Electrical Power and Energy Systems 63 (2014) 236–245

Contents lists available at ScienceDirect

Electrical Power and Energy Systems

journal homepage: www.elsevier.com/locate/ijepes

Application of thyristor-controlled series reactor for fault current limitation and power system stability enhancement

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ARTICLE INFO

Article history:
Received 25 May 2013
Received in revised form 8 May 2014
Accepted 19 May 2014
Available online 27 June 2014

Keywords:
Fault current limiter
Power system stability
Thyristor-controlled series reactor
Solid-state fault current limiter

ABSTRACT

Various types of Fault Current Limiters (FCLs) have been proposed and proven to offer numerous advantages with respect to transmission losses, voltage quality, and power system stability. However, FCL research has largely focused on only the FCL system, including optimization of components, efficiency improvement, and cost reduction. Conventional solutions to fault current problems, such as splitting buses, replacing switch gear, and installing permanently inserted series reactors, are still widely used in the field, but impair overall power system reliability. In this paper, a Thyristor-Controlled Series Reactor (TCSR) is used to limit fault current and enhance power system stability simultaneously. A TCSR controller is designed using an advanced mathematical approach and the impact of TCSR is analyzed from the perspective of voltage security enhancement. The benefits of the proposed TCSR-based FCL in terms of both voltage security and angle stability are demonstrated through bulk power system simulation results. The feasibility of real power system application is also assessed using actual power system data.

Introduction

Demand on electricity has increased tremendously, and many countries are investing a significant amount of money for a more reliable electric power supply. More generation plants and transmission lines have been constructed and power systems have become more complex than ever before. Major transmission lines tend to be long distance, and generation sites are large scaled. Load concentration requires more transmission lines interconnected. These characteristics of contemporary power systems have caused problems related to fault currents and system stability.

Several approaches to cope with the fault current problems are being used in distribution and transmission areas. Inserting series reactors, up-rating and replacement of switchgear, and splitting buses or transmission lines are the most commonly used conventional techniques to limit the fault current in power systems. These methods are regarded as secure measures for the operational reliability of power system facilities. However, up-rating and replacement of switch gear can be very expensive and may not reduce short-circuit current duty, and network splitting can deteriorate power system security. Permanently inserted current-limiting series reactors introduce a voltage drop, active and reactive power losses, and also adversely affect power system stability in normal operations, as well as in fault conditions. Many power systems are still divided into several subsystems to solve fault current problems in spite of many drawbacks.

So far, fault current and stability analysis have been studied separately because the network configuration affects each, but in an opposite way. When transmission systems are fully meshed, they tend to yield fault current problems rather than stability problems. On the other hand, when power is delivered through high impedance transmission lines, stability issues may arise instead of fault current problems. However, as the power systems became more complex with use of meshed transmission networks that have interconnected long-distance and high-power transmission lines, the two problems became co-existing. Consequently, countermeasures that deal with the fault current adversely impact the power system stability significantly more than before.

In this paper, a TCSR that limits the fault current and improves power system stability simultaneously is presented. The prior research related to fault current limitation and stability enhancement is reviewed in Section 'Current state-of-the-art', then a TCSR controller is designed using an advanced mathematical approach in Section 'Proposed approach'. Section 'Simulation results' demonstrates the benefits of the TCSR in terms of voltage security enhancement as well as fault current limiting with bulk power system simulation results using real power system data to assess the feasibility of the TCSR. Conclusions are presented in Section 'Conclusion'.

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http://dx.doi.org/10.1016/j.ijepes.2014.05.059
0142-0615/

Current state-of-the-art

Several types of Fault Current Limiters (FCLs) have been suggested as ways to solve power quality and stability problems caused by conventional permanently inserted current-limiting series reactors. The tuned series resonant FCL as shown in Fig. 1(a) was proposed to eliminate power losses and limit fault currents [1]. Under normal operating conditions, switch S is open to make the circuit almost transparent. When a fault occurs, the switch is closed, and the equivalent impedance becomes X^2/R, where X is the 60 Hz impedance of the reactive components. A series resonant FCL with a capacitor shunted by a Metal Oxide Varistor (MOV) is shown in Fig. 1(b) and suggested as a way to reduce voltage sags and limit fault currents [2]. The MOV remains inactive during normal operation, while it clamps the capacitor voltage and absorbs the energy during fault. However, the long cool-down time of the MOV and the possibility of Sub-Synchronous Resonance (SSR) [3] have been the drawbacks to be resolved. The Dynamic Voltage Restorer (DVR) using an energy storage device [4,5] and a Series Compensator (SC) [6,7] shown in Fig. 1(c) have been proposed to limit the fault current and improve the voltage quality of the power system. By adjusting voltage amplitude and the phase angle, they can control the real and reactive power between the series compensator and the power system. When there is a fault, the network is compensated by a lagging or leading voltage injected in quadrature to the load (fault) current, so that line voltage is restored and the fault current is confined to the load current.

