APPLICATION OF SATURATED REACTORS ON POWER TRANSMISSION SYSTEM

Dalton O. Camponês do Brasil

TESPO - Tecnologia em Sistemas de Potência
DOCB@NPD.UFPE.BR

Manoel Afonso de Carvalho Jr.

UFPE - Universidade Federal de Pernambuco
Dep. de Eng. Elétrica e Sistemas de Potência
MACJ@NPD.UFPE.BR

Abstract - This paper intends to present a summary of the studies developed about saturated reactors applications in transmission power systems. Within this context it is shown: basic principles and operating characteristics of such devices; ATP program modelling of a Twin-Triple type saturated reactor; typical steady-state and transient simulations in order to evaluate its performance. It was concluded from the technical analysis, considering the substitution of transmission lines shunt reactors by saturated reactors in comparison to other conventional mean of reactive compensation that the saturated reactors solution is really attractive.

Key Words: Saturated Reactor, Reactive Compensation, Voltage Control, Transmission System, Reactors.

1. INTRODUCTION

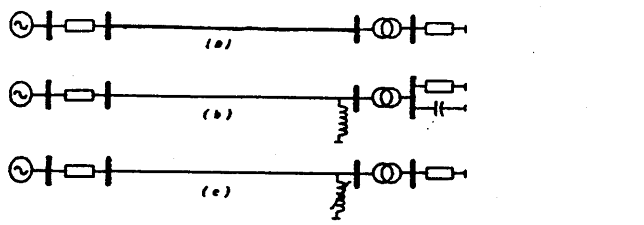
The voltage control and the reactive compensation in long EHV transmission systems are important to the system flexibility, reliability and economical operation. Issues like dynamic stability, voltage regulation control and overvoltages are intrinsically dependent on the reactive compensation type and level.

The reactive compensation is more important in systems with low short circuit level. In a long radial transmission system, considering only the voltage regulation and industrial overvoltage, the reactive compensation is responsible to assure the following operation aspects:

- Line and transformer energization, followed by load pickup (ex. V< 1.1pu).
- The appropriated voltage regulation (ex. V=1±0.05pu) at the load bus during the maximum and minimal load conditions.
- Impose acceptable voltage levels during energization and load rejection.

The conventional reactive compensation to the system shown in Fig.1a, is composed basically by shunt reactors, switched or not, placed at the line end; shunt capacitors, switched or not as well, at the load, Fig.1b.

The reactors are seized to keep the line end voltage, within predetermined acceptable levels, at the minimal and no load conditions. The capacitors are seized to satisfy the system necessities at the maximum load and contingencies.



(a) Basic Configuration; (b) Conventional Compensation

(c) SR Compensation

Fig.1 Transmission System

With this simple approach becomes difficult to achieve an adequate voltage control for loads natural variation, system voltage transitory and dynamic behaviours at load rejection.

This occurs because the reactive power generated is not continually controllable. To solve this problem different devices are applied such as: synchronous condensers, static compensators by thyristors switch reactors, natural or forced iron core saturation etc.

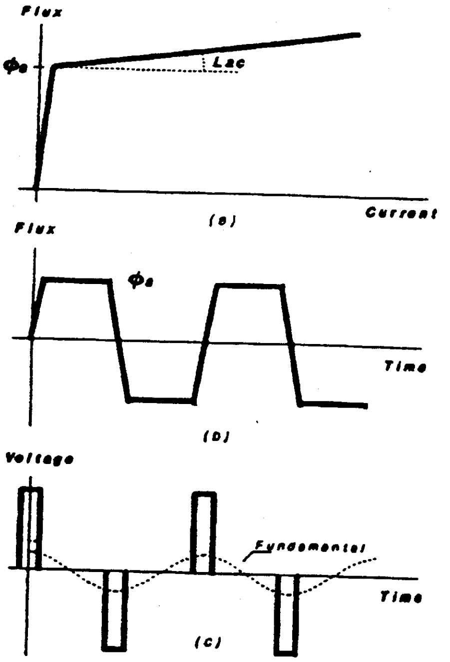
The Saturated core Reactor (SR) has some features, that can be more explored: there is no necessity of external control systems, has a considerable temporally overload capacity and an acceptable time response.

