# COMPARATIVE ANALYSIS BETWEEN CONVENTIONAL VOLTAGE REGULATION USING REACTORS AND CONTINUOUS VOLTAGE REGULATION USING TCR IN DYNAMIC OPERATION STATE

MIREA C.
Transelectrica, DISPECERUL ENERGETIC NATIONAL
constantin.mirea@transelectrica.ro

**Abstract – In this paper a diffrent approach for voltage regulation strategies is taken into consideration. At the National Power Dispatch Centre one important voltage regulation method is done by connecting/ disconnecting reactors in order to compensate the voltage variations. Each reactor has 100 MVAr, and it's fully connected/disconnected in the Electric Power System grid when needed, leading to voltage spikes in the power system which stresses the nearby equipments. By replacing the reactors with thyristor controlled reactors (TCR) the "on/off" regulation method is changed into a continuous regulation process and voltage spikes are eliminated. Dynamic simulations have been realised to show these differences using Eurostag simulation software and the National Power System database. Results are shown in the chapters below.**

**Keywords:** thyristor controlled reactor modelling, voltage regulation, reactor, electric power system.

## 1. INTRODUCTION

Presently in the National Power System, reactors are used to regulate voltage in the connection nodes and nearby area by connecting and disconnecting them in certain time intervals, in order to maintain voltage values within normal thresholds. At any moment, due to their fixed inductive reactance, their full reactive power is connected or disconnected to the grid producing high voltage variations inversely proportional with the short-circuit power of the node in which they are connected. In this paper the opportunity of modifying the fixed reactance of the reactors by creating a variable reactance with the purpose of making a reactive power regulation band is studied. In this case, voltage regulation will be continuous not in steps. At the moment there are 16 reactors operating in the system, adding up to 1600 MVAr, inductive reactive power.

By design there are two types of reactors, single phased and newer models three-phased. Reactors are used to locally regulate voltage by connecting them in the off-peak hours and disconnecting them in the peak hours to keep voltage within normal limits. The method implies connecting/disconnecting all available reactor capacity of a reactor to deal with voltage regulation. In an area with a low short-circuit power connecting a reactor leads to up to voltage swells, which stresses the equipment in the area, like the reactor's circuit breaker. As shown in the figure below high voltage spikes can be seen when connecting and disconnecting the 100 MVAr reactor in Suceava substation (SS). Up to 30 kV voltage spike was recorded on disconnection in the and up to 25 kV spike on connection.

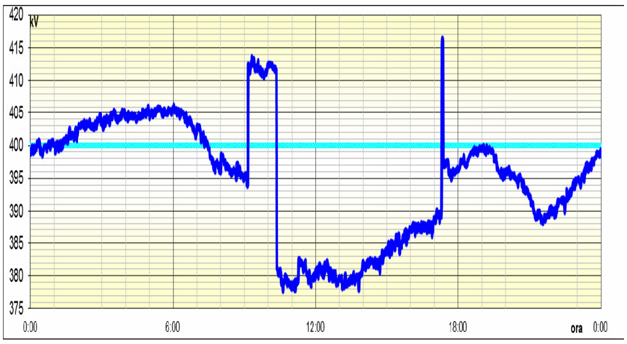


**Fig. 1 - Measured voltage curve in 400 kV Suceava Substation (SS).**

In this paper an alternative voltage regulation method is addressed, by using the reactors in a different mode. Fixed capacity reactors are replaced with variable capacity reactors, controlled by an automatic voltage regulator. This is technically possible by connecting in series the reactors with static bidirectional switches(fig 2). These static bidirectional switches are composed of valves formed of two thyristors connected in antiparallel one for each voltage alternation period. Thyristors continuously regulate the reactor's reactive power. By using them the reactive power supplied by the reactors is not fixed, either 0 or 100 MVAr, but varies between 0 and 100 MVAr. The electric current through the reactor can be continuously modified from maximum amplitude to zero, by using a phase regulation method. Electric current variation $i_{BC}(\alpha)$ is obtained by controlling the moment when the thyristors conduct, thus the duration time in every period. If the thyristors conduct when the voltage is at it's highest values, maximum conduction will result in the reactor, equivalent with bypassing the thyristor blocks. Thus the reactor compensates 100 MVAr, its nominal power [1].

