A Review on Fault Current Limiting Circuits – Its Classification, Benefits and Traditional Methods

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Abstract: *A fault current limiter (FCL) is a device that has a low impedance in normal operating conditions but can transition to a high impedance state when the current exceeds a certain threshold level due to a fault. In the event of a fault, such a device can boost the program's short circuit energy in nominal condition without endangering the apparatus. A FCL is a critical component for future smart grids because of this feature. We covered FCL, its categories, and FCL applications and advantages in this study. Inductive fault conditions limitation systems and their categories were also discussed.*

Keywords: DG, Circuit Breakers FCL, Inductive FCL

I. Introduction

Because of population growth, larger dwellings, more temperature control devices, and more powerful devices, the world's power requirement is rapidly increasing, and energy requirement has been racing ahead of supply. It will almost certainly not be able to meet our future electricity needs. The majority of the country still gets its power from coal and a large residential asset, which contributes to a dangerous atmosphere deviation. A lattice that provides power that is cleaner, more solid, efficient, and responsive than typical power lattice is required. Therefore, in order to reduce carbon emissions and unnatural weather variations, limitless sources of energy such as solar, wind, and geothermal must be incorporated into to the country's lattice.

The electric industry must transition from a highly concentrated, maker-controlled system to one that is less concentrated but more consumer-interactive. It will enable customers to use energy more efficiently, and it will enable utilities to diagnose and address issues with their systems more effectively. To fulfill the ever-increasing need for energy, there will be more access to disperse vitality assets in the future, with the disseminated systems using power electronic converters. As a result, in the future power framework, brought together age provides a piece of the vitality demand, while conveyed age creates another part.

The integration of distributed generators (DGs) into the electricity grid will increase voltage stability, control quality, and voltage backup security. The framework will be able to endure higher stacked conditions as a result of this. It will reduce our reliance on fossil fuels, reduce large-scale power outages, increase supplier quality and security, and so on. However, there are numerous negative consequences on the system caused by the introduction of a DG into a current conveyance system, with an increase in the estimate of fault conditions one of the most important difficulties. Deficiency current is the temporary flow that occurs when a short circuit occurs in an electrical power system. The hardware installed at the power station and the production station is astronomically expensive. As a result, it's critical to protect this gear against the current vulnerability.

A device that reduces the short out power is required both from a specialised and conservative standpoint.
The integrating of distributed generation with the micro - grid enhances voltage level, voltage quality, and load support. As a result, faults currents are generated, causing the overall network to be disrupted. The quantity of fault current generated determines how much DG gets into the system. Despite the fact that distributed generating with micro-grid has been increasingly popular in recent years, it poses a number of obstacles, the most significant of which is the major issue of transient conditions, which necessitates system protection. The most common transient state in the systems is fault current.

The equipment connected to the line suffers some damage as a result of the fault current. Temporary circumstances Being extremely severe in a microgrid necessitates the employment of numerous protection approaches in the existing power system, including adaptive protection schemes, voltage-based techniques, differential protection, distances protection, over-current protection, and the use of portable drives. In terms of internal and external devices, there are both traditional and modern options. Traditional devices include air core reactors, fuse, and circuit breakers, while Fault Current Limiters

(FCLs) are the most recent addition to the protective system. Traditional devices, on the other hand, have numerous downsides, as they are very susceptible to fault circumstances.

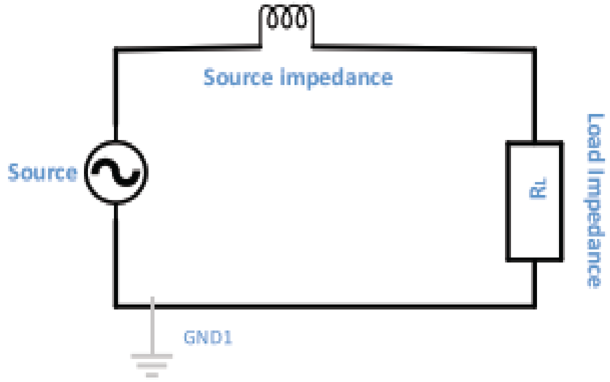

Figure 1 Diagram of Fault Current Limiter Reactor

Because of bigger houses, populations expansion, air conditioners, larger TVs, and much more computers, the need for electricity in the world is expanding at a rapid rate, including in India, as well as the demand for power is greater than the availability of power. Different solutions, such as higher impedance transformers, split bus bars, and fuses, have indeed been employed in the past to reduce the size of fault currents in so many industry.

