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STUDY OF REACTIVE POWER COMPENSATION USING STATIC VAR COMPENSTOR

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Abstract: ***This paper presents an application of a Static Var Compensator (SVC). A SVC is based on Power Electronics and other static devices known as FACTS (Flexible AC Transmission Systems) Controllers which it could be used to increase the capacity and the flexibility of a broadcast network. The effect of wind generators on power quality is an important issue; non uniform power invention causes differences in system voltage and frequency. Therefore wind farm requires high reactive power compensation; the advances in high power semiconducting devices have led to the development of FACTS. The FACTS device such as SVC inject reactive power into the system which helps in maintaining a better voltage profile.***

Keywords: FACTS, SVC, voltage stability, power limits, Voltage collapse; Reactive power injection; FACTS devices.

1. Introduction

The purposes of generators are to supply the active power, to provide the primary voltage control of the power system and to bring about, or at least contribute to the desired reactive power balance in the areas adjacent to the generating stations. A generator absorbs reactive power when under excited and it produces reactive power when overexcited. The reactive power output is continuously controllable through varying the excitation current. The allowable reactive power absorption or production is dependent on the active power output. For short-term operation the thermal limits are usually allowed to be overridden. The step-response time in voltage control is from several tenths of a second and upwards. The rated power factor of generators usually lies within the range 0.80 to 0.95. Generators installed remotely from load centers usually have a high rated power factor; this is often the case with large hydro-turbine generators. A SVC is one of controllers based on Power Electronics known as FACTS (Flexible AC Transmission Systems) Controllers, which can control one or more variables in a power system. The compensator studied in the present work is made up of a fixed reactance connected in series to a Thyristor Controlled Reactor (TCR) – based on bi-directional valves- and a fixed bank of capacitors in parallel with the combination reactance-TCR. The thyristors are turned on by a suitable control that regulates the magnitude of the current[1]. The system under study is an interconnected network located in the southeast area of Venezuela, where it is found a very important loads related to oil industry. This real and complex system, allows the study of strategies and feasible solutions for the application of the SVC. The following figure shows the systems under study:

The objectives of this study were to increase the transmitted power, under the thermal capacity, through an overhead transmission lines using a voltage stability criterion. The used approach has been the voltages stability, with the purpose of keeping the voltage magnitude on the main buses within the range of 0.8-1.2 p.u. during the transients state and after a fault located anywhere in the systems.

2. Static VAR Compensator (SVC)

The FACTS are controllers based on solid states technologies, whose two main objectives are: the increase of the transmission capacity and the control of the power flow over designated transmission routes. On this way, the Controllers FACTS can be classified into four categories: Series Controllers, Shunt Controllers, Combined series-series Controllers, Combined series-shunt Controllers. The SVC fall into Shunt Controllers category and it function as a fast generators or as an fast absorber of reactive power, with the purpose so as to maintain or control specific parameters of the electric power systems (typically bus voltage).