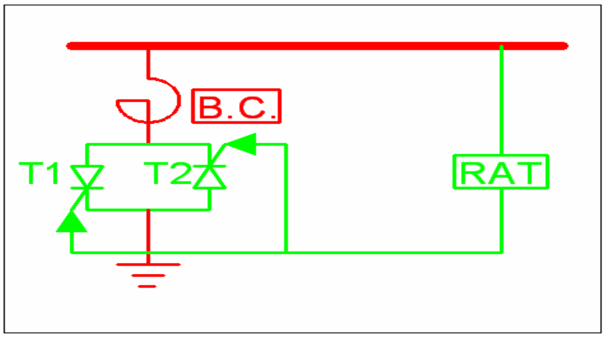


**Fig. 2 - Basic design scheme of a thyristor controlled reactor**

If the circuit from Figure 2 is supplied with a voltage $v(t)=\hat{V}\sin\omega t$, $\hat{V}$ being the maximum magnitude, the current can be calculated from the following differential equation: $L\frac{di_{BC}}{dt}=\hat{V}\sin\omega t$.

After calculating the integral, it results that $i_{BC}(t)=C-\frac{V}{\omega L}\cos\omega t$, where C is the integration constant. By adopting the following condition, $i_{BC}(\omega t=\alpha)=0$ it results that:

$$i_{BC}(t)=\frac{V}{\omega L}(\cos\alpha-\cos\omega t) \quad (1)$$

Depending on the conduction angle α, of the thyristors we can determine the reactor's admitance $B_{BC}(\alpha)$:

$$B_{BC}(\alpha)=B_{\max}\left(1-\frac{2}{\pi}\alpha-\frac{1}{\pi}\sin 2\alpha\right) \quad (2)$$

where $B_{\max}=\frac{1}{\omega L}$.

The thyristor controlled reactor can operate within a defined V – I characteristic, with borders determined by the maximum values of admittance, voltage and current (Fig. 3).

By defining σ as the conduction period, the relation between α and σ is the following:

$$\alpha+\frac{\sigma}{2}=\pi \quad or \quad \sigma=2(\pi-\alpha) \quad (3)$$

and considering that: $X_{Bc}=\omega L$ we can calculate the reactive power output of the TCR with the following formula [2]:

$$Q_{BC}=\frac{\sigma-\sin\sigma}{\pi X_{BC}}V^2 \quad (4)$$

Using phase regulation we can continuously control the inductive reactive power from 0 to 100 MVAr, according to the characteristic shown in figure 3.

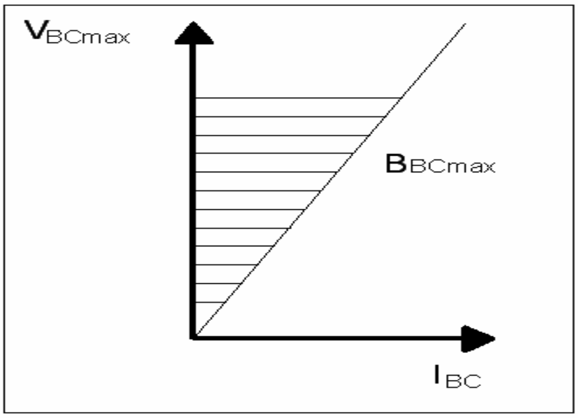


**Fig. 3 - V – I operation characteristic of a thyristor controlled reactor [2]**

Considering his continuous reactor voltage regulation concept, an analysis of the effects of this phenomena has been done using a database of the National Power System topology (NPS) modeled in Eurostag software [3].

## 2. MODELLING OF THE REACTOR AND THE TCR

For the simulations the 400 kV Suceava node was chosen due to it's small short circuit power, radial configuration and low active and reactive power flows on the Substation's 400/110 kV transformer.