These gadgets, on the other hand, might reduce the power system's reliability and increase power outage. One of the most recent answers to the issue of growing fault conditions is SFCL. Because of the various pathways from the producing plant to the conventional grid, DC and AC microgrids, excess fault current in one microgrid might have an undesirable effect on the nearby microgrid, resulting in a blackout in the entire system owing to the domino effect. Thus, in a smart grid with DC and AC micro - grids, SFCL could be used to suppress fault current magnitude because it not only has a faster response time to reduce fault conditions magnitude due to its quenching properties of a superconductor than traditional security mechanisms, but it also improves power distribution transient stability.

II. Conventional Methods for Fault Current Protection Scheme

As previously stated, the most often used conventional protection mechanisms include air core reactors, fuses, and circuit breakers. These gadgets are widely acknowledged around the world, and they provide greater protection. For decades, the air core reactor has been employed primarily for current limiting purposes. Despite the fact that air core reactors are widely employed, the inductances necessary for additional protective operation lead the reactor's size to grow correspondingly. One of the biggest disadvantages of such reactors is this.

As a result, there are substantial voltage drops, which necessitate cooling. The amount of current reduction is determined by the reactor system. Fuses are also the most widely used and commercially available technology. Fuses are more susceptible to fault scenarios in which an excessive current flow causes the entire device to fail. As a result, such a breakdown necessitates the replacement of fuses, which is a painful and time-consuming task. Circuit breakers provide the same function as the above-mentioned devices.

However, in this scenario, the CB permits the first cycle of peak current to pass before resuming operations for the following cycle, despite the fact that the efficiency in reducing the fault current is not up to par. As a result, in order to overcome all of these disadvantages, researchers have been working on a specific gadget that is both economically and technically acceptable for protection. Fault Current Limiters (FCLs) are such devices, and its purpose is to limit the fault current. This gadget provides a superior solution for enhancing the fault current's transitory situations while also boosting stability of the system.

III. FAULT CURRENT LIMITERS

New electrical generating should be installed in response to rising usage. Buildings network and their interconnections can increase fault current levels over the circuit breakers' maximum short-circuit power (CBs). Short-circuit currents pose a persistent threat to the quality of generating, bus-bars, transformer, switches, and generation & distribution lines, posing a constant threat to any electricity network. To overcome these challenges, several methods are used, such as upgrading switches and other related components, reconfiguring the power grid, and linking high-impedance transformers for networks impedance. By introducing a resistor into the circuit through which the leakage travels, advancements in fault current limiter devices have been examined. However, switchgear modifications and equipment expansion are both expensive options.

When a problem occurs in the system without complete separation, the FCL is a device that limits the potential fault current in lines for a decent equal stage. In general, the FCL has two parts: one, the fault current must be reduced to an acceptable equivalence stages, and the other, the faults in the system must be removed. There are two types of fault current limiters: passive and active power quality limiters. During both normal and contingency conditions in the system, the passively measures permanently raise the source impedance. However, because the active measures are conditioned, the impedance increase only when the network is experiencing faults. The following are the numerous technical approaches for FCL that are currently being developed:

• Superconductor FCLs (SCFCLs)
• Solid State FCLs (SSFCLs)
• Hybrid FCL and others