The use of SR to voltage control is reported in the technical literature [1], [2], [3]. This work considers the SR as a line reactor, placed as shown in Fig.1c, exploring the fact that the reactor can be designed to be unsaturated at normal operating voltage and goes to deep saturation under overvoltage during energization, load rejections or other conditions.

This is equivalent to switch the reactor only when it is necessary without any external device. This approach, also allows a substantial reduction on the capacitor bank power rating using by the conventional compensation, Fig.1b.

The work presented in this paper is under development as part of a M.Sc. thesis. It shows the following topics:

- Principles and basic operation characteristic of a RS.
- Modelling of a Twin-Triple SR type, on ATP program, to analyse its behaviour.



(a) Flux x Current ; (b) Flux x Time; (c) Pulse Voltage x Time

Fig.2 Basic Wave Form

- Application of the developed model in a 230kV real system.

2. BASIC PRINCIPLES

The saturated reactor can be considered as a transformer with an especial design that goes to saturation at a predetermined operating point. Its iron cores have the characteristics shown in Fig.2a.: high permeability in the unsaturated region, sharp knee, low permeability in the saturated region and low hysteresis loop.

If a sine current wave is applied to an iron core as it was considered, the flux will be a trapezoidal wave as shown in Fig.2b, alternating between $\pm\phi s$. Fig.2c shows the voltage pulse wave developed at the core windings terminals.

The pulse voltage time area is constant and independent of the applied current source amplitude. This leads to the SR a voltage current characteristic similar to the flux current wave Fig.2a.

The SR absorbs reactive power as an under-exited synchronous condenser and can be represented by the equivalent circuit shown in Fig.3 under steady state conditions.

The harmonics generated by SR can be very high; this problem is avoided using harmonic compensation techniques as: connecting the reactors windings in zigzag and multi-iron constructions. These reduction techniques keep the characteristics harmonics of order $2kn\pm1$ (n= number of core, k=1,2,....etc.) as low as 2%.

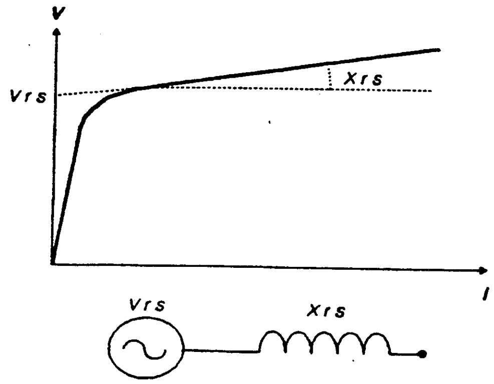


Fig. 3 SR Equivalent Circuit

To get harmonic compensation for larger operation band the SR has a delta winding feeding a non-linear reactance.

To use a SR in static compensator other devices are necessary:

- Slope Correction Capacitors. The SR has a slope reactance in the order of 5% to 15% on its base. To get a better regulation this reactance is reduced by connecting in series a slope reduction capacitor which brings these values to 3% to 5%.
- Damping Circuits. To avoid sub-harmonic oscillations, due to the series connection of the slope correction capacitor, a damper is necessary. It is placed in shunt of the capacitor.
- Step dawn transformer. The SR is connected in the secondary of a transformer to provide terminal voltage changes by the load tap changer.
- Harmonic Filter. To reduce the harmonic injections in the power system it is used harmonic filters tuned to the characteristics and non-characteristics harmonics. The filters capacitors improve also the load power factor.

3. THE SR ATP MODELLING AND TEST

Due to its non-linearity, to simulate the SR is necessary to use a tool such as the ATP program. The most used type of SR for high power output is the Treble-Triple. This work simulates a Twin-Triple due to its simplicity.

The Treble-Triple model can be obtained straightforward from the Twin-Triple one. In the simulated SR the non-linear load, to compensate the generated harmonics, was not included and it was replaced by a linear reactor. Fig.4 shows the Twin-Triple magnetic and electrical diagrams.