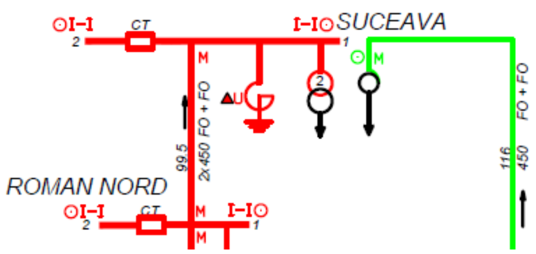


**Fig. 4 - Suceava substation and overhead line connection to Roman Nord substation.**

Using Eurostag the reactor was modelled as a Reactor bank connected to the Suceava 400 kV node.
The TCR was simulated in a different mode. Instead of replacing the 100 MVAr reactor with a 100 MVAr TCR to the existing configuration an 100 MVAr purely capacitive SVC has been added to the original configuration which uses a PI (proportional integrative) – regulator (fig 5). Thus the 100 MVAr inductive reactive power of the reactor can be varied from 0 MVAr to 100 by increasing the capacitive reactive power of the SVC. This method has been chosen because if the reactor were to be replaced with a TCR it will not load at 100 MVAr capacity in the initial operating conditions, making the comparative analysis difficult to realise.


ISSN 2067-5534 © 2012 JSE

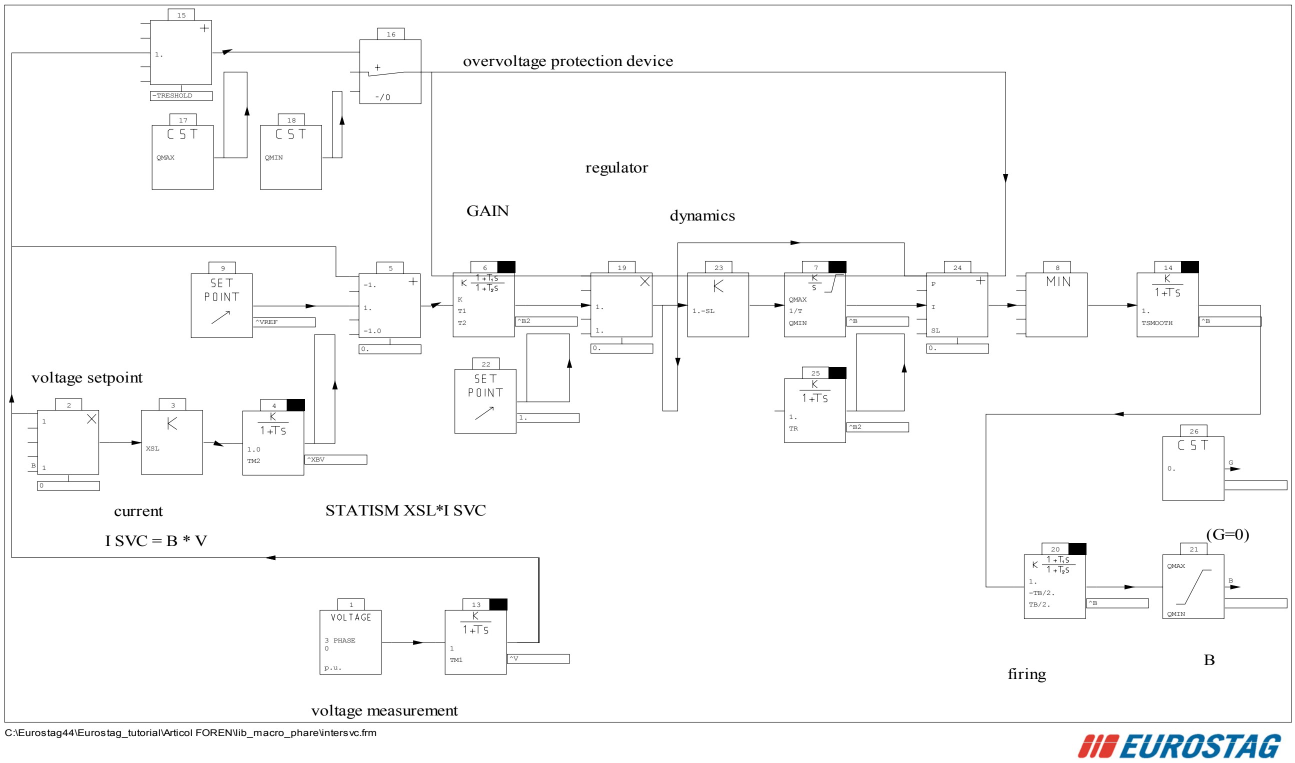


**Fig. 5 - P-I regulator structure belonging to the SVC, used in the simulations* [5]**

In normal operating conditions (all lines operational), on a winter generation schedule (9905 MW), the following simulations have been run:

