Applications and Power Quality Issues in Power System

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Abstract: *It is important to recognize the many fault modes, as well as their primary causes and issues, and to put into practice real-time automatic fault detection technologies that can halt the early stages of fault evolution for mitigating activities. Concerns over power quality have grown significantly among electrical suppliers and their customers. The meanings and impacts of power quality issues are discussed in this essay. We also covered the Fault Current Limiter (FCL) and its uses in the power grid.*

Keywords: Smart grids, power quality issues, FCL, SFCL

I. Introduction

Real-time, two-way communications is available at all levels of the power grid, from energy production to distribution, ensuring that it operates within reasonable bounds. The power business is now dealing with a number of issues, including power quality, transmission and distribution losses, and power demand. Power must be delivered to customers in a secure, dependable, and sustainable condition in order to meet this demand. Intelligent power technologies, monitoring devices, Advanced Metering Infrastructure (AMI), smart sensors, phasor measurement unit (PMU), DG resources, smart communication, smart protective controls, etc. are all parts of the updated digital power grid known as the "smart-grid." We will be able to coordinate large-scale power generation, transmitting, and distribution, electricity generation marketplaces, operators, customers, and providers, as well as reduce the greenhouse effect and simultaneously improve the quality of the energy, thanks to the development of the power grid structural system. Power from centralized generation was intended to be delivered via the current power distribution networks to fixed consumers and anticipated loads. Distribution networks grow increasingly decentralized and bidirectional as a result of the integration of distributed generation (DG) sources, micro-grids, and energy storage technologies, enabling network self-healing and systems reconfiguration.

There are a lot of disagreements that accompany this new advertising over how to regulate the network's bidirectional power flow, voltages, and frequency damping oscillations. Numerous faults, such as source and load side faults, converter faults (inverter and converter), cable faults, network communications faults, cyber security, Internet of Things (IoT) protocol failure, data leakage, insufficient data, smart meter faults, and others, may develop in the system under these circumstances. These faults are hard to manage, detect, and control. A significant issue that affects the fundamental framework of energy transmission and supply is the growth of faults in different smart components. Additionally, several failure mechanisms in the same element can show signs of defects. These errors can cause instability and other serious issues in the network if the proper detection and mitigation measures are not followed. Therefore, it's crucial to recognize the many fault modes, as well as their primary causes and issues, and to put into practice real-time automatic fault detection technologies that can halt the early stages of faulty evolution and take corrective measures.

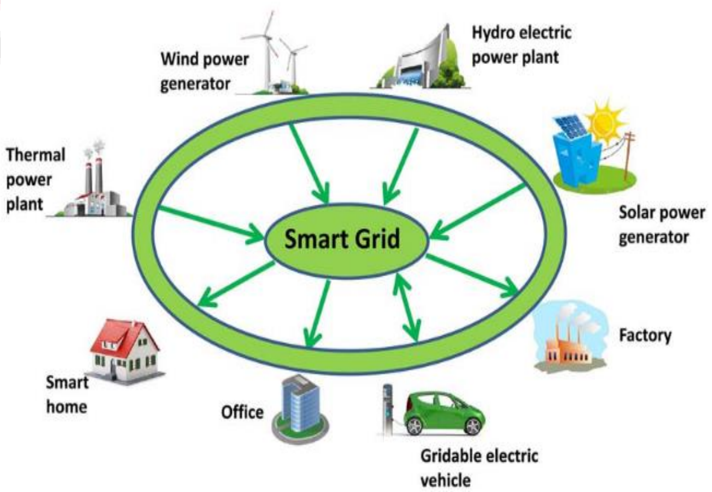

Figure 1: The schematic layout for the smart grid

II. POWER QUALITY ISSUES

Concerns over power quality have grown significantly among electrical suppliers and their customers. From the perspective of the consumer, disruptions might result in generating loss of hundreds of thousands to millions of dollars. Utility companies perceive interruptions as a source of lost revenue, burden, and customer satisfaction. Any divergence from a voltage source's regular behavior can generally be classified as a power quality problem. Rapid occurrences such voltage impulses, voltage transients, high-frequency noise, faults, voltages swells/sags, and total power loss are examples of power quality problems [2]. Therefore, problems with voltage stability directly affect electrical machinery. Lightning and other natural occurrences, energization of capacitor banks and transformers, the start-up or trying to switch of large loads like motors, the operation of non-linear and unbalanced loads, or failure of machinery like transformers and cables are some of the disturbances that may result in power quality problems.