It is assumed that the yokes have sufficient cross section area to avoid saturation due to the applied overvoltage. This allows to consider the SR as a magnetic structure built of single iron cores.

It is not available in the publish literature the necessary data to simulate a SR using the ATP program.

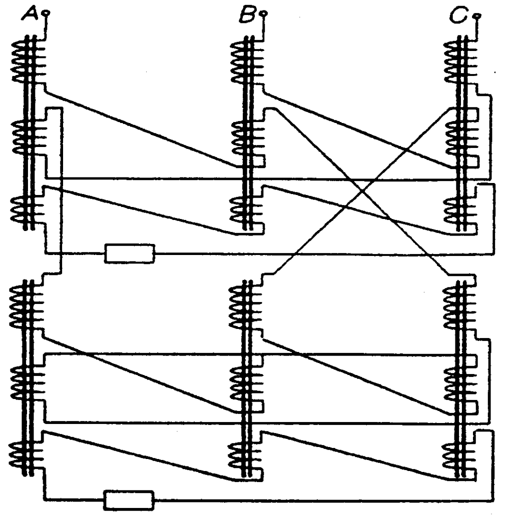


Fig. 4 Twin-Triple SR

This is overcome by development of a simplified project for basic data definition.

Considering the intended application the following input data was assumed:

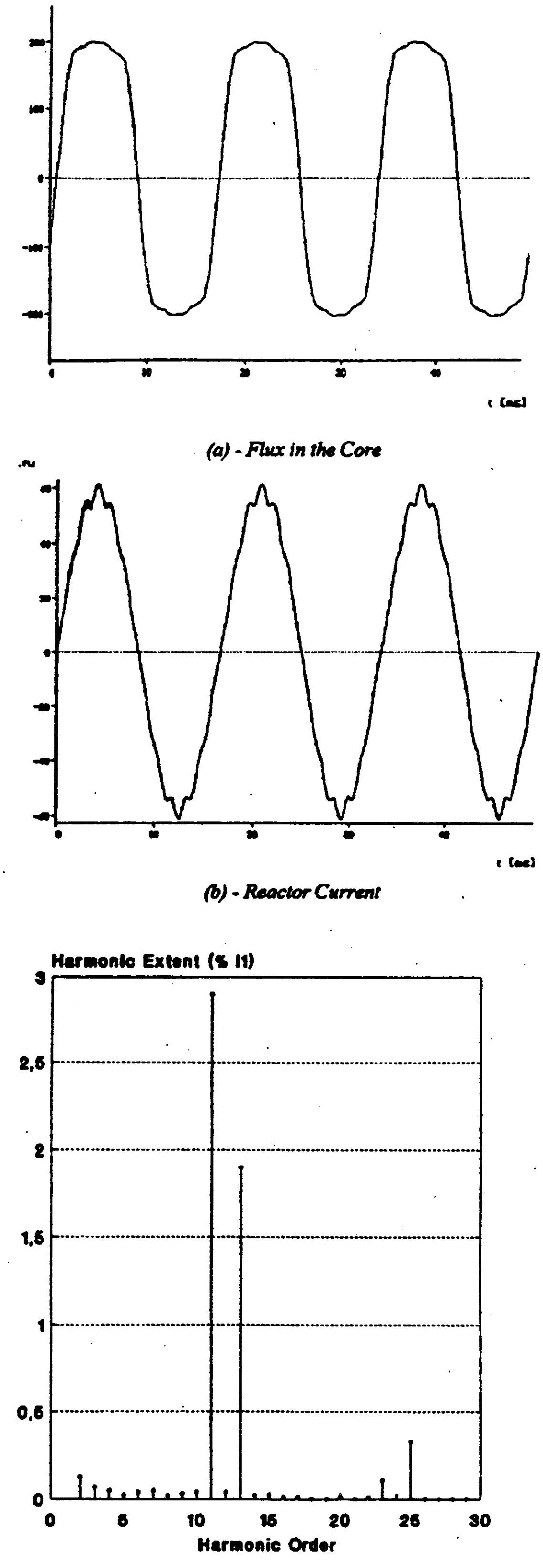
- Nominal Power output 10MVA to 20MVA
- Saturation characteristics:
  . Knee 0.85pu to 1.0pu
  . Magnetization current 0.01%
  . Saturated Reactance 5% to 25%
  . Leakage Reactance 5% to 25%

The SR was simulated using the standard multiwindings transformer model available in the ATP version 5. The saturated branches are in the primary windings. To avoid oscillations due to numerical integration a dumping resistance was used in shunt of the saturation branches.

