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Design and Optimization of a Solid-State Fault Current Limiter for Improving Stability and Power Quality: A Case Study of Ilam Gas Refinery

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Abstract

This paper presents the design and optimization of a solid-state fault current limiter (SSFCL) for industrial power networks, with a focus on the electrical system of Ilam Gas Refinery. The rapid growth of fault levels in modern grids, especially in the presence of distributed generation and increasing load demand, can threaten equipment insulation, protection coordination, and overall system stability. To address this challenge, a simple and fast-acting SSFCL topology based on semiconductor switching elements and a local current-based control unit is proposed. The limiter remains nearly inactive during normal operation, thereby minimizing losses and avoiding undesirable influence on voltage and current waveforms. When a fault occurs and the measured current exceeds a predefined threshold, the control unit disconnects the bypass switch and inserts the limiting branch into the circuit. The proposed scheme was modeled and tested in PSCAD/EMTDC under several practical installation scenarios, including placement before the transformer, after the transformer, simultaneous installation at two buses, and connection near a distributed generation source. The simulation results show that the proposed SSFCL significantly reduces fault current peaks, improves voltage recovery, and enhances power quality and network stability. The study demonstrates that a locally controlled SSFCL with industrially available components can provide an effective and economical protection solution for critical refinery power systems.

Keywords

Fault Current Limiter (FCL), Solid-State Fault Current Limiter (SSFCL), Short-Circuit Current Management, Industrial Power Networks, PSCAD/EMTD

1. Introduction

The increase in power demand and distributed generation has raised short-circuit current levels in many electrical networks beyond the interruption capability of conventional circuit breakers. In industrial facilities such as gas refineries, this issue is especially critical because unplanned outages, equipment damage, and protection malfunctions can lead to substantial economic and operational losses. Traditional remedies, including network restructuring or upgrading system ratings, are often expensive and may reduce operational reliability. For this reason, fault current limiters have attracted attention as a practical solution for controlling excessive fault currents without disturbing normal operation.

Among the available technologies, solid-state fault current limiters offer fast response, compact structure, and no need for cryogenic systems. However, many existing SSFCL structures suffer from complexity, high cost, or dependence on centralized coordination. The main contribution of the present work is the development of a simple SSFCL topology that uses a diode bridge, an IGBT bypass switch, a series reactor, and a local current-based controller. This configuration is designed to provide rapid fault limiting with low normal-state loss and practical deployability in industrial substations. Figure 1 shows the proposed SSFCL topology used in this study, including the diode bridge, the IGBT bypass switch, and the limiting reactor.

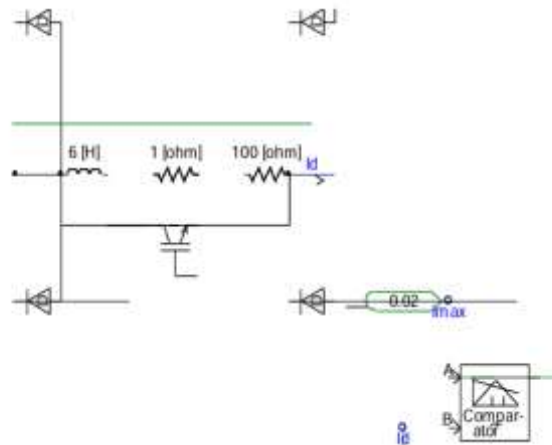


Figure 1. Proposed optimized topology.

2. Methodology

The proposed SSFCL operates by continuously measuring the branch current and comparing it with a preset threshold current. Under normal conditions, the IGBT remains ON and bypasses the reactor and limiting resistor, so the limiter introduces almost no loss into the network. Once the measured current exceeds the threshold, the controller identifies a fault condition, turns the IGBT OFF, and inserts the limiting impedance into the circuit. This causes the reactor to charge during the transient interval and restricts the rise of fault current.

The control strategy uses only current sensing and a simple local decision rule, which makes the scheme easy to implement and independent of other protection units. Two operational intervals are considered during a fault: the charging transient and the post-charging steady state. In the charging phase, the reactor absorbs part of the fault energy and limits the current rise rate; after charging is completed, the limiter enters the steady mode and the resistor further suppresses the current. This behavior allows fast response while preserving operational simplicity.

3. Simulation Setup

The proposed limiter was evaluated on the Ilam Gas Refinery distribution network using PSCAD/EMTDC. Four placement scenarios were studied to identify the best practical installation point and to examine the effect of network location on performance. These scenarios included installation at bus 3 before the 20/0.4 kV transformer, installation after the transformer, simultaneous installation at buses 1 and 3, and installation near a 400 V distributed generation source.

The simulated SSFCL parameters included a 100 Ω resistor, a 6 H reactor, a 1 Ω internal reactor resistance, and a 50 Hz IGBT switching frequency. The fault event was applied at 0.5 s as a three-phase short circuit, and the system response was observed in terms of fault current peak, bus voltage sag, and recovery time. This setup made it possible to compare the limiter performance under both normal and faulted operating conditions.

4. Discussion and Results

In the first scenario, the proposed SSFCL reduced the fault current peak from about 7.5 pu to 2.3 pu within approximately 8.5 ms, while the bus voltage recovered from a severe sag of about 0.52 pu to a steady value near 0.09 pu. In the second scenario, when the limiter was installed after the transformer, the fault current decreased from 6.9 pu to 2.1 pu in less than 9 ms, and the bus voltage was restored from around 0.48 pu to approximately 0.11 pu.

In the third scenario, where two SSFCL units were installed at buses 1 and 3, the fault current dropped from 7.2 pu to nearly 2.4 pu with a response time of about 9 ms, and the bus voltages recovered to values close to 0.13 pu after the initial sag. In the fourth scenario, with the limiter connected near the distributed generation source, the fault current peak was reduced from 6.7 pu to 2.0 pu in about 8 ms, and the voltage sag of roughly 0.50 pu was improved to a stable level near 0.10 pu. These results confirm that the limiter location strongly affects performance, and that strategic placement can improve both protection effectiveness and voltage profile.

5. Conclusions

The study shows that the proposed SSFCL topology can significantly reduce fault current in less than half a cycle while maintaining negligible impact during normal operation. Its simple structure, local current-based control, and reliance on standard industrial components make it attractive for practical deployment in refinery and industrial power

systems. The results also indicate that optimal installation location is important for achieving the best combination of fault current reduction and voltage support.

Overall, the proposed design improves network stability, power quality, and protection coordination, while offering a relatively low-cost and easily implementable solution. Future work can extend this study by examining protection coordination with other devices, assessing more detailed power-quality indices, and exploring hybrid designs that combine SSFCL concepts with advanced optimization or superconducting elements.

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