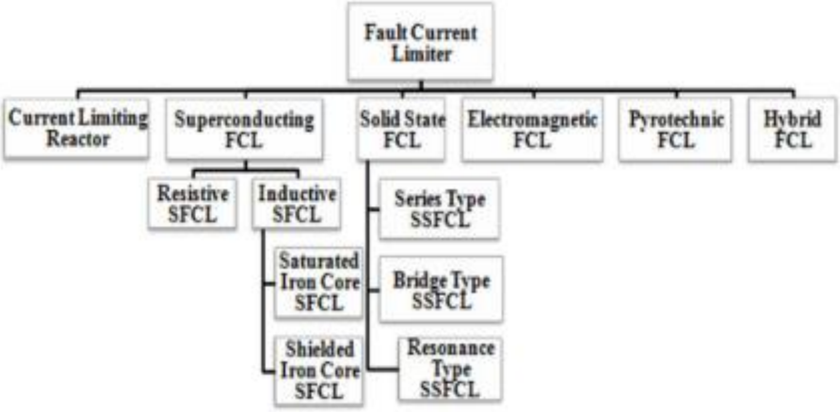

Figure 2 Types of Fault Current Limiters (FCL)

Resistive The operation of superconductivity FCL is based on the transitional properties of superconductivity material. It's the transition from zero resistance during normal operating conditions to extremely resistive material when there's a problem. Because the resistance SFCL heats up during quenched, it's frequently connected to a shunted elements to prevent further damage and allow it to recover. The shunt element may also have an impact on the SCFCL's behavior. To prevent the leakage current from reaching its peak value, SSFCL employs semiconductor devices that lower the initial rate of rise of current. Self-commuting devices such as GTOs, IGBTs, and GCTs are used to achieve this. Hybrid FCL contains modules that perform specific activities. It comprises of a detecting unit that monitors the current condition and activates when a problem occurs. During normal operation, the FCL is sequestered by the Super-fast working switching, which also reduce losses.

IV. TRADITINAL METHODS FOR FAULT CURRENT LIMITER

The most often used traditional components for protection, such as air core reactors, fuses, and circuit breakers, are mentioned in the list above. These devices offer more protection and are projected to be used all around the world. The modern limited methods air core reactor has been used for decades. The importance of inductance in the defensive process cannot be overstated. If air core reactors are utilized in excess, the scope of the reactors expands, which is a major disadvantage of this reactor design. Fuse devices are the most common and widely utilized devices. They're more prone to make a mistake. If an excessive amount of current runs through the fuse, the entire gadget will fail. It replaces fuses, which is a time-consuming task. The primary effect on power distribution tools due to increasing fault current is an increase in dynamic influence of current, an increase in thermally influence, and the ability of circuit breakers to interrupt current may exceed.

The future approach is to modify the substation to cope with the new maximal short circuit current, both mechanically and thermally. It will require a significant investment, but adding a device with a manageable valuation will be economically appropriate to limit fault current and improve system consistency. Fault current limiters have the potential to reduce fault current while also allowing the use of lower-rated protection systems

V. FCL APPLICATIONS IN SMART GRID

At both the transmission & distribution layers, a microgrid integrates modern sensor technologies, control mechanisms, and integrated communications into the current energy infrastructure. A smart grid with a multi-agent system can function more effectively and flexibly than traditional electric power systems' Supervisory Control and Data Acquisition (SCADA) systems. FCLs can be regulated by a smart grid communication system of multi-agent networks, which play an important role in FCL applications and can improve system protection accuracy and dependability. Smart control centres, smart transmission networks, and smart sub - stations are the three interacting, smart components that make up a smart transmission grid. Smart grid's enabling infrastructures, real-time communication networks, provide more computations and controls for more reliable protection. Intelligent electronic equipment with smart techniques in the transmitting line and distribution network in the smart grid can also identify fault areas.

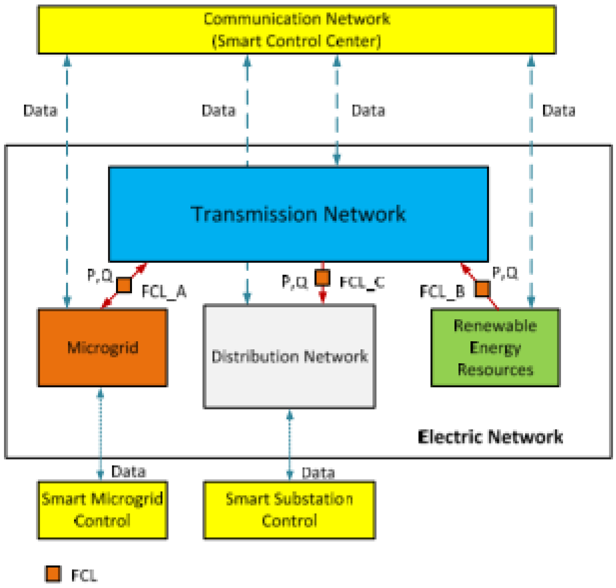

Figure 3 Diagram of a smart grid with electric network and communication network.