3.1 The SR simulation test

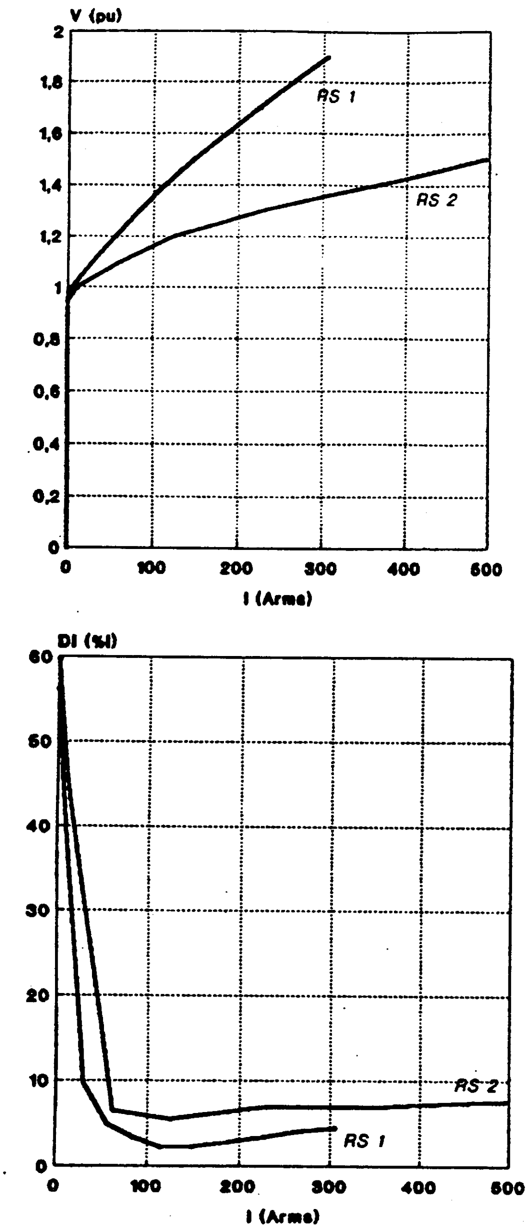
A set of simulations was carried out to adjust the SR design parameters. The SR was energised connected to a infinite bus, using different voltage amplitudes for a period of 100ms. After 50ms all the voltages and currents reach the steady state.

Fig.5 shows the Flux and Line Current wave forms and the current harmonic contents to the infinite bus voltage at 1.15pu. From the harmonic spectrum it is clear that the 11th, 13th, 23rd and the 25th are the lowest order ones left and that they have acceptable amplitude.



(a) Core Flux; (b) Current ; (c) Harmonics Contents

Fig. 5 Steady State Wave



(a) Vx I Characteristic; (b) Total Current Distortion

Fig. 6 Steady State Characteristics

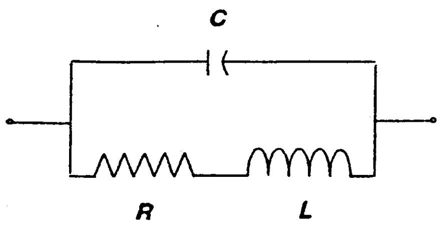
3.2 The SR steady state characteristics

Keeping the same test conditions the Vx I characteristic and the total current distortion, for two basic design (SR1 and SR2), were determined.

