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Impact of the hybrid reactive power compensator on the power grid used a fuzzy PI regulator

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Article Info	ABSTRACT
	The work presented in this article is a contribution to the problem of controlling reactive powers and voltages in an electrical network. Among these control tools, the static reactive power compensator (SVC) was chosen because of its simplicity of control. SVC is one of the alternative flexible current transmission systems (FACTS) devices which help to solve the problems encountered in the operation of electrical networks, either on the distribution side or on the transport side. To increase its compensation efficiency in the face of harmonic currents which cause voltage distortion, we have introduced a three-phase harmonic filter. This new hybrid SVC is used to control the reactive power, the voltage and in addition to reduce the voltage distortion and the correction of the power factor in the electrical energy transport network. In order to improve its efficiency, two voltage regulation systems have been chosen in the control system for this compensator, the fuzzy PI regulator and the PIP regulator.

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1. INTRODUCTION

The increasing use of electrical energy in the economic, social and industrial life of each country is causing more and more problems of disturbances, overvoltages, voltage drops and harmonics in electrical networks. The rapid development of power electronics has had a considerable effect on improving the operating conditions of electrical networks by controlling their parameters by introducing control devices based on advanced very high power electronic components known as the name of FACTS: Alternative Current Transmission Systems [1]-[3].

The research reported in this article is motivated by the desire to improve the control of reactive powers and voltages to further reduce the distortion of voltage and current in an electrical energy transport network by means of a FACTS device, the hybrid static Var Compensator SVC. This new SVC hybrid compensator is made up of SVC based on the controllable power electronics coponents [4], and the three-phase harmonic filters used to eliminate different order harmonic currents and thus maintain the stable state of the transient voltage within the desired limits. The SVC injects or absorbs reactive power into the busbar where it is installed to meet the demand for reactive power from the load. It allows flexible and continuous control of the busbar tension [5], [6].

In this work, this hybrid SVC is used to control reactive power and voltage in an electrical power transmission network, using two voltage control systems in the control system of this compensator to improve its performance the first is the fuzzy PI regulator and the second is the PIP regulator [7]-[9].

Harmonic filters reduce harmonic currents by diverting them into low impedance paths so they reduce the THD (Harmonic distortion rate) of the voltage at the same time.

2.   STATIC REACTIVE POWER COMPENSATOR HYBRID (HSVC)

The SVC reactive power compensator hybrid is a device used to keep the transient and stationary voltage within the desired limits in the presence of harmonic currents in the network. It injects reactive power into the bar where it is connected in order to satisfy the demand for reactive power of the load. In general, the SVC hybrid is a combination of thyristor-controlled reactors (TCR), TSC (thyristor-switched capacitors), and three-phase harmonic filters. These are three constituents of the HSVC are:

2.1. Thyristors controlled reactance (TCR)

The TCR is one of the most important components of an SVC. It provides fast, continuous control of reactive power on the power grid. The Thyristor-Controlled Reactor (TCR) thyristor controlled reactor has a bidirectional thyristor valve T_1 and T_2 connected in series with a fixed inductance coil L, shown in Figure 1. The thyristors are switched on with a certain ignition angle α and drive alternately over half a period. The ignition angle α varies from 90° to 180°. In full conduction (α = 90°), the current is essentially reactive and sinusoidal, and when α = 180°, one is in null conduction [10]-[12].
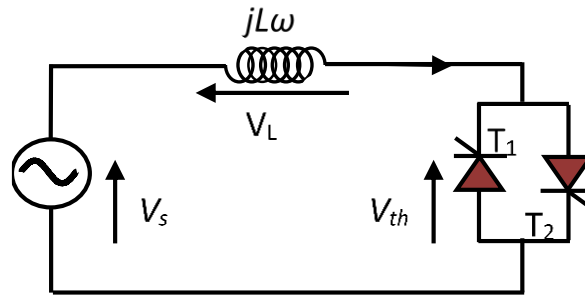

Figure 1. Single-phase circuit of a TCR

Relationship between the ignition angle α and B_{max} the susceptance B_{TVR} of inductance L:
Let the source voltage v_s given by the following relation:

$$v_s(t) = V_m \sin(\omega t) \tag{1}$$

From Figure 1 the equation of the voltage of the circuit is:

$$L\frac{di_{TCR}(t)}{dt} - v_s(t) \tag{2}$$

With the initial condition (ωt0 = α), the solution of this equation is given by:

$$i_{TCR}(t) = \frac{1}{L}\int_{\alpha/\omega}^{t} V_s(t)\,dt \tag{3}$$

We then get:

$$i_{TCR}(t) = -\frac{V_m}{\omega L}(cos\,\alpha - cos\,\omega t) \tag{4}$$

According to the Fourier analysis, the fundamental component i_{TCR} (t) of the current is given by:

$$i_{1TCR}(t) = a_1 cos\,\omega t + b_1 cos\,\omega t \tag{5}$$

From (4), the current is a function pair i_{TCR} (t) = i_{TCR} (-t), that is to say b_1 = 0. The coefficient a_1 is:

$$a_1 t = \frac{4\omega}{\pi} \int_{\alpha/\omega}^{\pi/\omega} -\frac{V_m}{L\omega}(\cos\alpha - \cos\omega t).\cos\omega t.dt \tag{6}$$

