010	1	15,73	5,54	14,72	69,37	132
Line 0009-0014	1	52,05	22,14	47,11	64,82	132
Line 0010-0011	1	36,39	14,29	33,46	66,86	132
Line 0012-0013	1	51,9	38,49	34,82	42,13	132

Line	Distance [km]	Z1	R1	X1	Angle	Voltage
Line 0013-0014	1	67,55	29,78	60,63	63,84	132

4. Results and discussion

Fig. 5 shows the behavior of the stresses in buses 3, 9, 10, 13 and 14 in p.u. values. These buses are selected because they are the nodes where the effects of the SVC in the electrical system are best evidenced and are compared with the baseline (blue line), which is the state of the circuit without the installation of the SVC.

Fig. 5 shows the behavior of the stresses in buses 3, 9, 10, 13 and 14 in p.u. values. These buses are selected because they are the nodes where the effects of the SVC in the electrical system are best evidenced and are compared with the baseline (blue line), which is the state of the circuit without the installation of the SVC.

As can be seen, there is an improvement in the voltage values of the buses, the SVC maintains the voltage level of the bus in which it is installed at 1 p.u., absorbing or delivering reactive energy dynamically according to the behavior of the circuit and the demand. This also presents an improvement in the nearby buses and in the percentage generation and transmission, as well as an improvement in the loadability of the transformers.

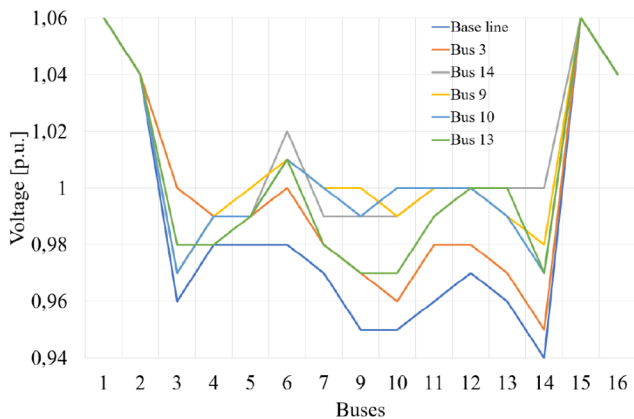


Figure 5. Voltage variation in p.u. of the buses with SVC.

Fig. 6 shows the behavior of the voltage on lines 0002 and 0003 when their load increases, and this same scenario is compared by installing an SVC on bus 0003. The dotted line is the behavior installing SVC and as can be seen, the device maintains the voltage constant at 1 p.u., without SVC, solid line graph, voltage decreases as load increases.

Line 0002 is the one that best shows the effects of this device, it starts with 0.96 in p.u. values and falls to 0.81 when the load increases to 56%, while with the SVC the voltage remains at 1 and with the same load that reached a voltage drop of 0.81 p.u., the line loadability did not exceed 48%, there was an optimization of the line of 8%.

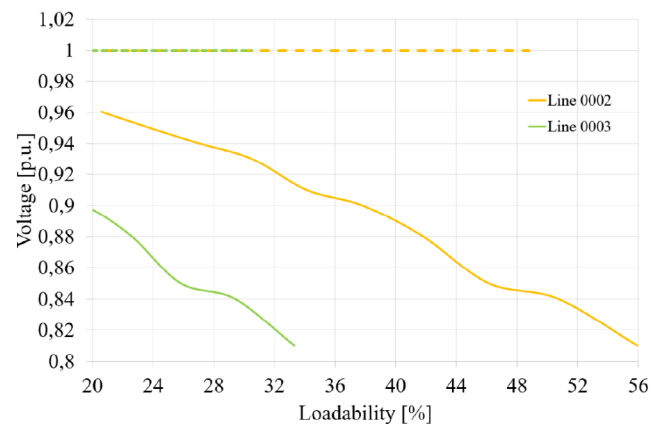


Figure 6. Voltage variation in p.u. regarding the load (- - -with SVC; —without SVC).