Model	Knee(pu)	Xac	Xl
SR1	1.0	15%	15%
SR2	1.0	5%	5%

Base 230kV / 18MVA

Assuming 1.05pu as the maximum steady state voltage, the SR power is 7.3MVA and 18MVA respectively for the model SR1 and SR2. In their own bases, the slope



$C = 45.1\ \mu F \quad R = 41.6\ \Omega \quad L = 0.156\ H$

Fig.7 Slope Compensation Damper

reactance obtained as a result of simulation was 13% for the model SR1 and 4% for the SR2, Fig 6a.

The total harmonic distortion has a minimum value in the order of 2% to 3%, and is variable with the iron core saturation level Fig.6b. The simulations show a minimum point and not a band that could be necessary for some practical applications.

This band can be obtained by changing the linear reactor of the 3rd windings by a non-linear one. This is equivalent to increase the third harmonic injection in these windings what spreads the minimum band [4]. The optimum value for this non-linear reactor is under evaluation.

The harmonic distortion for the low current value is acceptable because these values will have little influence in the power system, this is equivalent to a transformer magnetizing current.

The harmonic distortion in the high current region can be acceptable because the intended use of the SR is as line reactor and the high current region is reached only during a short period of time

4. APPLICATION IN A 230kV RADIAL SYSTEM

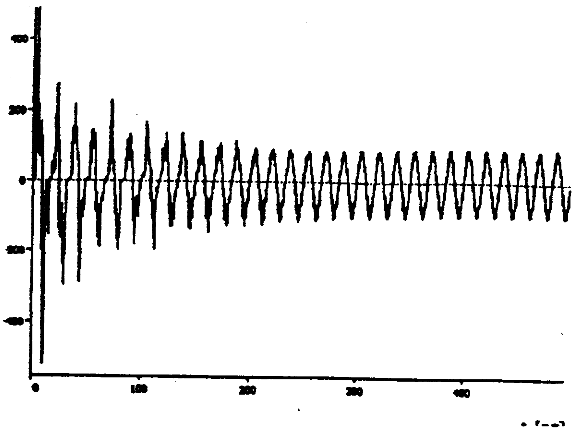
To compare the technical behaviour of the proposed compensation scheme, a 230kV radial system is analysed using a conventional line reactor and then using a SR, Fig.1b, 1c. The system characteristics are:

- Short Circuit Level: 1000MVA at the source and 250MVA at the load point.
- Transmission Line: 300km and 130MW SIL.
- Load: 87MVA maximum, pf 0.95, at the 69kV.

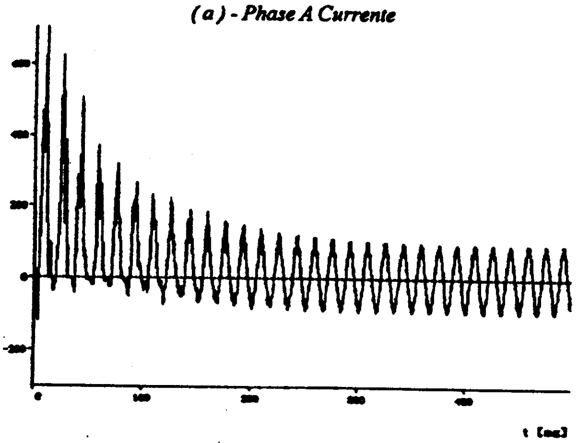
The characteristics of the traditional compensation are: shunt reactor 20MVAr / 230kV (39% of compensation) at the line terminal, a capacitor bank 15MVAr / 69kV

The SR compensation uses two schemes. The SR2 model described in 3.2 and the SR2 with a slope correction capacitor. The slope compensation is equal to 50% and to avoid sub-harmonic oscillations a damper circuit is used as shown in Fig.7.

