



# Mitigation of the impact of transformer inrush current on voltage sag by TCSC

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## ARTICLE INFO

### Article history:

Received 27 April 2008

Received in revised form 11 January 2010

Accepted 12 January 2010

Available online 6 February 2010

### Keywords:

FACTS devices

Inrush current

Power quality

Thyristor Controlled Series Capacitor (TCSC)

Transformer

Voltage sag

## ABSTRACT

Thyristor Controlled Series Capacitor (TCSC) as a dynamic system, besides its capability in increasing power transfer in transmission lines, can be used to enhance different power system issues. In this paper, the effect of TCSC on voltage sag following transformer inrush current is investigated. It is shown that excessive transient inrush current occurring during transformer energizing can be mitigated by TCSC. Hence, voltage sag as one of the key components of the power quality is alleviated for the sensitive loads that are connected to the same bus which the power transformer is energized from. During a fault, TCSC can improve the voltage sag by limiting the current and help to keep the voltage as high as possible. Moreover, the inrush currents and the associated voltage sags that usually occur after clearing heavy single- or multistage faults are mitigated by the presence of TCSC. The model used for simulating inrush current is based on the characteristics of the major hysteresis loop out of which the internal trajectories are defined using the translation principal and a linear compensation to generate closed loops. An arctangent relation between the flux and the exciting current is defined. The expression parameters are deduced by curve fitting empirical data defining the major loop or the single-valued saturation characteristic.

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## 1. Introduction

Power quality is becoming increasingly important to electricity consumers at all levels of usage [1,2]. Most power quality complaints are concerned with voltage sags, which are short duration voltage drops that are mainly caused by short circuits on transmission/distribution systems and transformer energizing. Typically a voltage sag is a decrease in system voltage to between 0.1 per-unit (p.u.) and 0.9 p.u. at the power frequency lasting from 1/2 cycle to 1 min.

Use of electronically controlled equipments (computers, office facilities, electronic ballasts, variable speed drives, consumer electronics and programmable logic-based process controls) has escalated over the last decade. Thereby, the consequences of voltage sags due to faults and inrush currents are becoming more important.

Transformer energizing is a regular operation in an electric power system. Often energizing results in the transformer drawing large inrush current which eventually decays down to a small magnetizing current. The time it takes inrush current to decay depends on the resistance and reactance of the circuit, including the transformer's magnetizing reactance. Since the magnetizing inductance of transformer is high, the inrush current can take a long time to reach its steady-state value. The inrush current causes a temporary

voltage drop due to impedance of the network between the sources and the energized transformer. If the short circuit MVA available at the transformer bus is low (or the source impedance is high), the resulting voltage drop can be significant. The voltage drop reduces with decay of the inrush current [3,4]. Voltage sags can be mitigated by different means that include investments on the power systems through reinforcements; the use of power conditioners to protect the load against these sags, etc. [5–7].

Thyristor Controlled Series Capacitors (TCSCs) are already used for power flow control, transient dynamic compensation, sub-synchronous resonance mitigation, and may also be used for limiting fault current by adjusting its impedance dynamically to a large inductive value that depends upon the TCSC design [8–12]. In [13] voltage sag mitigation by TCSC is reported, but simple models are used for TCSC, not accurate enough to show the transients. During a heavy fault, TCSC may mitigate voltage sag by switching to inductive mode and hence limits the fault current. After removing the fault, TCSC switches back to capacitive mode, but RMS voltage variations occur that lasts for many seconds. This is not favorable to power quality and sensitive loads.

In this paper, the application of Thyristor Controlled Series Capacitor (TCSC) to mitigate voltage sags, caused by short circuits on transmission lines and transformer energizing is investigated. This is an extra feature of TCSC, which is mainly used to improve the power transfer capability of long transmission lines. Metal Oxide Varistor (MOV) that is normally used to save capacitors during overvoltages, will help to reduce the variations. The simulation results are performed by using the salient role of MOV in damp-

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