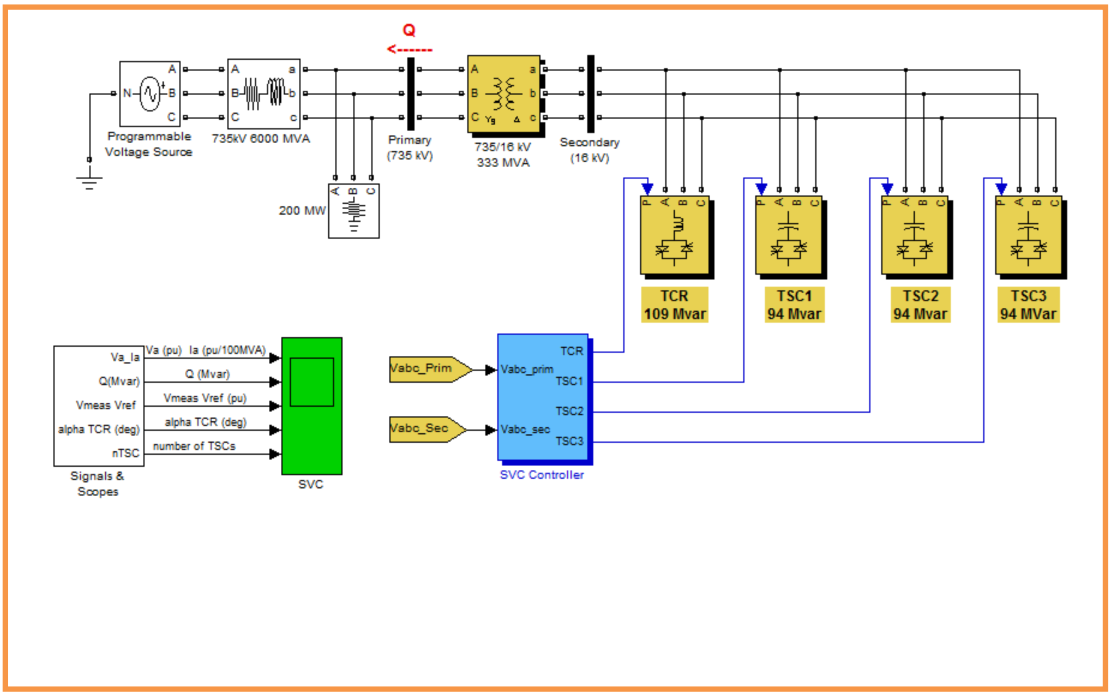


Fig.1 Model of the electric system under study for TCR and TSC(SVC)

The SVC consists of a Thyristor Controlled Reactor (TCR) and a Fixed Capacitors(FC) banks. The TCR is a thyristor controlled inductor whose effectives reactance varied in a continuous manner by partial conduction control of thyristor valve. [1], [2]. The basic elements of a TCR are a reactor in series with a bidirectional thyristor switch as show in figure Nº 2.

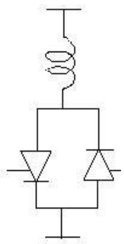


Fig. 2. Thyristor Controlled Reactor (TCR)

The thyristors conduct alternates half-cycles of supply frequency depending of the firing angle α, which is measured from a zero crossing of voltage. Full conduction is obtained with a firing angle of 90°. The current is essentially reactive and sinusoidal. Partial conduction is obtained with firing angles between 90º and 180º. Firing angle between 0° and 90° are not allowed as they produced asymmetrical current with a dc component. The effect of increasing the firing angle is to reduce the fundamental harmonic component of the current. This is equivalent to an increase in the inductance of the reactor, reducing its reactive power as well as its current. So far as the fundamental component of current is concerned, the thyristor–controlled reactor (TCR) is a controllable susceptance, and can therefore be applied as a static compensator[1].

Also, the conduction angle σ can be define as a function of the firing angle α by:

$$\sigma = 2(\pi - \alpha) \qquad (1)$$

The instantaneous current in the TCR is given by:

$$i = \begin{cases} \frac{\sqrt{2}\,V}{X_L}(\cos\alpha - \cos\omega t), & \alpha<\omega t<\alpha+\sigma \\ 0, & \alpha+\sigma<\omega t<\alpha+\pi \end{cases} \qquad (2)$$

where V is the voltage r.m.s applied the TCR and XL=ωL is fundamental-frequency reactance of the reactor. The fundamental component is found by Fourier analysis and is given by:

$$I_1 = \frac{V}{X_L}\,\frac{\sigma - \mathrm{sen}\,\sigma}{\pi} \quad [A]\ \text{r.m.s} \qquad (3)$$

We can write equation (3) as:

$$I_1 = B_L(\sigma)\,V \qquad (4)$$

where BL(s) is an adjustable fundamental-frequency susceptancia controlled by the conduction angle according to the following control law,

$$B_L(\sigma) = \frac{\sigma - \text{sen}\,\sigma}{\pi X_L} \qquad (5)$$

as a function of the firing angle, α

$$B_L(\alpha) = \frac{2(\pi - \alpha) + \text{sen}2\,\alpha}{\pi X_L} \qquad (6)$$

The maximum value of the variable susceptancia is 1/XL, obtained with σ =180º (α=90º) and the current on the reactor is maximum. The minimum value is zero, obtained with σ = 0º (α=180º). This control principle is called phase control[1].

A. Characteristic of SVC for phase 1

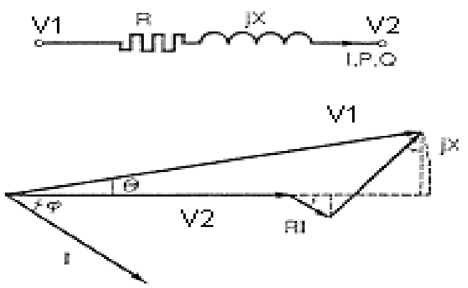
Speed of response: The TRC has a control in its firing angle α that varies between 90º and 180º. Its speed of response is sufficiently quickly in applications caused by rapidly fluctuating loads. On the other hand, in power system is important that the control of the TCR is stable and exact.