The magnitude of the fundamental current is the result of (6):

$$I_{1TCR}(t) = a_1(t) = \frac{V_m}{\omega L}\left(\frac{2\pi - 2\alpha + \sin 2\alpha}{\pi}\right) \tag{7}$$

$$I_{1TCR}(t) = V_m B_{TCR}(\alpha) \tag{8}$$

This relationship can be written as:

$$B_{TCR}(\alpha) = B_{max}\left(\frac{2\pi - 2\alpha + \sin 2\alpha}{\pi}\right) \tag{9}$$

$$B_{max} = \frac{1}{\omega L} = \frac{1}{X_l} \tag{10}$$

2.2. Thyristor switched capacitor (TSC)

The thyristor-switched capacitor TSC is composed of a fixed capacitor C plus an attenuation inductance coil L connected in series with a bidirectional thyristor valve Figure 2. The function of the switch is to turn on and off the capacitor for an integer number of half cycles of the applied voltage. The capacitor is thus not controlled in phase, but simply switched on and off. The attenuation inductance serves to limit the current in case of abnormal operation and to avoid resonance with the grating at particular frequencies. To have a minimum of transient disturbances, the switching times are chosen so that the voltage across the thyristors is minimal. Interlocking is therefore performed when the residual voltage of the capacitor is equal to the instantaneous network voltage [13]-[16].

The capacitor can be switched with a minimum of transient if the thyristor is on (state on), at the instant when the voltage v_C of the capacitor and the voltage v_s of the network have the same value. Since the susceptance is fixed, the current in the TSC varies linearly with voltage V (which explains the absence of harmonics on the TSC). Typically, TSC type SVC contains n bench of TSCs mounted in parallel. The susceptance is adjusted by controlling the number of parallel capacitors in conduction. Each capacitor always drives for an integral number of half cycles.
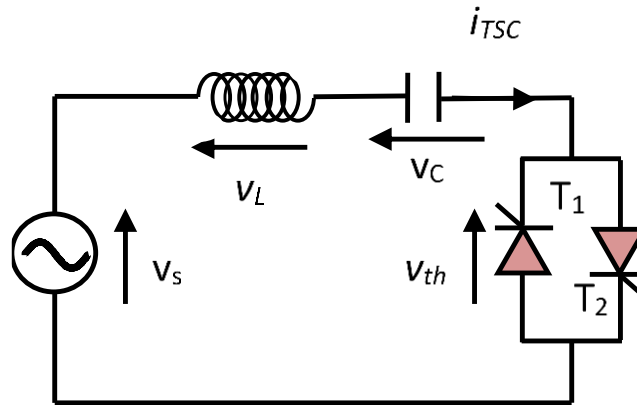

Figure 2. Single-phase circuit of a TSC with series inductance

2.3. Three-phase harmonic filters (HF)

Three-phase harmonic filters (built of RLC elements) Figure 3 are shunt elements that are used in power systems for decreasing voltage distortion and for power factor correction. Nonlinear elements such as power electronic converters generate harmonic currents or harmonic voltages, which are injected into power system. The resulting distorted currents flowing through system impedance produce harmonic voltage distortion. Harmonic filters reduce distortion by diverting harmonic currents in low impedance paths.

Harmonic filters are designed to be capacitive at fundamental frequency, so that they are also used for producing reactive power required by converters and for power factor correction.

The most commonly used filter types are [17], [18]:

a) Band-pass filters, which are used to filter lowest order harmonics such as 5th, 7th, 11th, 13th, etc. Band-pass filters can be tuned at a single frequency (single-tuned filter) or at two frequencies (double-tuned filter).

b) High-pass filters, which are used to filter high-order harmonics and cover a wide range of frequencies. A special type of high-pass filter, the C-type high-pass filter, is used to provide reactive power and avoid parallel resonances. It also allows filtering low order harmonics (such as 3rd), while keeping zero losses at fundamental frequency.

Single-tuned   C-type High-pass   Double-tuned   High-pass
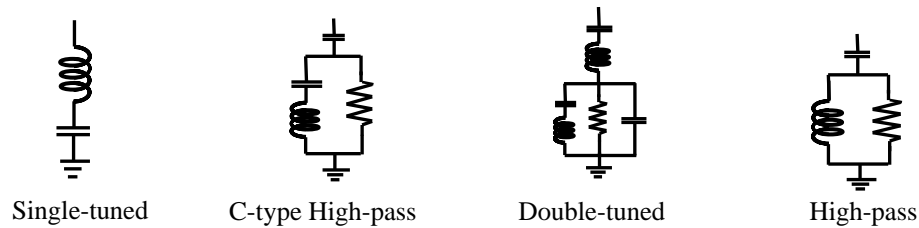
Figure 3. Shows the different types of three-phase RLC harmonic filter