A smart grid, which incorporates an electrical network and a communications system, is depicted in Figure 2. Power plants, transmission networks, and distribution networks with master control make up the traditional power network. Microgrids and renewable energy resources are spread across the transmission system in a power grid.

VI. CATEGORIES OF INDUCTIVE TYPE FCLS

Building various types of inductive FCLs has taken a lot of time and work. Inductive FCLs will be separated into numerous groups based on the sorts of technology in order to study their principles and comparing their performance. The categories of inductive type FCLs are depicted in Figure 3.

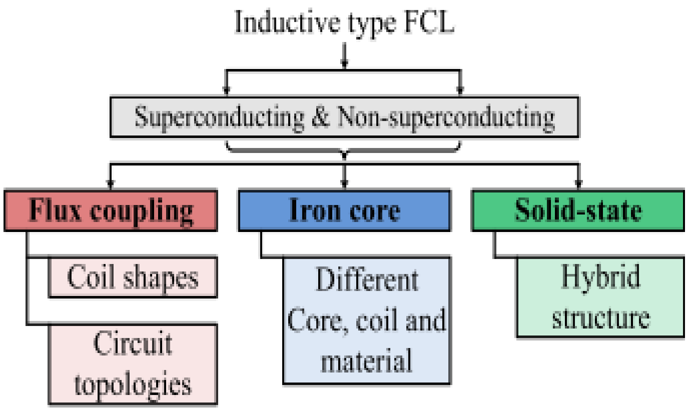

Figure 4 Categories of Inductive type FCL

The inductive FCL categorization, which includes flux coupling, iron core, and solid-state, is depicted in Figure 4. The first group can be divided into distinct coil shapes and topology based on various coil topology. Meanwhile, varied core, coil, materials, and other topological designs can be subdivided into the iron core type. The solid-state type FCL is sophisticated and frequently used in conjunction with power electronic equipment. As a result, various hybrid structures of this type will be presented and studied. Because SC coils are commonly employed in the construction of FCL devices, the following study will apply and cover these categories of FCLs that use both SC and non-SC technologies.

VII. LITERATURE REVIEW

(Yuan et al., 2020)The problem of short-circuit power exceeding the norm is growing more important as the capability of the power system expands. Fault current limiter is a promising solution that is slowly becoming a hotspot for research. Fault current limiters are divided into four groups in this study. Also discussed are saturated-core fault current limiters, including their operating concept and comparisons to the other three groups. According to the paths leading to the saturation core, saturated core faults current inclusion and exclusion criteria are separated into four branches. This report provides a complete overview of the research efforts and upcoming technologies for saturated-core fault conditions limiters for AC power systems. The operating principle & typical structure of DC-biased, permanent-magnet, superconductivity, and hybrid-type saturated-core fault conditions limiters is described. From the perspectives of current-limiting efficiency, iron core size, and DC magnetomotive force, the benefits and disadvantages of four types of saturation core fault current limiters are evaluated in depth. Real-world grid program. these programs of various device kinds are shown, as well as new advancements in the approaches, which are examined and analyzed in depth. This study's information may be useful as a comprehensive literature review or as pragmatic technical advice.

(Naderi et al., 2018)The fault current limitation characteristics of fault conditions limitation devices used in the doubly-fed induction machine is investigated. Fault current inclusion and exclusion criteria or series dynamically brake resistors are primarily considered as a result. All configuration are detailed in detail, including their benefits and drawbacks. Two critical parameters that have a substantial impact on the behavior of the doubly-fed induction machine in a fault condition are the impedance kind and the locations of the fault conditions limiting devices. The effects of these two elements on the essential parameters of the all the more induction machine are researched primarily through simulation.