Independent Phase Control: The Three-Phase TCR used in the SVC, can be independently controlled the three-phase of a power system, so that it can balance any unsymmetrical three-phase load when it are presented [3].Under unbalance conditions, a TCR can generate more harmonics than under balanced conditions. For this reason, it is necessary, usually, to placed passive filter LC, using for that the same compensation capacitors. In this case, the injection of the reactive power of the SVC is due to the filters and the fixed capacitors.

Response to Overvoltage and Undervoltage: This is one of the most important characteristics of the SVC, because it compensates the voltage when conditions of very high or very low voltage are presented in the bus where the compensator is placed. In that case, it injects the reactive power necessary to restore the normal voltage magnitude.

B. Thyristor Controlled Reactor with Unswitched (Fixed) Capacitor (TCR-FC)

The SVC under study, consist of a thyristor controlled reactor (TCR) and a fixed capacitors bank (FC) as it is shown in figure No 3 showing voltage drop of series impedence.



'tor

The fixed capacitors bank (FC) alone supplies a part of the capacitive var required by the system, while the other part by the passive filters. The filters are placed in parallel with the fixed capacitors bank and they are tuned to the most relevant harmonic frequency. The third harmonic can be attenuated by the delta connection of the TCR. The fixed capacitors (FC), and the thyristor controlled reactor may be considered essentially to consist of a variable reactor (controlled by delay angle α) and a fixed capacitors, with an overall var demand versus var output characteristic as shown in figure No 4.

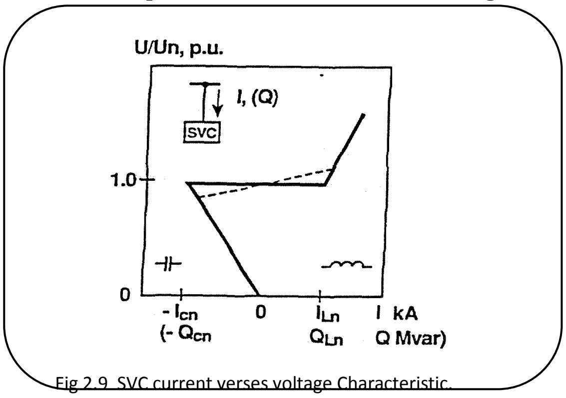


Fig 2.9 SVC current verses voltage Characteristic.

Fig. 4.Vars demand versus vars output characteristic

As seen, the constant capacitive var generation "QC" of the fixed capacitor is opposed by the variable var absorption "QL" of the thyristor-controlled reactor, to yield the total var output "Q" required. At the maximum capacitive var output, the thyristor-controlled reactor is off (α=180°). To decrease the capacitive output, the current in the reactor is increase by decreasing firing angle α. At zero var output, the capacitive and inductive current become equal and thus the capacitive and inductive vars cancel out. In the studied case the capacitive vars equal the maximum inductive vars that output the TCR.

Principles of operation:

Two types of Thyristor-controlled elements are used in SVCs:

1. TSC — Thyristor-switched capacitor
2. TCR — Thyristor- controlled reactor

From a power-frequency point of view they can both be considered as a variable reactance, capacitive or inductive, respectively

3. Voltage Regulation Stability

The static var compensator (SVC) is frequently used to regulate the voltage at dynamic loads. But also, it is used to provide a voltage support inside of a power system when it takes place small gradual system changes such as natural increase in system load, or large sudden disturbance such as loss of a generating unit or a heavily loaded line[6]. These events can alter the pattern of the voltage waveform in such a manner that it can damage or lead to mal function of the protection devices. Generally, there are sufficient reserves and the systems settles to stable voltage level. However, it is possible, (because a combination of events and systems conditions), that the additional reactive power demands may lead to voltage collapse, causing a major breakdown of part or all system.

The SVC can improve and increase significantly the maximum power through the lines. This is achieved, if the SVC is operated an instant after of a disturbance providing the necessary flow of power. Therefore, if the approach of maximum transmitted power, is of voltages, it is possible to increase the power flow. In the studied case, it is seen that the transmitted power rise enough according to the used approach, keeping the voltage magnitude within the range of 0.8-1.2 p.u..

4. Power Systems in RP

The power system considerate in this study, is modeled by means of the ATP/EMTP program [4], [5]. It is a part of the interconnected power system of Venezuela, located in the southeast region of the country. It consists of four (4) generator bus, twelve (12) load bus, nine (9) power transformers, three (3) reactors and twenty three (23) transmission lines. All the elements were modeled using the ATP/EMTP models like : the sources type 59 for the generators, the saturable transformer for the three-phase transformers, pi-equivalent circuit for the transmission lines and uncoupled, lumped, series R-L-C branch for the loads. To turn on or to turn off the thyristors[1],[2],[6] a transient analysis control system(TACS) is used.