The Frequency-Domain Response of three-phase harmonic filters HF is given according to its four components. The frequency of the single-tuned filter is fn = 5 * 60Hz (filtering of the 5th order harmonic), of the C-type high-pass filter is fn = 3 * 60Hz (filtering of the 3rd order harmonic), of the Double – tuned filter are fn1 = 11 * 60Hz and fn2 = 13 * 60Hz (filtering of the 11rd and 13rd order harmonics) and the high-pass filter is fn = 24 * 60Hz (filtering of the 24rd order harmonic). This frequency domain and the phase of this filter are shown in Figure 4.
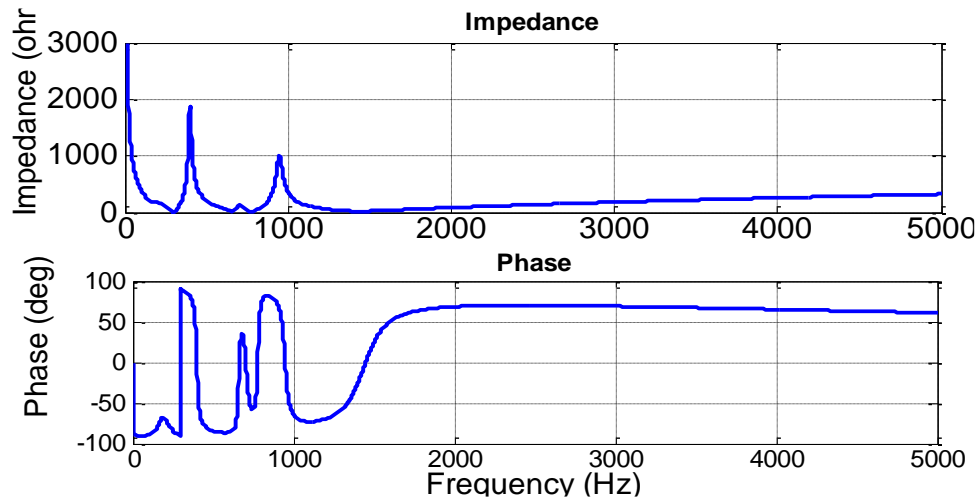

Figure 4. Frequency-domain response and phase of three-phase harmonic filters HF

3. SVC COMMAND

The SVC adjusts these values automatically in response to changes in network operating conditions as it has possibilities to establish capacitive or inductive currents of this network. The operation of an SVC is based on the main function of the essential elements that constitute this compensator such as the measuring circuits, the voltage regulator, the comparators, and the conduction circuits of TCR and TSC.The control model of an SVC is shown in Figure 5 with a measured voltage regulator. In this work I will compare the results for two regulators, the PIP and the PI fuzzy.
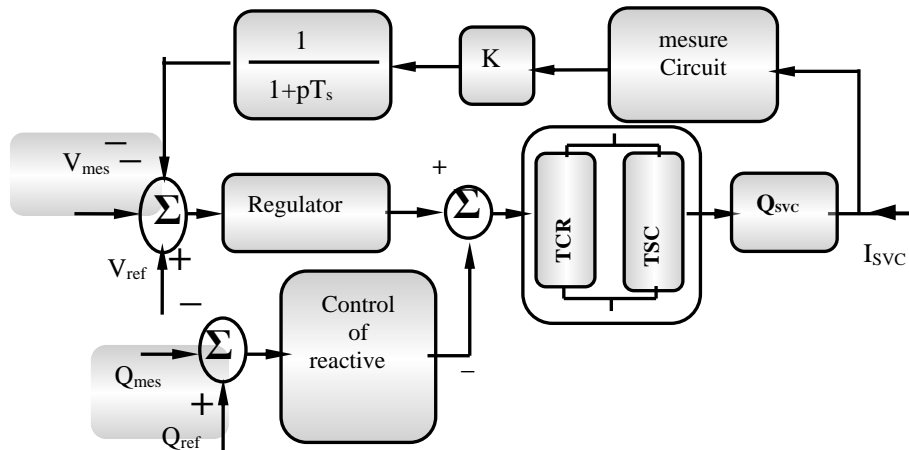
Figure 5. Simplified block diagram for controlling an SVC

3.1. PIP regulator

The proposed PIP regulator is an IP regulator associated in parallel with a proportional regulator P [19], [20]. The block diagram of the control voltage V_{mes} including the PIP controller is illustrated in Figure 6.
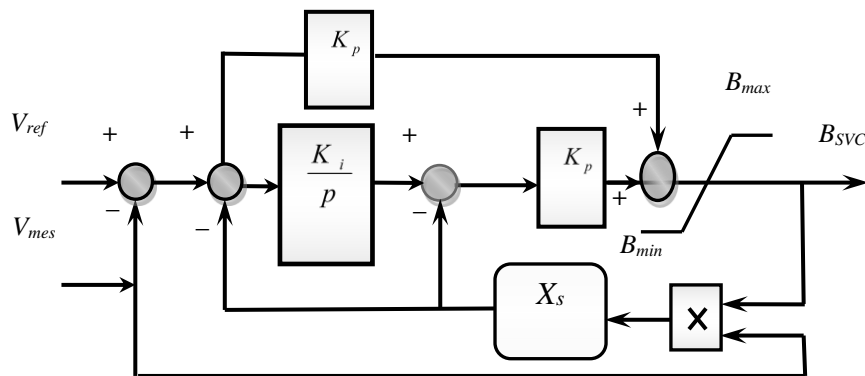

Figure 6. PIP regulator scheme for the rms value (V_{mes}) of the network voltage

where K_i is an integral gain, and K_p a proportional gain.
X_s is a reactance obtained from the following relation: $V_{mes} = V_{ref}\text{-}X_s.I_{SVC}$