- Load variation on the 110 kV node of Suceava substation, the load was varied from 100 MW and 20 MVAr to 130 MW and 60 MVAr.
- Successful auto-reclosure of the line 400 kV Roman Nord - Suceava
- Connection/disconnection of the 100 MVAr reactor in Suceava Substation
- Progressive reactive power decrease of the TCR from 100 MVAr to 0
- Progressive reactive power increase of TCR from 0 to 100 MVAr.

## 3. SIMULATION RESULTS

a) Load variation on the 110 kV node from Suceava substation, the load was varied from 100 MW and +20 MVAr to 130 MW and +60 MVAr. Both normal reactor operation and TCR were simulated. Results are shown below:

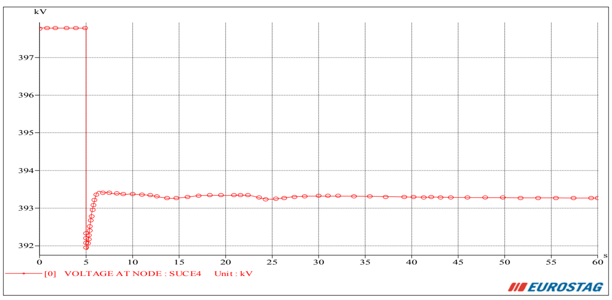

**Fig. 6 - Voltage variation on Suceava node on t = 5 sec using a reactor**

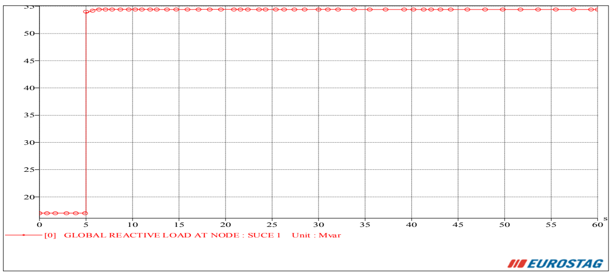

**Fig. 7 - Reactive power variation at t = 5 sec using a reactor**

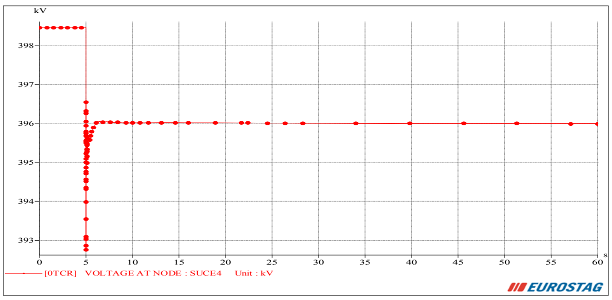

**Fig. 8 - Voltage variation on Suceava node at t = 5 sec using TCR**

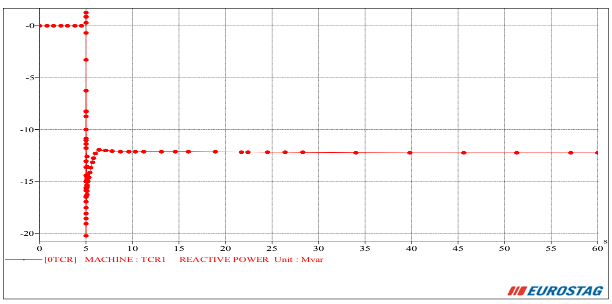

**Fig. 9 - Reactive power variation on Suceava node at t = 5 sec using a TCR**

Comparing the two simulations it can be said that using the reactor the voltage drops from 398 kV to 393.5 kV when the load increases while using a TCR the voltage drops from 398 to 396 kV, a higher value, than using the reactor, measuring the reactive output of the capacitive SVC and making a reactive power balance it results that 85 MVAr are being absorbed in the node, instead of 100 MVAr in the conventional case. It can be said that using a TCR, which has a reffrence voltage, when the load increases in the node its reactive power output decreases, to mantain the voltage close to the reffrence value.