Approaches using power-electronics-based FCLs have also been proposed for fault current limitation and power system stability enhancement. With the advances in power electronic devices and control technologies, Flexible AC Transmission Systems (FACTS) devices have been developed and are in operation for security enhancement of power systems [8,9]. The FCLs use solid-state devices, such as Insulated Gate Bipolar Transistor (IGBT), Silicon Controlled Rectifier (SCR), and Gate Turn-off Thyristor (GTO), which can be classified into: (1) Series-switch-type FCL, (2) Bridge-type FCL, and (3) Resonant FCL [10]. Although the configuration of Solid-State FCLs (SSFCLs) can be different according to their application purposes, the operational principles for SSFCLs are almost identical. Currents flow through a zero impedance path in normal operating conditions and are switched into the fault current limiting reactor in any case of short-circuit faults. Different series-switch-type FCLs are described in [11] and a Thyristor-Controlled Series Reactor (TCSR) was applied to reduce furnace arc flicker [12]. Bridge-type FCLs that use different types of switching device were also proposed [13,14], and the influence of this type of FCL on power system transient stability was investigated [15]. Another application using FACTS-based Short-Circuit Current Limiter (SCCL) was suggested in [16,17], where a Thyristor-Protected Series Compensator (TPSC) was combined with an external reactor to show benefits for fault current limitation and SSR mitigation. Transient stability was also evaluated for this type of series capacitor compensated FCL in [18]. Basic configurations for TCSR and SCCL are illustrated in Fig. 2(a) and (b), respectively.

Proposed approach

A TCSR-based FCL system is proposed in this paper. The proposed system limits fault current under a tolerable level using a fault current limiting reactor in series. At the same time, it improves the voltage level by controlling the equivalent reactance of the FCL. Instead of simple reactor switching, the thyristor in the proposed FCL system is actively controlled to respond to different fault characteristics, such as fault location, fault current, and bus voltage level. As a result, the optimal combination of fault current limitation and bus voltage drop compensation can be achieved. Furthermore, the voltage level improvement using the proposed FCL scheme can enhance the voltage and angle stability of power systems. So far, however, dynamic control of FCL reactance for simultaneous fault current limitation and power system stability enhancements has not been extensively investigated. Prior FCL research has mainly focused on the FCL system itself, including optimization of components, efficiency improvement, and cost reduction.

To analyze the behavior of the proposed TCSR-based system and design a controller, the state-space averaging technique, which is a small-signal method widely used for DC/DC converters, is used. Because this technique cannot be directly applied to an AC system because of the periodic time-varying characteristic, reference frame transformation theory [19,20] is applied, so that the three-phase AC variables can be treated as two-phase DC quantities in a synchronously rotating reference frame.

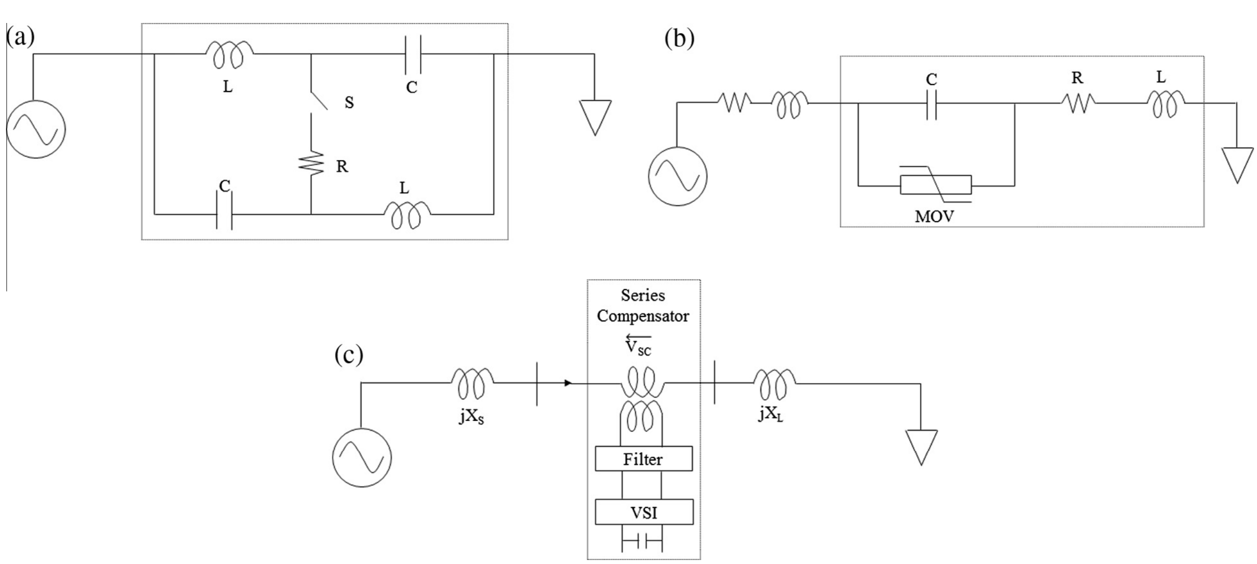

Fig. 1. Different types of FCLs: (a) FCL with tuned impedance, (b) FCL with a capacitor only shunted by MOV, and (c) FCL using a series compensator.