3.2. Fuzzy PI regulator

The fuzzy PI regulator is given in Figure 7. The basic diagram of the PI-fuzzy regulator rests on the structure of a traditional regulator PI [21]-[24]. On found in input and output of the controller fuzzy gains known as "factors of "scale" which allows to change the sensitivity of the fuzzy controller without changing the structure, the input and output variables being normalized.
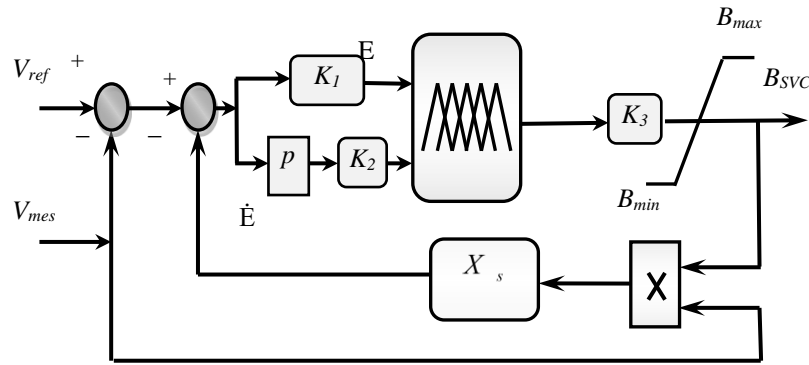
Figure 7. Regulator scheme of the rms value (V_{mes}) of the inter-phase network voltage

The error : $E= (V_{ref}-V_{mes})-X_s.I_{SVC}$
$\dot{E}$: the derivative of the error.
We find in the input and output of the fuzzy controller gains called "scale factors" that can change the sensitivity of the fuzzy controller without changing the structure. Each linguistic variable (E, $\dot{E}$, u) is characterized by seven terms of fuzzy subsets: NG: negative grand; NM: negative Medium; NP: negative Small; EZ: about zero; PG: Positive grand; PM: Positive Medium; PP: positive Small. The rule base for the fuzzy logic controller can be framed by taking possible combinations of the input variables as presented in Table 1.

Table 1. Inference rule of the PI fuzzy regulator managing the output

$\dot{E}$ \ E	NG	NM	NP	EZ	PP	PM	PG
NG	NG	NG	NG	NG	NM	NP	EZ
NM	NG	NG	NG	NM	NP	EZ	PP
NP	NG	NG	NM	NP	EZ	PP	PM
EZ	NG	NM	NP	EZ	PP	PM	PG
PP	NM	NP	EZ	PP	PM	PG	PG
PM	NP	EZ	PP	PM	PG	PG	PG
PG	EZ	PP	PM	PG	PG	PG	PG

4. SIMULATIONS AND DISCUSSION OF RESULTS

The different parts of the HSVC studied previously, the electrical network and a non-linear load (high voltage AC/DC converters HVDC with 12-pulse thyristors) are simulated on MATLAB/Simulink. The structure studied in Figure 8 is composed of the Hybrid SVC (HSVC) with these two power and control parts, used to compensate the reactive power and therefore regulates the voltage at the busbar of the electrical network and reduce the distortion of current and voltage.

The nominal source voltage is initially set at 1.004 pu. In addition, the reference voltage V_{ref} is fixed at 1.0 pu, the SVC is initially floating (zero current). This operating point is obtained with a TSC in operation and the TCR almost in full conduction. The source voltage is programmed with two variations (Figure 9), the first an overvoltage of 1.0125 pu, the second a voltage drop of 0.93 pu carried out respectively in time intervals in seconds [0,1 0.4] and [0.4 0.7].

The three-phase harmonic filters are: Single-Tuned, High-Pass filter, Double–tuned filter, C-type High-pass filter already described above. To optimize the efficiency of the HSVC, I used tow regulation of the effective value (V_{mes}) of the network voltage between phase, two regulators the PIP and the fuzzy PI. The HSVC compensator controls the fundamental voltage and sends the appropriate pulses to the 24 thyristors (6 thyristors for each phase) to obtain the susceptance required by the voltage regulation. The values of various components of the system to be simulated are shown in Figure 10.
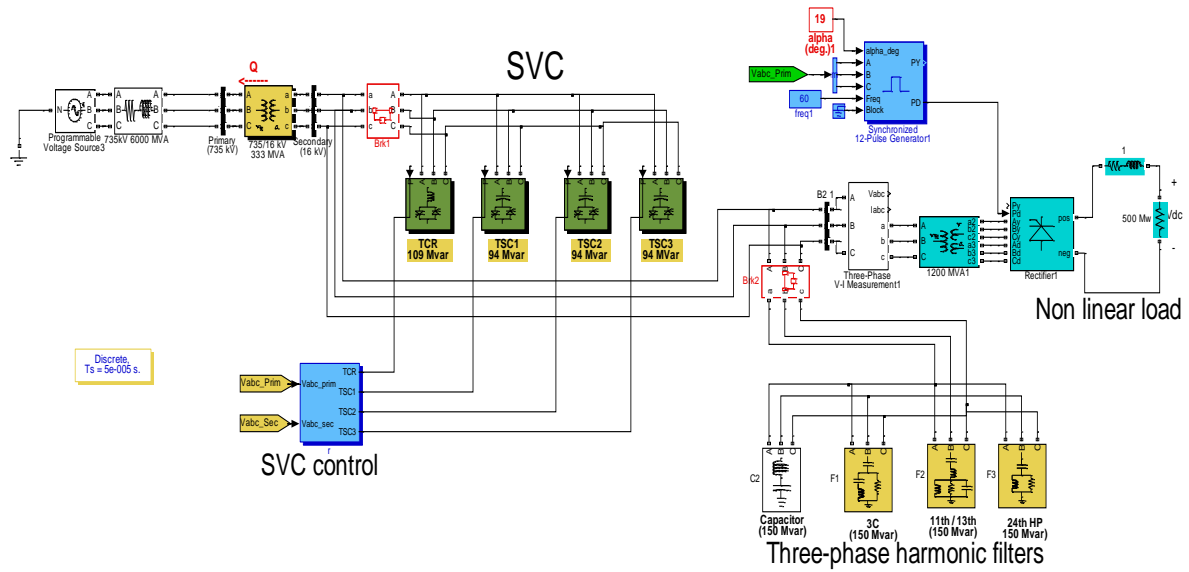
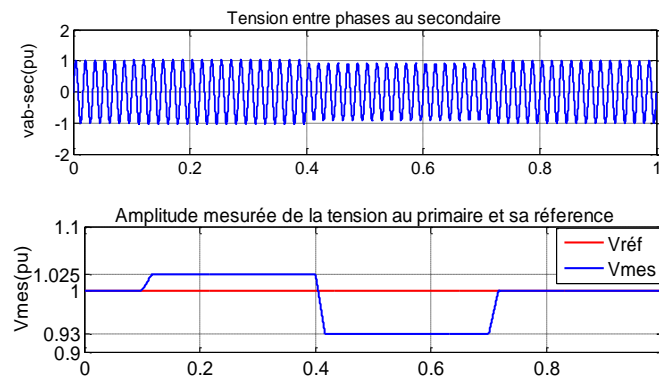Figure 8. Overall scheme of the system to simulate in MATLAB/Simulink