b) Successful auto-reclosure of the line 400 kV Roman Nord – Suceava

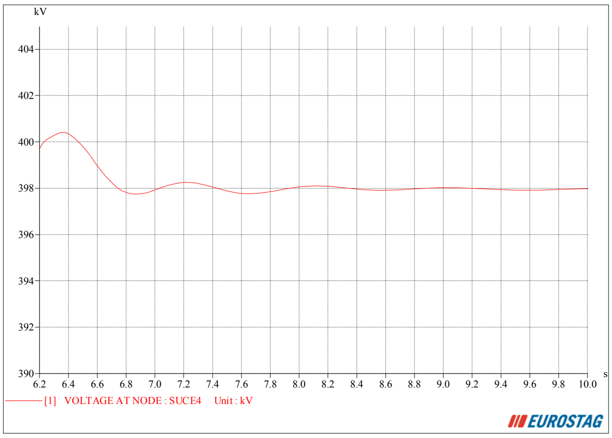


**Fig. 10 - Successful auto-reclosure of the line 400 kV Roman Nord – Suceava when reactor is connected**

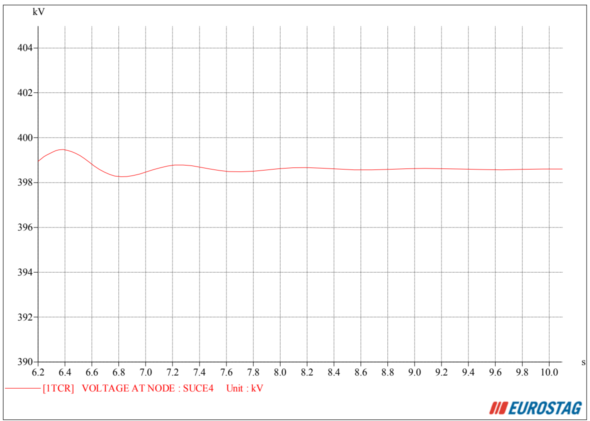


**Fig. 11 - Successful auto-reclosure of the line 400 kV Roman Nord – Suceava when TCR is connected**

In this case the difference is not great, but it can be noticed that when a TCR is used the wave oscillations are reduced from 9 seconds to 8 seconds by 1 second, due to the P-I regulator.

c) Connection/disconnection of the 100 MVAr reactor in Suceava Substation

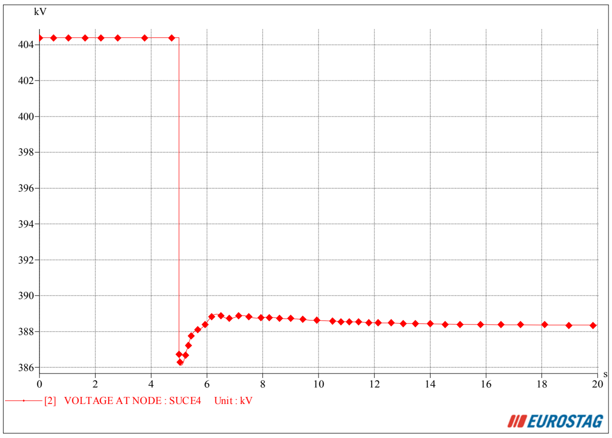


**Fig. 12 - Connection of the 100 MVAr reactor in SS Suceava**

In the studied simulation it can be noticed that connecting the reactor produces a 20 kV voltage surge in the connection node, this surge also propagates in the nearby 400 kV nodes Bacau Sud, Roman Nord and Gutinas (fig 12):