On the other hand, Fig. 7 shows the losses in MW of lines 0002 and 0003 without the implementation of the SVC device (solid line). The losses on line 0002 start at 0.5 MW and as the load increases, the losses increase up to 3.1 MW. In the case of the implementation of the SVC, losses under the same scenario start with losses of 0.5 MW and increase to 2.7 MW, a reduction of 13%. Losses on line 003 had similar behavior to the previous line,

starting with losses of 0.2 MW and increasing up to 2 MW, with the installation of the SVC the losses started at 0.2 MW and increased up to 1.8 MW, reducing 10%.

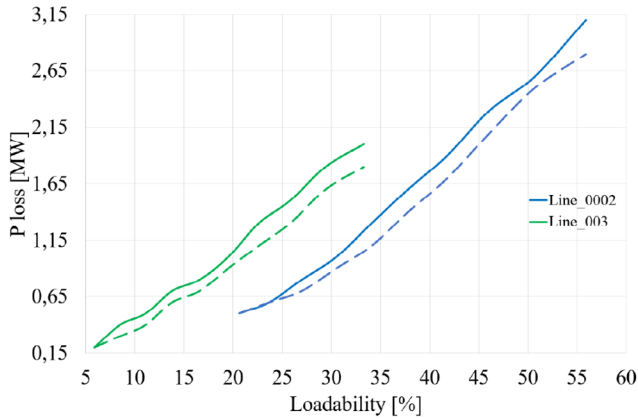


Figure 7. Transmission lines power losses (- - -with SVC; —without SVC).

Fig. 8 shows transformers 2, 3, and 4 where reactive power changes occur with the implementation of the SVC and without the implementation of the SVC by increasing the demand for active power in the electrical system. Transformer 2 shows an increase in reactive power to -150 MVar as demand increases and a loadability of 148%. With the implementation of the SVC under the same demand scenario, there is an increase in reactive power of -77 MVar and a loadability of 81%. A reduction in the transformer's loadability of up to 49%.

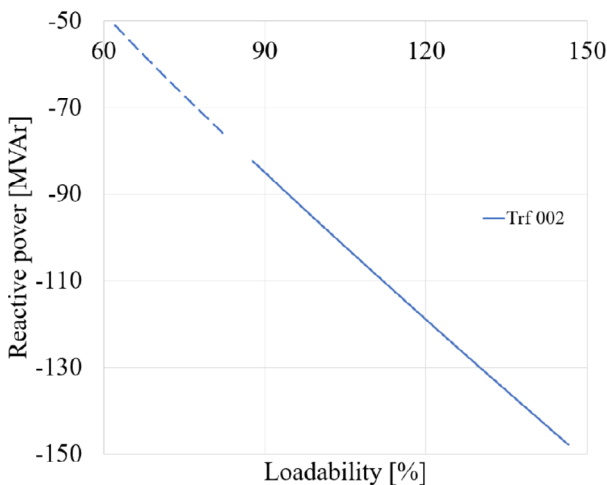


Figure 8. Transmission lines power losses (- - -with SVC; —without SVC).

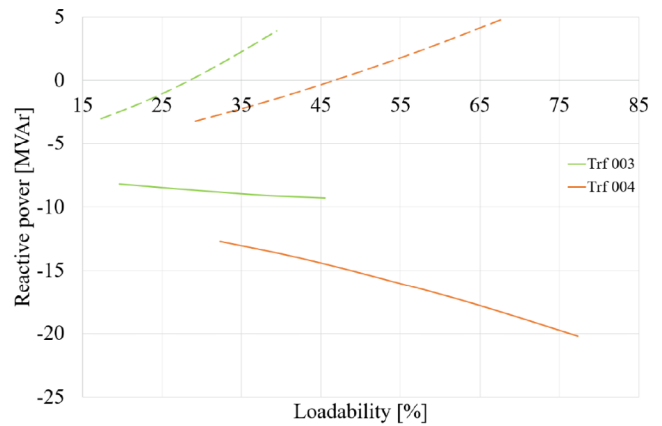


Figure 9. Transmission lines power losses (- - -with SVC; —without SVC).

5. Conclusions

The implementation of the SVC reduces the losses of the analyzed power system, optimizing and increasing the performance of the system, achieving stability in the bus of the voltage levels, and a reduction in the loadability of generators and transformers. In conclusion, SVC is a great alternative for reactive control and to get the most out of the currently installed system, achieving more users with less infrastructure and reducing operating costs.