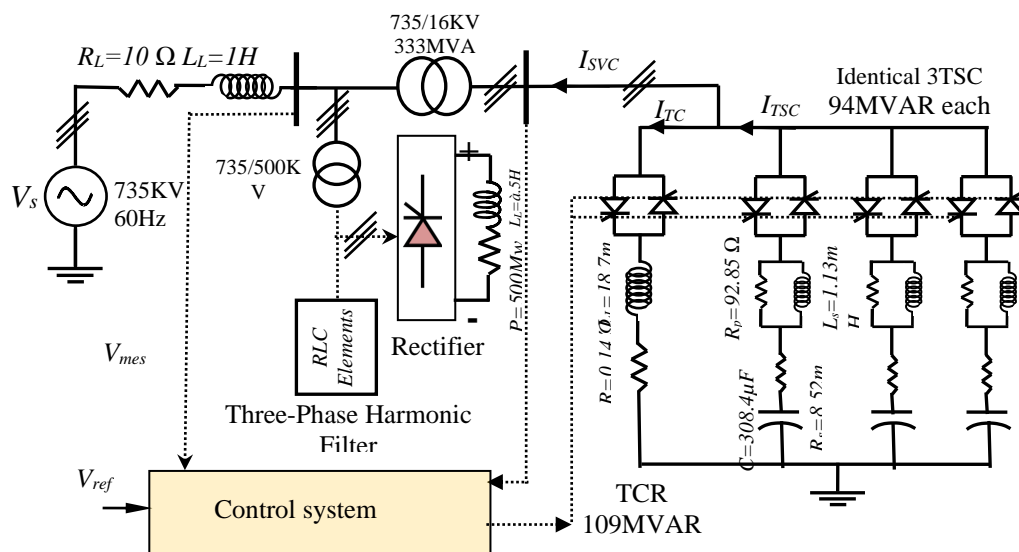Figure 9. Voltage between phase in primary and its amplitude provided by the programmable source

Figure 10. Overall scheme of the system to simulate (single-line diagram)

4.1. Simulation results (hybrid SVC disconnected)

In this first case, we represent the shape of the source voltage, its amplitude, the voltage of the nonlinear load, their zoom, and their total harmonic distortion THD (Figure 11). The SVC and the three-phase harmonic filter are disconnected.
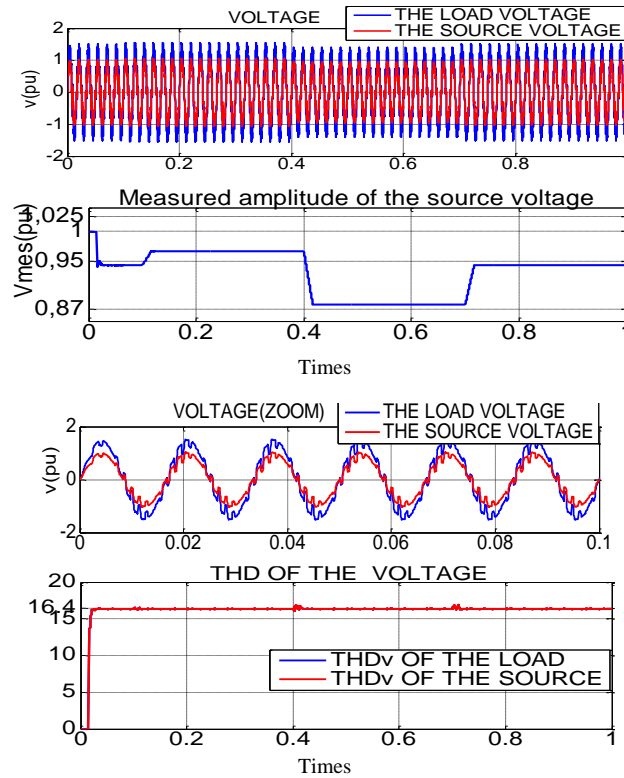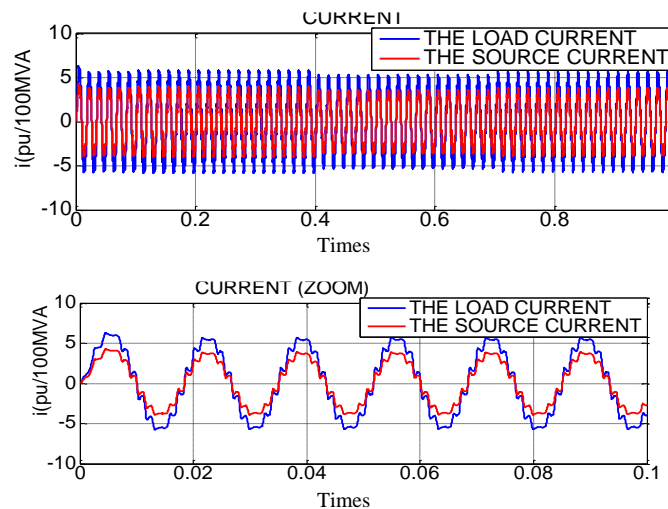
Figure 11. Source voltage, its amplitude, load voltage and their THD (total harmonic distortion)

