A Novel Approach on Voltage Unbalance Improvement using SFCL on Electric Railway System


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Abstract*— This paper presents a novel approach to determinethe power system stability using resistive superconducting faultcurrent limiter (SFCL) of an electric power grid (EPG). Inaddition, the electric railwaysystem has rapidly changing loadcharacteristics in time. An unbalance is generated owing to therapidly changing large single-phase loads. Subsequently, the unbalanced load causes an unbalanced transmission line. Avoltage unbalance in the source influences the power equipmentby causing a reduction in the power generation capacity of thegenerator and a decrease in the output of the other facilities in thetransmission line. In addition, many flexible ac transmissionsystems are applied to transmission lines to compensate for andcontrol electric power. A voltage unbalance causes a control errorin these systems. In addition, we analyzed the effects of theproposed method using MATLAB simulation.

I. INTRODUCTION

WITH the increasing of system capacity, fault occurrence probability becomes higher, that can induce severedamages in electrical power system [1]. For example, the highvalue of the short circuit current can damage the insulationstrength of electrical devices, synchronous generators, protective relays, lines transmission, and loads. In addition, theelectrical power needed by the system when a fault occurs ismodified and induced instable state of the power generators. Recently, the development of superconducting faultcurrent limiters (SFCL) offers one of the most attractivealternatives to solve the fault current problems [3]–[5]. Thanksto their fast transition from a low to a high impedance,superconducting devices can limit, ina very short time, thevalue of any fault current. What is attractive is that thetransition is due to an intransit behavior of the material itself.

The presence of the SFCL in a power system can increasethe system stability and distributed energy quality [10]–[15].When an SFCL is introduced in an electric power grid (EPG),three important factors must be considered:

1) optimal location of the SFCL in the EPG [16];
2) optimal resistive value of the SFCL [17];
3) protection-coordination problem with other existing devices(circuit breaker, OCR, etc.).

In response to the unbalances, flexible AC transmission systems(FACTs) are applied to control transmission system powerflow and to improve system stability. A thyristor-controlledseries capacitor (TCSC) is one of the practical devices that canimprove the implementation of FACTs [4]. Actual line voltageand current information is quite important TCSC control scheme. However, voltage and current unbalance produced byan electric railway load causes serious TCSC control errors.This problem can influence system stability. In particular, avoltage and current unbalances after fault will cause furtherproblems.

The simulation results show the effectiveness of theproposed method. In fact, the optimal location determined forthe SFCL improves the transient stability of the power systemand decreases the low frequency oscillation of the generatorsspeed when a severe damage is introduced (three-phase fault).The advantage of the proposed method is that the selectedlocation of the SFCL takes into account the fact that the faultcan occur anywhere in the studied grid.

II. PROPOSED SYSTEM

An electric railway is connected to a 154 kV transmissionline through a Scott transformer in Korea. Fig. 1 shows a transmissionsystem connected with railway equivalent model.

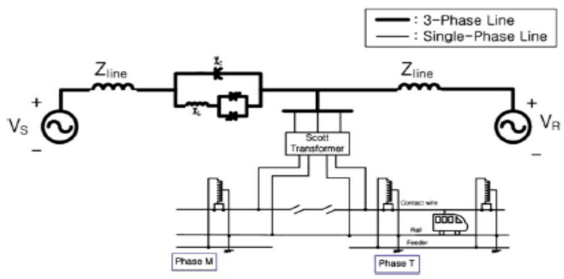


Fig. 1. Transmission system connected with a railway.

A TCSC facility is installed to control power flow in transmissionline, and an electric railway includes a single phase load thatcauses a voltage unbalance. In addition,the self- and mutual impedance of transmission and rail of theKorean electric railway system were considered [1]. Here, inorder to analyze the influence of an electric railway connectionon the transmission line fault, we simulated a fault situation.

Fault starting time is 0.4 s and fault duration time is 0.1 s.Fig.. In case offault on the transmission line without electric railway, 3-phasevoltage decreased owing to fault and after fault removal, thereis a transient phenomenon that has a small offset voltage butreturned to a steady state. In addition, this simulation showeda small magnitude difference between offset voltages. Currentis generated a large transient current during fault and reach to steady state, load current, after fault removal. In contrast, largeoffset voltages are represented in simulation result about fault on transmission line with electric railway.

Especially, voltage of phase B is increased up to 350 kV in a moment. In addition, voltage unbalances of transmission linebecame more serious compared with above case. Line currentsare also increased and caused unbalance owing to transientvoltage. We think that closing phase angle control of TCSCsystem is influenced by generated transient voltage and currentas the cause of these results. These phenomenon will causeproblem about voltage stability and malfunction of protectionscheme in the transmission grid. These results show that an electric railway connection aggravates voltage unbalance in thetransmission line.