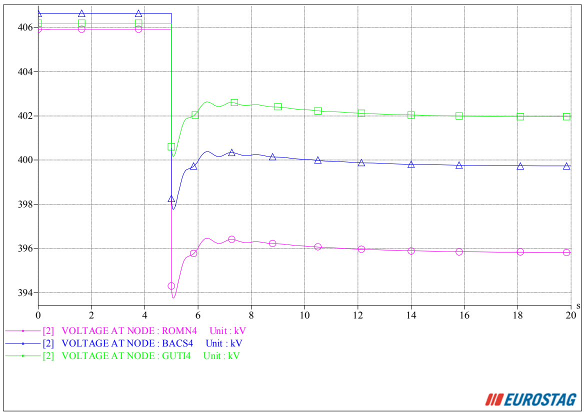


**Fig. 13 - Voltage surge in SS Roman Nord, Gutinas and Bacau Sud produced by connection of the 100 MVAr reactor Suceava**

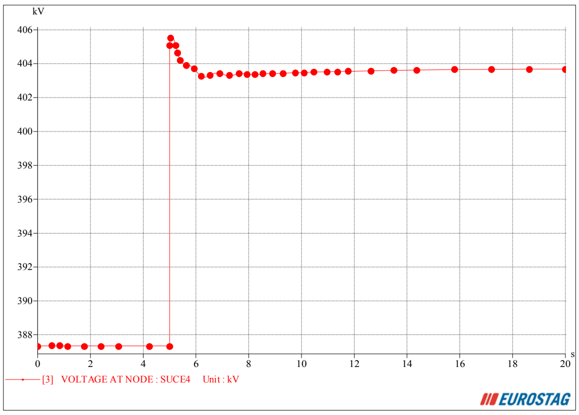


**Fig. 14 - Voltage surge produced by disconnection of the 100 MVAr reactor in SS Suceava**

Considering the same operation parameters disconnection of the reactor produces a 18 kV voltage decrease in the connection node, also propagated in the nearby nodes (fig. 14).


ISSN 2067-5534 © 2012 JSE

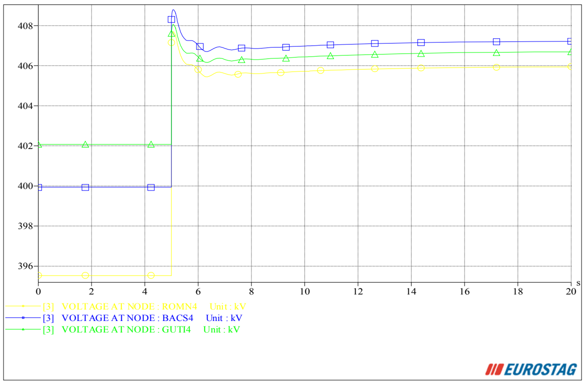


**Fig. 15 - Voltage surge produced in in SS Roman Nord, Gutinas and Bacau Sud by disconnection of the 100 MVAr reactor in SS Suceava**

d) Progressive reactive power decrease of the TCR from 100 MVAr to 0.

In order to eliminate the potentially harmfull situation created when operating the reactor, a diffrent approach has been simulated using the TCR. A variable increase/ decrease of the reactor power has been simulated. The increase/ decrease speed was determined to be 2 MVAr/sec. The following graphs have been obtained:

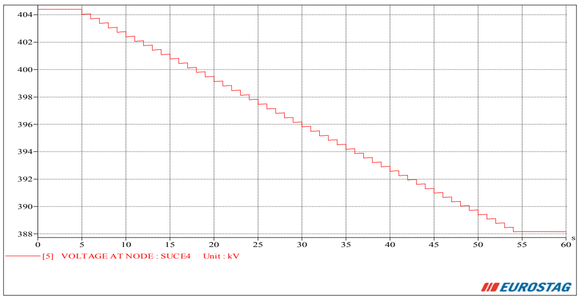


**Fig. 16 - Voltage variation due to progressive reactive power increase of the TCR from 0 to 100 MVAr**

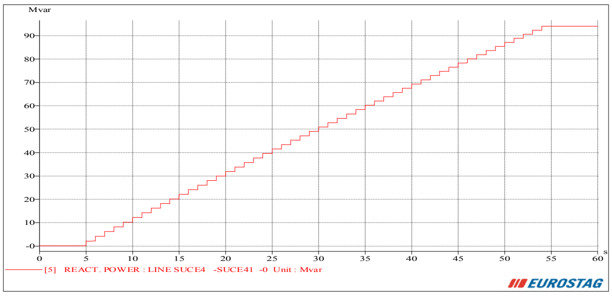


**Fig. 17 - Progressive reactive power increase of the TCR from 0 to 100 MVAr**

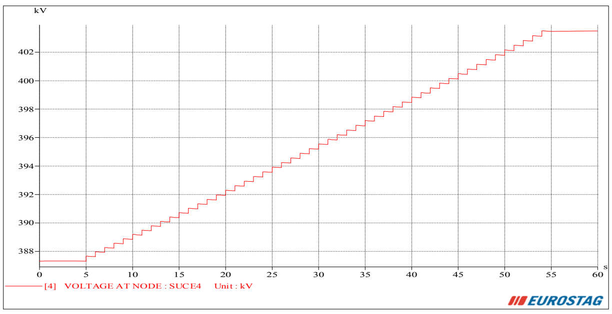


**Fig. 18 - Voltage variation due to progressive reactive power decrease of the TCR from 100 MVAr to 0**

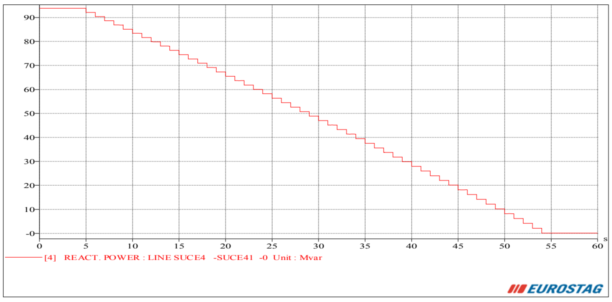


**Fig. 19 - Progressive reactive power decrease of the TCR from 100 MVAr to 0**

In this method voltage is droped in steps, every step is controlled, therefore the surge is eliminated.

## 4. CONCLUSIONS

In this paper a comparative analysis between a conventional reactor and a thyristor controlled reactor has been realised, in the National Power System topology, and it has been shown that a TCR can be safer to use for the equipment in the area. Due to its proportional integral regulator the amount of reactive power absorbed from the system can be controlled to adapt to the variable working conditions and also, during fast dynamic events, like when the line auto-recloses oscilations are dampened. Therefore the security in the area is improved.

In case of load increase the reactive power consumption is reduced in order to maintain a stable voltage, as close to the initial voltage as possible. Also by setting a reffrence voltage in the selected node, the voltage in the surrounding area is also controlled. Therefore the voltage variation curve has smaller swells. In case of connection/disconnection of the devices, while the reactor induces a voltage variation up to 30 kV, a TCR can gradually control the voltage variation, in order to maintain power system security and steady operation in the area.

## REFERENCES

[1] C. Bulac, M. Eremia – "Power System Dynamics" in Romanian "Dinamica sistemelor electroenergetice". Ed. Printech Bucuresti, 2006

[2] M. Eremia – "Simulation and modelling in FACTS devices" Course notes, in Romanian "Modelarea si simularea dispozitivelor FACTS.", Universitatea Politehnica din Bucuresti, 2009

[3] K. H. Chung, G. H. Kwon, T.B. Parkand, G.Y. Liin „Voltage Sag and Swell Generator with Thyristor Controlled Reactor" IEEE Transactions on Industry Applications, No.5, Sep. 1979

[4] A Owegard, K Walve, G Waglund - Improvement of transmission capacity by thyristor controlled reactive power", IEEE Transactions on Power Apparatus and Systems, Vol. PAS-100, No. 8 Aug. 1981.

[5] Eurostag modelling and simulations – User's manual.

[6] S. Phichaisawat, Y. H. Song, X. L. Wang & X. F. Wang "Combined Active and Reactive Congestion Management with FACTS Devices"