In the same case we represent the shape of the currents of the source and of the nonlinear load, their zoom, and their total harmonic distortion THD (Figure 12).
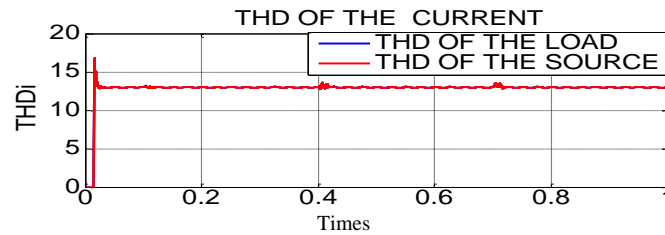
Figure 12. Currents of the source and of the nonlinear load and their THD

4.2. Simulation results (hybrid SVC connected)

In the second case, we represent the shape of the source voltage, its amplitude, the voltage of the nonlinear load, their zoom, and their total harmonic distortion THD (Figure 13). The SVC and the three-phase harmonic filter are connected.
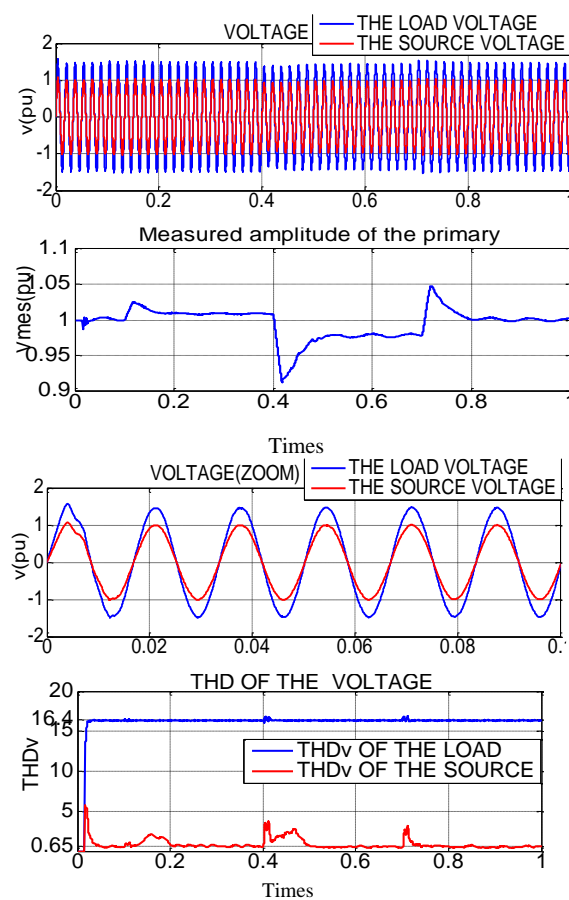

Figure 13. Source voltage, its amplitude, load voltage and their THD

In the same case we represent the shape of the currents of the source and of the nonlinear load, their zoom, and their total harmonic distortion THD also the reactive power absorbed or provided by the SVC to compensate the disturbances of the source voltage (voltage drop, overvoltage or distortion) (Figure 14).

Figure 14. Currents of the source and of the nonlinear load, their THD and the reactive power absorbed or provided by the SVC

4.3. Simulation results (SVC connected and the three-phase filter disconnected)

In the tird case, we represent the shape of the source voltage, its amplitude, the voltage of the nonlinear load, their zoom, and their total harmonic distortion THD (Figure 15). The SVC is connected and the three-phase harmonic filter is disconnected.