III CONTROL SCHEME

Power transmitted between a sending-end bus and areceiving-end bus in an AC transmission system is dependenton the series impedance. Further, impedance of a transmissionline consists mainly of inductive reactance, with resistanceaccounting for only 5–10% of impedance [5], [6]. If a seriescapacitor is inserted into transmission line, the inductive reactanceof transmission line could be compensated by a capacitivesupply. This concept of series compensation is illustrated inFig. 2. Typical configuration of a TCSC from a steady-stateperspective involves a fixed capacitor (FC) with a thyristorcontrolled reactor (TCR). TCSC structure is shown in Fig. 3

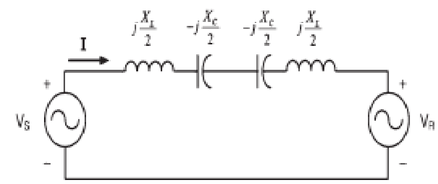


Fig. 2. Series compensation concept for a power system.

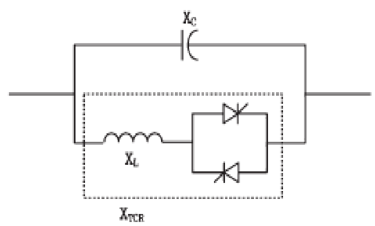


Fig. 3. Configuration of a typical TCSC.

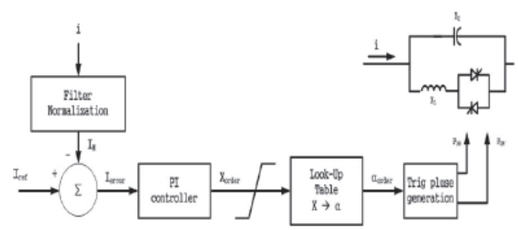
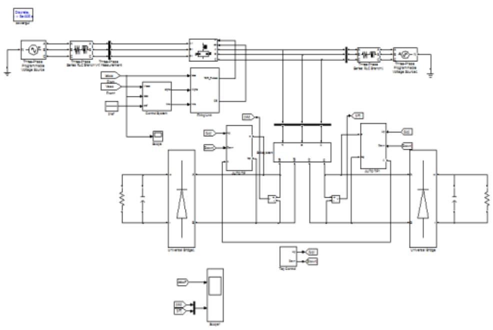


Fig. 4. TCSC closed-loop constant current control methodology

Control of α typically applies open-loop control or closedloopcontrol. Fig. 4 details a schematic of a constant currentclosed-loop control [8]. In Fig. 4, *Iref* is desired transmissionline current, *IM* is actual current, and *Ierror* is differencebetween *Iref* and *IM*. In particular, *Ierror* is an importantquantity in this control loop. A current unbalance can causeserious issues for TCSC control.

we discoveredfollowing features: 1) the larger resistance of a resistortypeSFCL, the more voltage unbalance was improved. 2) InSFCL operating process, there are differences of recovery timebetween superconducting elements owing to unbalance faultcurrent. If a fault occurs, the proposedmethod clears voltage unbalance and protects TCSC. Thus,transmission system can quickly return to operating in a conventionalstate. As a result, we will expect improvement effectfor the problems about voltage stability and protection schememalfunction.

IV SIMULATION RESULATS



Fig;5 Simulation circuit

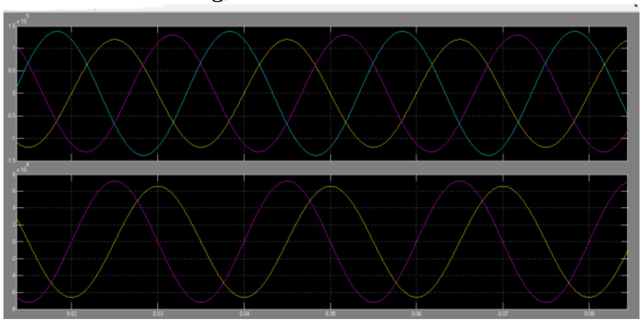


Fig. 6 Typical primary and secondary voltages of a Scott transformer undera T-phase load.