(Ouali & Cherkaoui, 2020)Fault current limiters (FCLs) are a promising fault current control measure that is also one of the most cost-effective solution to today's electric power system difficulties. They have the potential to be used more widely in power systems. Several efforts have been proposed in the literature to give the ideal position, number, kind, size, and parameters setting of FCL in order to achieve maximum efficiency at the lowest possible cost. The current studies on FCL integration is evaluated in this article in terms of design variables, network structures, FCL kinds, limitations, protective devices, and optimization algorithm that were used. The major goal of this page is to give electricity engineers and researchers with a guide to the accessible FCL placement work.

(Chewale, n.d.)The current power grid has a significant influence in indistributed generation. As power systems become increasingly complex, some power electronic devices are being incorporated. Limiting the leakage current is critical since it affects the protection of power electronic equipment as well as the system's reliability. The current limitation strategies described in this study are used to suppress the excessive magnitude of fault conditions during faults. The power system employs a variety of fault conditions limiters. The emphasis is on superconductivity fault conditions limiter reactors in this paper. The SFCL is a device that solves the issues caused by rising fault current levels. The functioning principle and structure of different from place to place current limiters are clearly explored in this study.

(Heidary et al., 2020)A fault current limiter (FCL) is a potential power system protection technology that effectively limits fault currents. This study provides a comparative overview of FCL scientific research and upcoming technologies, as well as a detailed discussion of the characteristics of an inductive FCL. Inductive FCLs outperform conventional FCLs in terms of performance and speed of operations. An inductive FCL's magnetism structure is crucial to its high performance. The feasibility and effectiveness of magnetically flux-based FCLs are discussed in this review research. The magnetism behaviour of FCLs is also explored in the context of an analytical study of their comparable circuits. Furthermore, based on technical operating properties, a complete comparison evaluation of induction FCLs is offered.

(Patil & Thorat, 2017)Recently, development on FCL has accelerated in the domain of power system failure diagnosis. Traditional means for limiting fault current in the electricity network include fuses, circuit breakers (CBs), and transformers, among others. However, a fuse is a one-time use device that requires manual replacement, and CBs have higher rating constraints. Another issue is transformers inrush power. This study provides a thorough examination of different fault conditions limiter setups, control methodologies, recent trends, and applications implementations.

(Alam et al., 2018)a complete study of the literature on the use of various types of FCLs in power systems The following are some of the applications of high temperature superconductors and non-superconducting FCLs: (1) generation, transmission, and distribution networks; (2) alternating current (AC)/direct current (DC) systems; (3) renewable energy resource integration; (4) distributed generation (DG); and (5) application for reliability, stability, and fault ride thru the performance improvement. Models, impacts, and controlling solutions for a variety of FCLs in energy systems are provided, along with effective implementation scenarios from around the world. The performance of FCLs in energy systems can be improved by modifying their architecture, placing them optimally, and using suitable control design. This review study will serve as an excellent starting point for scholars interested in power system stability challenges, as well as industry looking to put current findings into practice.

(Safaei et al., 2020)The technology of fault current limiters (FCLs) in power systems is discussed in this study. First, superconducting FCLs (SFCLs), solid-state FCLs (SSFCLs), hybrid FCLs (HFCLs), as well as other technology have been divided into four categories. The literature is then studied for each grouping, and the technical aspects of each clusters are stated. The FCLs' technological development hurdles are also discussed. The FCLs were compared based on these qualities and specifications. Finally, the future trend of the FCL is examined based on a review of papers found in the IEEE and SCOPUS databases, as well as a review of patents found in the US Patent Office, European Patent Office, and considering applications in queues. In this discipline, the pioneering nations, universities, and scholars are also recognized.