Figure 15. Source voltage, its amplitude, load voltage and their THD

In the same case we represent the shape of the currents of the source and of the nonlinear load, their zoom, and their total harmonic distortion THD also the reactive power absorbed or provided by the SVC to compensate the disturbances of the source voltage (voltage drop, overvoltage or distortion) (Figure 16).
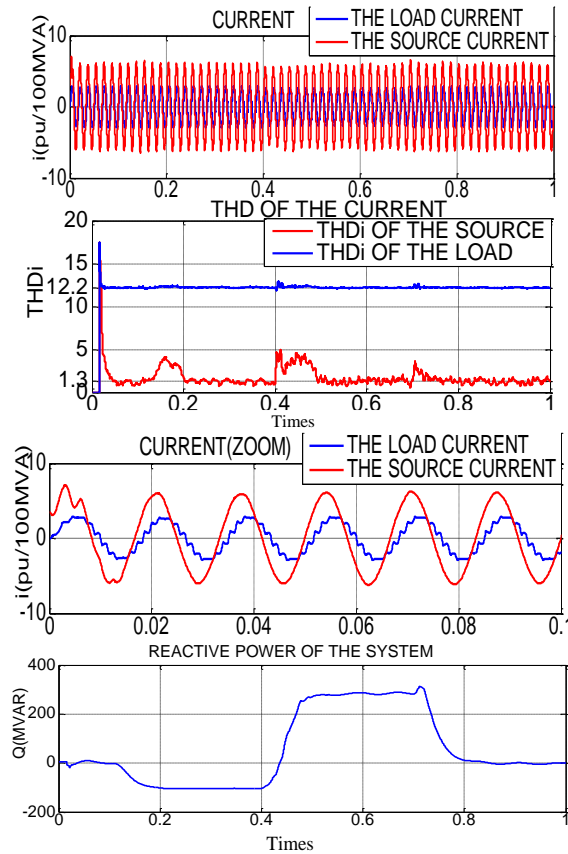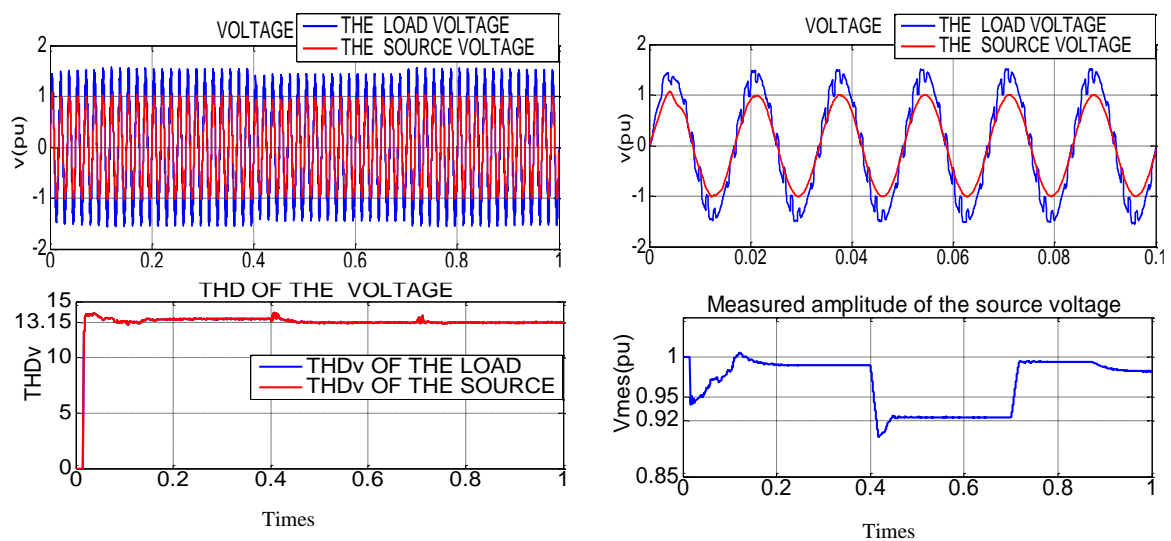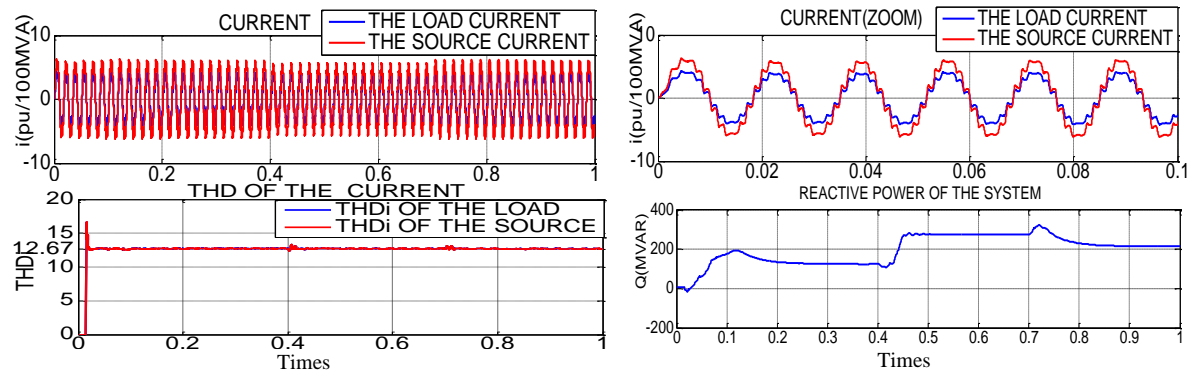

Figure 16. Currents and their THD and the reactive power absorbed or provided by the SVC

4.4. Comparative result of the amplitude of the source voltage

In Figure 17, we represent the shape of the amplitude of the source voltage for comparison between the three cases of simulation.