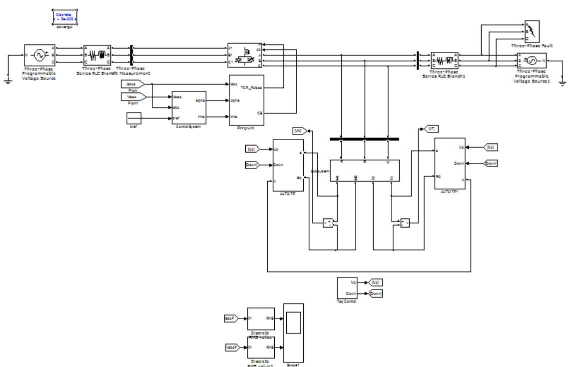


Fig. 7. Simulation circuit for three-phase fault(a) without railway

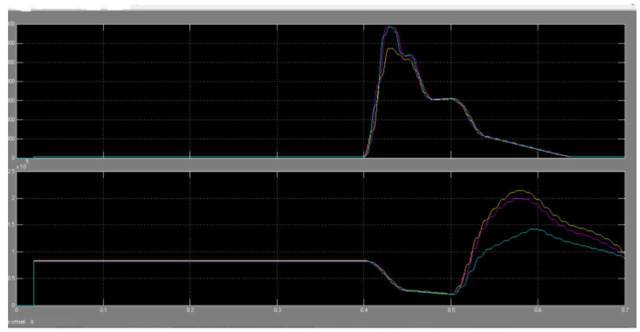


Fig. 8. Voltage and current results from the simulation: (a) without railway

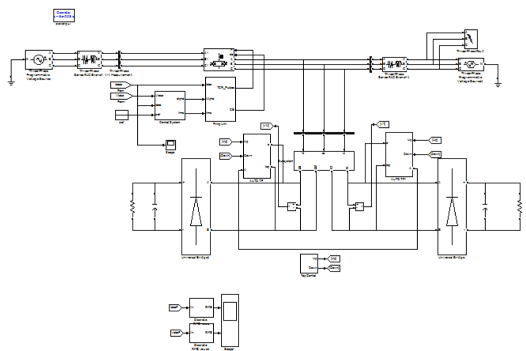


Fig. 9. Simulation circuit for three-phase fault(a) with railway

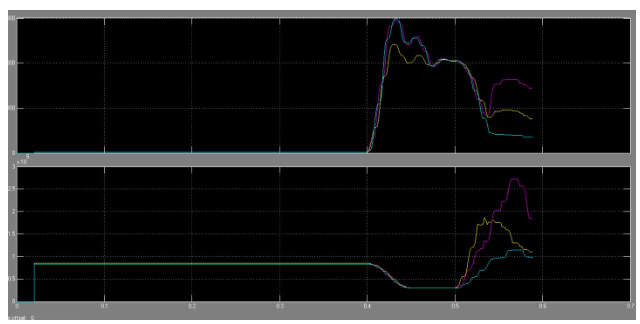


Fig. 10. Voltage and current results from the simulation: (a) withrailway

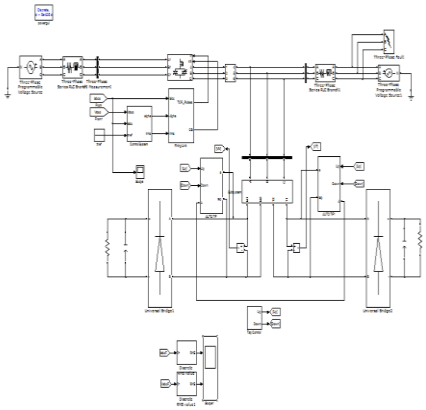


Fig. 11 Simulation results for electric railway system and SFCL

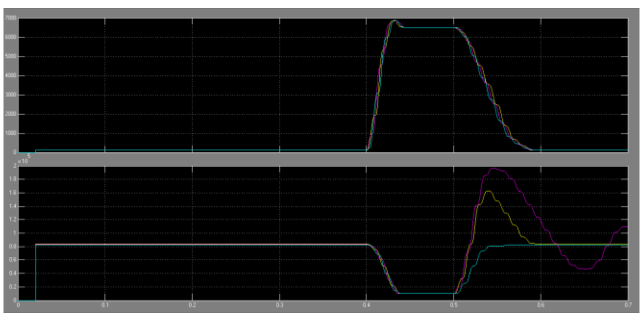


Fig 12. Voltage & Current

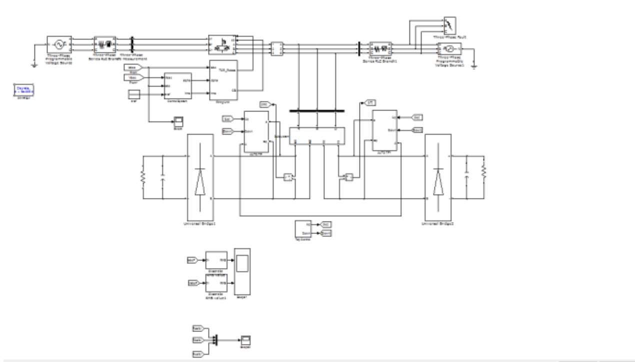


Fig 13. SFCL simulation circuit

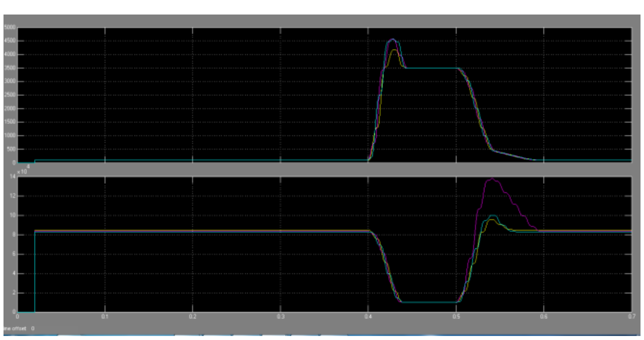


Fig.14. Voltage & Current Results

V. CONCLUSION

This paper proposed a method to reduce voltage unbalancefor a TCSC-compensated transmission line using an SFCL.First, the configuration and operation of a compensated transmissionline and connected electric railway system were modeledand detailed. Next, voltage unbalance in transmission linewas studied when line fault occurs. Finally, the method foralleviating this problem with SFCL was considered

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