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Fault Current Limiters for Distribution Grid Protection and Voltage Sag Reduction: A Systematic Review

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Abstract – *A high potential fault current levels in power grid is not a new approach, and should eventually exceed, the limitation of short-circuit-current would be existed protection devices. Different to pricey system upgrades of protection devices, Fault Current Limiters (FCL's) gives an additional cost efficient solutions to forestall recent protection devices and different instrumentality on the system from being broken by excessive fault currents. Evaluation of short circuit faults may usually the origin of voltage sags at a purpose of common coupling point (PCC) during a power network, the extent of the voltage sag is proportional to the short current level, reducing the fault current level at intervals the networks will scale back voltage sags throughout faults and defend sensitive loads that are interfaced to a similar PCC. The planned structure prevents voltage sag and counter balance the phase-angle of the PCC once fault prevalence. As a result, different feeders which are interlinked to the sub-station PCC can have attentive power quality. During this paper a high performance 3-phase fault current electrical model is planned. A Matlab/Simulink model is developed and simulation results are conferred.*

Keywords- ***Fault current limiter (FCL), point of common coupling (PCC), power quality (PQ), semiconductor switch, total harmonic distortion (THD), and voltage sag***.

I- INTRODUCTION

Voltage sag is one of the most frequent and significant power quality issues affecting contemporary electrical distribution systems. It commonly arises from short-circuit faults, abrupt load variations, motor starting, and switching operations. Even brief voltage sags can cause severe disturbances, leading to malfunction or shutdown of sensitive industrial equipment such as programmable logic controllers (PLCs), variable-speed drives, robotics, and automated manufacturing systems. As industries increasingly rely on electronics-based and power-electronic-driven processes, their tolerance for voltage variations has diminished considerably. Consequently, maintaining voltage stability has become a major operational challenge for distribution utilities. Fault Current Limiters (FCLs) have gained attention as an effective solution not only for restricting excessive fault currents but also for enhancing system stability during transient conditions. Conventional protection devices—such as circuit breakers, relays, and fuses—are essential for fault isolation but are not designed to mitigate voltage sags. In contrast, FCLs introduce dynamic impedance during fault events, thereby reducing fault current magnitude and minimizing the severity and duration of voltage sag. Their fast response, automatic operation, and negligible impact on normal system performance make them highly suitable for modern power distribution networks.

Over the years, several FCL technologies have been developed, including Superconducting Fault Current Limiters (SFCLs), Solid-State Fault Current Limiters (SSFCLs), resistive and inductive types, and hybrid FCL structures. Each exhibits unique advantages in terms of speed, reliability, cost-effectiveness, and application feasibility. SFCLs, for instance, offer ultra-fast response and low losses, while SSFCLs provide high controllability and compact design, making them particularly suitable for smart grid integration. As distribution networks continue to evolve with the increasing adoption of renewable energy sources, electric vehicle charging stations, and distributed generation, challenges related to fault current levels and voltage stability are intensifying. Renewable-dominated grids often experience bidirectional power flow and fluctuating voltage profiles, amplifying the need for advanced protection and voltage support mechanisms. This has further strengthened the demand for innovative FCL technologies capable of enhancing grid resilience and voltage regulation.

This review paper aims to present a comprehensive assessment of FCL technologies, focusing on their operating principles, characteristics, and effectiveness in mitigating voltage sag in distribution systems. It also examines recent developments, practical challenges, and emerging trends in the field. By evaluating the capabilities and limitations of various FCL configurations, this paper provides valuable insights for researchers, system engineers, and utility planners seeking effective solutions to improve voltage stability and overall power quality in modern distribution networks.

II-METHOLOGY

- Implementing a single phase and three phase line without FCL.,
- Implementation of Fault current limiter
- Implementation will be the desirable operation of the system for undesirable conditions for example Sag mitigation and harmonics reduction..
- Simulation of the model can be done in MATLAB software. Evaluation of the performance.