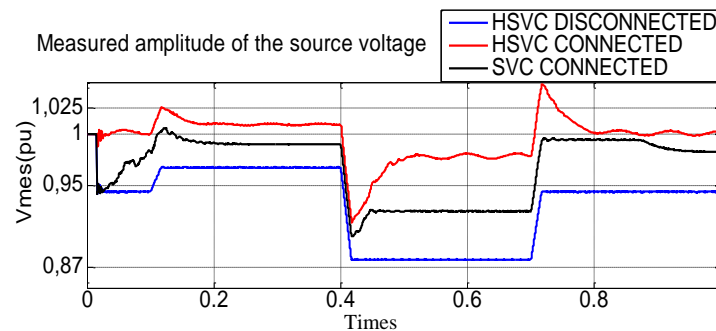Figure 17. Comparative result of V_{mes} for the three cases

4.5. HSVC behavior with the two regulators

In Figure 18 we have represented the amplitude of the voltage source and the reactive power absorbed or provided by the SVC with the two regulators proposed, the PIP and the Fuzzy PI in order to compare these results.
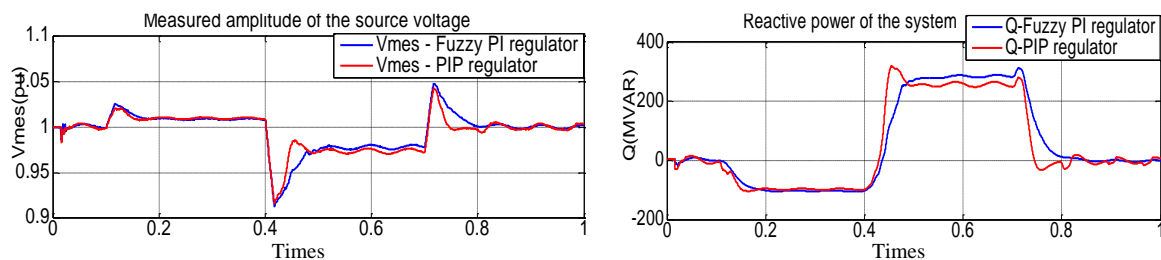

Figure 18. Source voltage amplitude and reactive power absorbed or provided by the SVC

4.6. Discussions results
4.6.1. 1st case: the HSVC disconnect
Initially, the source voltage undergoes a deep fall because of the two variations existing from the source and presents a distortion and because of the nonlinear load which generates harmonic currents and therefore consumes of two ways the reactive power. The voltage dropped in this case down to-0.87 pu (Figure 11 voltages and their THD (Harmonic distortion rate) and amplitude of the source voltage). So no compensation is reached by the HDVC.

4.6.2. 2nd case: the HSVC connected
In this case, the harmonics filter eliminates harmonic currents and therefore reduces the consumption of the reactive power. The THD (Harmonic distortion rate) of current and voltage are very visibly reduced, the THD_v becomes 0.65% (Figure 13) and the THD_i becomes 1.30% (Figure 14). At t = 0.1s, the voltage increases to 1.025 pu. The SVC reacts to deliver it to its reference by absorbing reactive power. At this point all the TSCs are out of service and the TCR is almost in full conduction. At t = 0.4s, the source voltage is abruptly decreased to 0.93 pu. The SVC reacts by producing reactive power, thereby increasing the voltage near its reference. At this point the three TSCs are in service and the TCR absorbs approximately 40% of the reactive power. Each time a TSC is initiated, the angle α of the TCR changes suddenly from 180 degrees (no conduction) to 90 degrees (full conduction). Finally, at t = 0.7s, the busbar voltage is increased to 1.0 pu and the reactive power of the SVC is reduced to zero (Figure 13 amplitude of the source voltage).

4.6.3. 3nd case: SVC connected and HF disconnected
The SVC reacts to return the voltage to its reference by supplying the reactive power during the time interval [0.1 1] (Figure 16) reactive power of the SVC). At this point in the time interval [0.1 0.4], two TSCs are in service and in the remaining time the three TSCs are in service the TCR remains closed (the angle α of the TCR remains at 180 degrees (no conduction)) given the large reactive power consumed. In this case the fall is improved but it is not the most desirable. This is due to harmonic currents and the consumption of reactive power by the non-linear load.

The SVC alone without the harmonic filter does not achieve the desired compensation, the Harmonic distortion rate THDi = 12.65% of the load current and the THD_v = 12.65% of the source voltage remain unchangeable (Figure 15 and Figure 16). Finally, In general, the SVC was able to give satisfactory compensation results by using the two voltage regulators. With the PI Fuzzy regulator, the SVC gave maximum compensation and the best results compared to the PIP regulator. The PIP regulator has a shorter stabilization time compared to PI fuzzy (Figure 18).

5.   CONCLUSION
In this work, I have tried to illustrate the usefulness, efficiency and speed of control ling voltages and reactive power, as well as eliminating harmonic currents and voltages by inserting the hybrid SVC controller. In this dispute I have described the structure of the hybrid SVC with a study of each model. The simulations are made on the SVC constituted by a TCR and three TSCs by adding an HF harmonic filter to it to become the hybrid SVC (HSVC). And to make the latter more efficient I have introduced two voltage regulators, the first is the PIP and the second is the regulator using the fuzzy PI. The results obtained show that the HSVC control device can play a very important role in the field of reactive power compensation and the control of the voltages of the different nodes. In particular, the HSVC with the fuzzy PI regulator presented more satisfactory results.

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BIOGRAPHY OF AUTHOR

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