6. References

1. C. A. Ávila Mendoza, "Aplicaciones del SVC en el control de la tensión en sistemas eléctricos de potencia," 2011.
2. C. F. Egüés Mendoza, "Mejoramiento de los perfiles de tensión en sistemas de distribución con la inclusión de un compensador estático de potencia reactiva (DS-TATCOM)." B.S. thesis, 2019.
3. S. P. Dash, K. Subhashini, and J. Satapathy, "Optimal location and parametric settings of facts devices based on jaya blended moth flame optimization for transmission loss minimization in power systems," *Microsystem Technologies*, vol. 26, pp. 1543–1552, 2020.

4. S. Morello, T. J. Dionise, and T. L. Mank, "Installation, startup, and performance of a static var compensator for an electric arc furnace upgrade," *IEEE transactions on industry applications*, vol. 53, no. 6, pp. 6024–6032, 2017.
5. Y. Y. Ojeda-Rebolledo, L. D. Pabón-Fernández, E. Caicedo-Peñaranda, J. L. Díaz-Rodríguez, and A. Pardo-García, "Compensador estático var para sistemas de distribución," *Mundo Fesc*, vol. 11, no. 21, pp. 70–86, 2021.
6. D. X. Barros Gualotuña and L. F. Caiza Jacome, "Análisis de las perturbaciones (sags y swells) de la red de distribución para mejorar la calidad de energía en el alimentador primario "d" en la subestación chimbacalle–quito, basado en el uso de compensadores reactivos." B.S. thesis, Ecuador: Latacunga: Universidad Técnica de Cotopaxi; UTC., 2021.
7. P. A. Achig Santamaria, "Compensación óptima de potencia reactiva en sistemas eléctricos de transmisión mediante búsqueda armónica." B.S. thesis, 2019.
8. F. Issouribehere, P. Issouribehere, J. C. Barbero, F. Scarafoni, and G. Campomar, "Modelado y verificación por ensayos en campo de un compensador estático de reactivo (svc) de ± 250 mvar," in XVII Encuentro Regional Iberoamericano de CI-GR ´E (Ciudad del Este, Paraguay, 21 al 25 de mayo de 2017), 2017.
9. H. Tariq, S. Czapp, S. Tariq, K. M. Cheema, A. Hussain, A. H. Milyani, S. Alghamdi, and Z. S. Elbarbary, "Comparative analysis of reactive power compensation devices in a real electric substation," *Energies*, vol. 15, no. 12, p. 4453, 2022.
10. R. S. Vedam and M. S. Sarma, *Power quality: VAR compensation in power systems*. CRC press, 2017.
11. S. Keskes, N. Bouchiba, S. Sallem, L. Chri-fi-Alaoui, and M. Kammoun, "Transient stability enhancement and voltage regulation in smib power system using svc with pi controller," in 2017 6th International Conference on Systems and Control (ICSC). IEEE, 2017, pp. 115–120.
12. C. Edwards, K. Mattern, E. Stacey, P. Nannery, and J. Gubernick, "Advanced state var generator employing gto thyristors," *IEEE Transactions on Power delivery*, vol. 3, no. 4, pp. 1622–1627, 1988.
13. J. S. Salas and M. M. Gomez, "Simulation of the influence of statcom on power system losses," 2023.
14. J. Ramírez, L. Ortiz, and A. Aguila, "Control pasivo tolerante a fallos de sensado en dispositivos de compensación dinámicos-svc mediante una estrategia híbrida," *Ingenius. Revista de Ciencia y Tecnología*, no. 28, pp. 34–43, 2022.
15. J. L. Loor Lopez et al., "Diseño y simulación del control de un compensador estatico de reactivos (svc)," B.S. thesis, Espol, 2017.
16. X. Qiao, J. Bian, C. Chen, and H. Li, "Comparison and analysis of reactive power compensation strategy in power system," in 2019 IEEE Sustainable Power and Energy Conference (iSPEC). IEEE, 2019, pp. 689–692.
17. CREG, "Plan de expansión del sSTN 2022," 2022.
18. CREG, "Resolución 018 de 2005," 2005.
19. UPME, "Plan de expansión de referencia generación transmisión 2020-2036," 2020.



UNIVERSIDAD
LIBRE[®]
Vigilada Mineducación