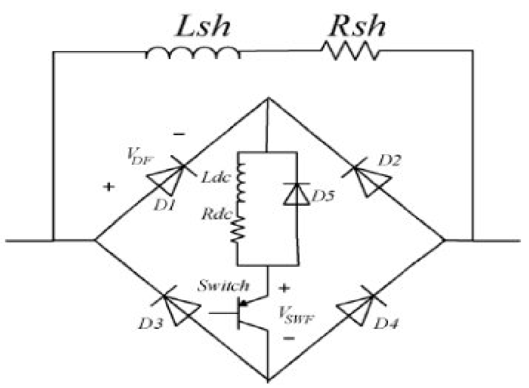
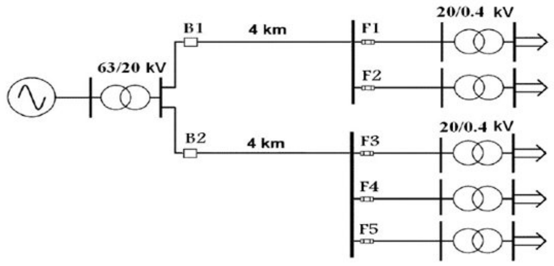
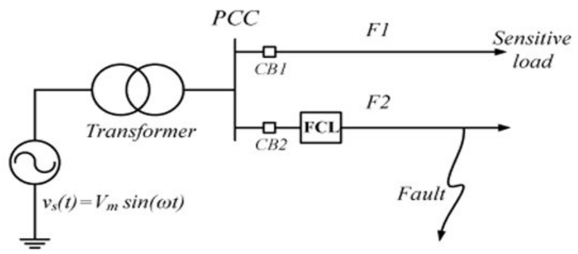


Fig. 1- Fig 1 Proposed FCL technology





As Fig. 1 depicts the schematic diagram of proposed FCL topology which is comprised based on two following parts? 1) One is bridge part that contains a un-controlled rectifier form in bridge manner as a coordination of small dc limiting reactor (Ldc). (Note here internal resistance (Rdc) is engaged too), a power electronic switch (may be IGBT or GTO) with a supportive diode for freewheeling action (D5). 2) Another component is shunt branch, acts as a limiter for enhancing the fault currents; it involves a shunt resistor and a shunt inductor (Rsh + i Lsh). So many researchers introduced some structures for this type of applications [10], [11], [12] in that preferred more numbers of switching devices at bridge model instead of one power-electronic switch inside the bridge configuration. For this power electronic system requires a more complicated control scheme as well as more operation delay (turn off point at first zero cross-over), Ldc has a high value to excavate the fault current in between the fault occurrence period and thyristor turn-off period properly. his substantial estimation of L prompts a respectable voltage drop on the FCL and the power loss misfortunes including ac power loss influences to misfortunes on the shunt impedance as well as dc reactor loss component (that is non super-conductor) in the ordinary condition. By utilizing the semiconductor switch within the proposed structure and its quick operation, it is conceivable to pick a little esteem for Ldc to avert serious di/dt at the start of the fault event. Nowadays, high evaluating semiconductor switches are accessible in practice. Moreover, utilizing a self-turn-off power electronic switch rather than thyristors in the proposed structure prompts higher expense [13]-[17]. From a power loss perspective, in the typical condition, the proposed FCL has the somewhat loss on the rectifier topology, the semiconductor switch, and Rdc. Every diode of the rectifier topology is ON in half period of a cycle, while the semiconductor switch is constantly ON.

III - CONCLUSION

Fault Current Limiters (FCLs) are highly effective in controlling excessive fault currents and reducing voltage sag in distribution systems. The review highlights that superconducting, solid-state, hybrid, and bridge-type FCLs each offer specific strengths in terms of speed, control, and performance. Although SFCLs deliver superior results, their cost and cooling needs limit widespread use. Solid-state and hybrid FCLs provide faster control and compact structure but involve added complexity. Ultimately, selecting the right FCL depends on system needs and economic feasibility. With the growing adoption of renewable energy and sensitive loads, advanced FCL technologies will play an essential role in improving voltage stability and overall power quality.

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