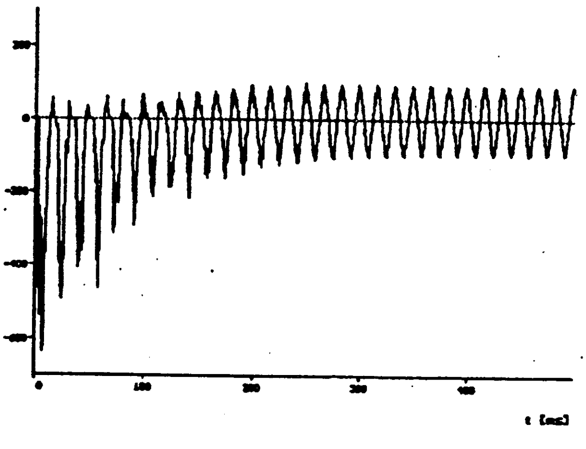
The steady state behaviour of the system without and with compensation are summarised bellow:



(a) - Phase A Currente



(b) - Phase B Current



(c) - Phase C Current

Fig. 8 SR Phase Currents

Scheme	Line end Voltage (pu)		Regulation
	Load	No load	%
No Comp.	0.970	1.196	23.3
Conventional	0.950	1.100	15.8
SR2	0.969	1.096	13.1
SR2 + C	0,969	1.081	11.6

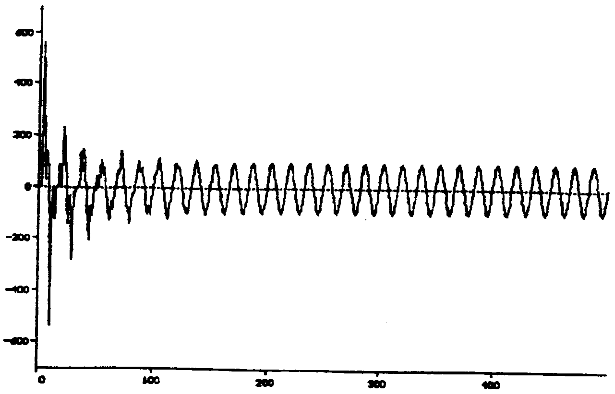


Fig. 9 Phase A current with Slope Correction

Through these results can be noticed the regulation, the no load and the load line end voltage improvements.

The maximum voltage pick at line energization and load rejection are almost the same in the two compensation schemes, these values are:

Scheme	Energization	Rejection
Conventional	1.96pu	1.41pu
SR	1.86pu	1.42pu

The SR three phase current waves to the line energization are shown in Fig.8. Can be observed that at 500ms the offset current is almost zero, and for all practical purpose reaches the steady state.

For the SR with slope correction the oscillation period is small due to the slope capacitor damper circuit, Fig.9.

These results indicate that a Saturated Reactor for this type of application is technically suitable and has an economical advantage, in comparison with the conventional scheme, considering the fact that the capacitors banks are not necessary.

The SR was simulated directly connected to the power line (230kV). The viability to construct such reactors must be one challenger to the manufacturers, considering that in the literature the high terminal voltage reported of a SR is 132kV (GEC).

5. CONCLUSION

The ATP program has all the necessary tools to simulate a SR, and can be used to determine its performance in the power system.

The proposed scheme is attractive to be applied in transmission and sub-transmission systems in Brasil due to their characteristics (long radial) considering the facts that the use of compact lines and lines with natural high power level are under studies to be implemented by some regional Power Companies.

The work, shown in this paper, is under further development to:

- Model a SR with nine core.

- Include in the SR an auxiliary reactor to minimise the harmonic generation.

- Evaluate the dimension of a SR to be direct connect at the transmission level and access core losses and weigh, through contact with manufactures.

6. REFERENCES

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Manoel Afonso de Carvalho Jr. was born in Mataripe Ba, Brasil, 1950. Received the B.Sc. degree in electrical engineering from Universidade Federal da Bahia in 1973 and the Ph.D. in 1983 from UMIST. His current research interest includes modelling and digital technique for Power System Analysis. Since 1988 he has been with Universidade Federal de Pernambuco as senior lecturer and is the Power System Group head . MACJ@NPD.UFPE.BR

Dalton de Oliveira Campônes do Brasil was born in São Paulo, 1949. Received the B.Sc. degree in electrical engineering from Escola Politécnica da Universidade de São Paulo - USP and has Pos-grad curse at the same school. He is a Power System specialist in the network planning as overvoltage studies and is correctly pursuing the M.Sc. degree at the Universidade Federal de Pernambuco. DOCB@NPD.UFPE.BR