A. Simulation Results

The results are obtained for four cases of the network state:

a. Network without the wind generators and the SVC devices with standard load.
b. Network without the wind generators and the SVC devices with increased load.
c. Network with integration of the wind generators.

The simulations were carried out for the following contingencies:

a. Load increase in order to rise the power flow through the main transmission system.

b. Three-phase fault in the "Guri" bus after the load increase.

In the contingency "a" the load at "San Gerónimo" bus is increased, and the voltage profile will be different. Therefore, each time the load is increased it will be necessary to run a power flow analysis program to get the new voltage profile which it will be the new initial conditions for the fault calculations.
In the contingency "b", the three-phase short-circuit have a clearance time of three cycles. After this time interval the transmission line is out of operation, therefore the configuration of the system changes and the control system will be able to change the operation point of the SVC.

At the second step a SVC was connected to "Malena" bus. A dynamic compensator of 400 Mvar capacitive supplies by the filters and the fixed capacitor allow to rise the maximum power through the lines between "Malena" and "San Gerónimo" buses for the three phase fault about 48 % while the voltage level was kept within the range of 1.2-0.8 p.u. The inductive rating of the compensator to fully compensate for the reactive power requirement at the "Malena" bus is 400Mvar. Hence a compensator of –400, +400Mvar will meet the voltage requirement.

B. Results

In figure No 5 and in Table I are shown the results of the simulation without the dynamic compensator (SVC) and a three-phase fault located at "Guri" bus, where it can be seen that the maximum power flow through "Malena" –"San Gerónimo" overhead lines reach 2175.6 Mva per phase, keeping the level voltage within the specified range of 1.2-0.8 p.u.

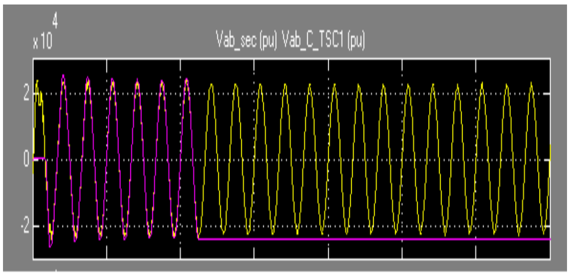


Fig. 5 Voltage levels at the system buses for three-phase fault without SVC

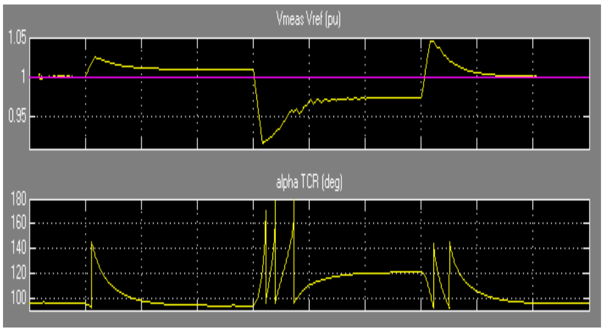


Fig. 6 Voltage levels at TCR (deg) for three-phase fault with SVC

Table I.-Power increased for three-phase fault

	Transmitted Power (pu)	Maximum Transmitter (MVA)	Power Increment (MVA)	Power Increment (%)
System without SVC	0.42	75.6	-	-
System with SVC (800)	0.62	211.4	111.0	**67.8 %**
System with SVC (400)	0.59	1056.2	580.6	**41.35 %**

Thermal Capacity = S_b = 5480 MVA (three lines)

5. Conclusions

This disconnection can deteriorate a production inequity and therefore accelerate the advent of a major incident in the network. The impacts of the addition of generators in an electrical supply network on the voltage stability are presented. The performance of FSIG with SVC or no SVC is compared in the simulation. It can be seen that SVC can

improve static and dynamic stability of power system. And the performance comparison of only FSIG connected to power grid and coordinated control of FSIG and DFIG are researched too. Additionally to the increment of the maximum transmitted power through the main power lines, the SVC offers other operative advantages that should be considered in the analysis of costs, since it contributes to improve substantially: the transient system stability, the quality standards of the electric service at low voltage level, the unbalances of the system and the voltage profiles in the steady and transient state.
For last, it is important to stand up the practical and simple handling of the models of the ATP/EMTP to implement a very complex study.

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