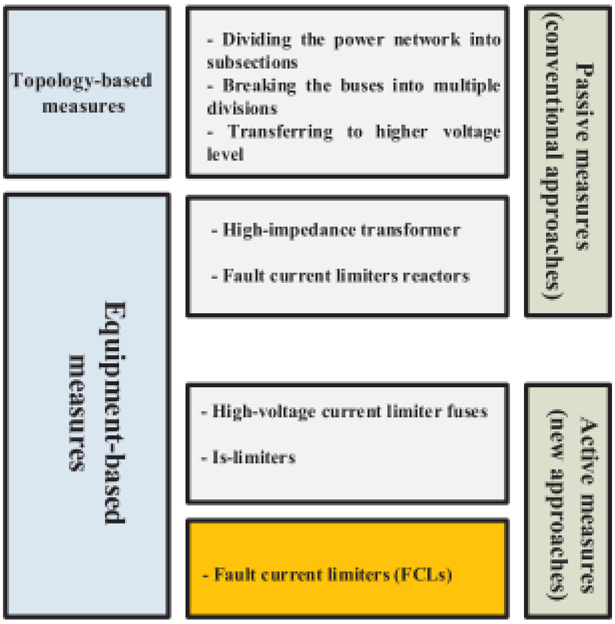

Figure 5 Classification of fault current limiting measures

(Hyun, 2017) examines new field testing and applications of high-temperature superconducting fault current limiters (SFCL) (HTS). The evaluation focuses in particular on the trends in field tests in terms of technical elements and SFCL commercial activity. Numerous research and development operations for SFCLs working at distribution voltages to transmission voltages have been done worldwide as a result of the discoveries of HTS. SFCLs of several varieties have been designed and field-tested. As a result, over 20 field experiments and application have been carried out on real networks around the world while distributing electricity to clients. These field tests have indeed supplied records of operations, including difficulties and maintainence, but they have also demonstrated their overcurrent protection capacities against real failures, making this new technology highly feasible.

(Morandi, 2013)In normal operating settings, a superconducting fault current limiter (SFCL) has a minimal impedance, but reliably flips to a high impedance state in the event of extra-current. A gadget like this can boost an electrical program's short circuit power while also removing the threat that occurs during a malfunction. It is an important component in future electric power systems. The state of the art of superconductivity fault conditions limiters that are mature for applications is briefly reviewed in this study, along with the device's possible impact on the design and operating paradigms of energy systems. The adoption of the FCL in particular is addressed as a means of allowing more connections of MV bus-bars as well as increased immunity to power disruptions caused by essential customers. The idea of more distributed generation being integrated into the distribution network is also being investigated.

(Morandi, 2013)The fault current levels in an interconnected power network have increased as power consumption has increased. If not appropriately mitigated, the fault current may surpass the switchgear's maximum rating. Many traditional protective relays, such as series reactors, fuses, high impedance transformer, and other similar devices, have a high cost, increased power loss, and reduction in power stability analysis, all of which can lead to lower dependability and operational flexibility. Due to its successful means of reducing leakage currents within first cycles of fault conditions, reduced weight, and zero impedance during normal operating conditions, the Superconducting Fault Current Limiter (SFCL) offers a flexible alternatives to the employment of conventional protection systems. This paper examines several SFCL concepts and their application in energy systems.

VIII. BENEFITS OF FAULT CURRENT LIMITER

1. The main benefit of FCL is that it reduces the value of fault current that can be handled by existing protective devices by eliminating lower graded value and mounting advanced grading devices in existing installations.

2. FCLs are installed for each phase of the line, and series impedance is added to bind the leakage current to a specific extent. FCLs lower the short circuit level.
3. Adding a resistors to the circuitry whereby the leaking current flows is a step forward in fault conditions limiter research.
4. There are options, such as improved switchgear and other components, to avoid power system troubles. FCRs are utilized in grid system reconstruction and to connect impedance transformers for networking impedance.

IX. Conclusion

The following methods can be used to address power system protection issues associated with increased fault conditions: I designing circuit breakers with increased power interruption ratings for retrofitting existing substations; (ii) recruiting the power process to minimize fault currents; and (iii) installing fault current limiting (FCL) systems to limit leakage current to levels compatible with extant protection systems. The classifications, applicability, and benefits of FCL have been examined in this work.

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