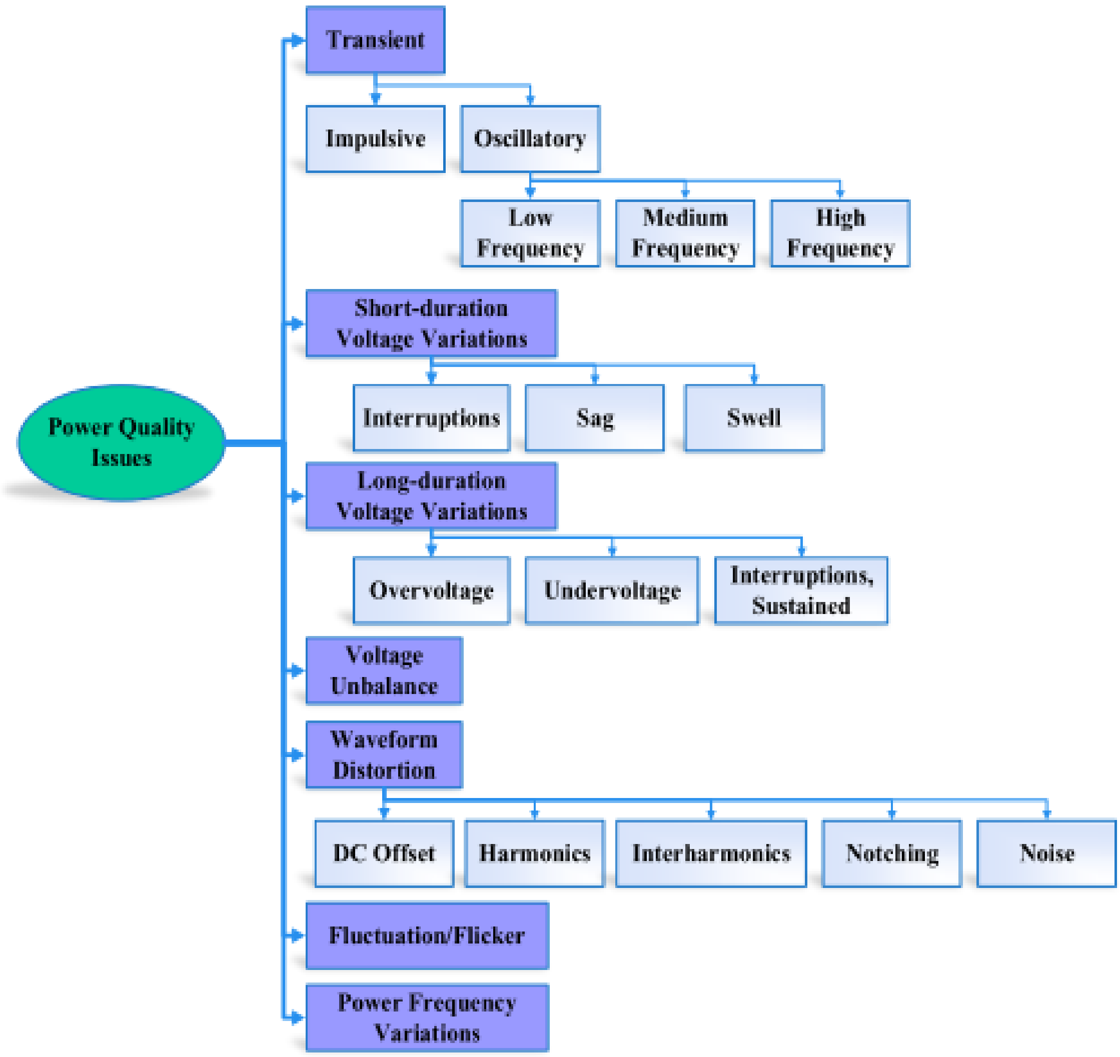

Figure 2: Power Quality Issues [2]

Storage units are intended to protect crucial equipment from disruptions that could cause voltage sags. Batteries, Flywheel Energy Storage System (FESS), Superconducting Magnetic Energy Storage (SMES), Ultra-capacitors (UCAP), and UPS are a few examples of storage solutions. These are utilized to make up for the energy lost due to faults and voltage sags. Custom power devices (CPDs) are the most effective means of minimizing voltage sags/swells among the many various approaches. CPDs ensure that clients receive a high-quality and dependable supply, much to how Flexible AC Transmission Systems (FACTS) may enhance the energy quality and stability of the contemporary power grid.
A fascinating interest that is expanding as a result of significant improvements in the processing of the materials and the commercial accessibility of HTS tapes is the application of high-temperature superconducting (HTS) technology in the development of effective electrical power devices and systems. Electrical power equipment such motors, generators, transformers, cabling, fault voltage limits in place, and strong magnetic storages are all practical applications of HTS technologies.

Table 1: Power quality issues and their definitions, causes and effects.

Problems	Definition	Causes	Effects
Voltage sag/dip	A decrease in Root-Mean-Square (RMS) voltage	Faults, starting of large loads, grid loading, supply voltage variations, inrush current, Inaccurate connection	Overloading or stalling of motors, lock-up, unreliable data
Voltage swell/rise	An increase in RMS voltage	Start/stop of heavy loads, supply voltage variation, inrush current, inaccurate connection	Data loss, damage to equipment, lock-up, unreliable data
Transient	An abrupt change in voltage, current or both	Snubber circuits, lightning, start/stop of heavy loads, inaccurate transformers connection	Disturbance in electrical equipment, data loss, The flickering of lights, damage of sensitive equipment
Harmonic	Integral multiples of the Fundamental frequency, resulting in a distorted voltage or current waveform	Non-linear loads Load	Losses in electrical equipment, transformers and motors overheating, lock-up, unreliable data
Voltage fluctuation/flick	Variations or random alteration in the voltage magnitude	Load switching, fluctuation of supply voltage	Over and under voltages, The flickering of lights, damage the equipment at the load-side Inefficiency
Power frequency variation Voltage	Deviations of the system frequency	Heavy load Failure	Inefficiency in motors and sensitive devices, heating up, gradual breakdown
Voltage interruption	A decrease to less than 0.1 pu in supply voltage or load current	Failure of protecting devices, insulation failure, control malfunction	Malfunction in data processing equipment

III. Fault Current Limiter (FCL)

The rate of increase in electricity consumption is very rapid, and it is outpacing supply. The introduction of dispersed energy resources is the major change impacting the distribution network (DES). Electronic power converters have been used to increase DES integration with the distribution system in order to meet the ever rising electricity consumption. Future predictions indicate that distributed power resources penetration will continue to rise. This causes the fault currents to grow above the electrical protection switching gear's rated limit. In such cases, the current infrastructure will be harmed and must be safeguarded because it is an expensive endeavor. Therefore, it is necessary to introduce a technology that restricts the fault current.

Due to elevated fault present levels, a Fault Current Limiter (FCL) is a device that can solve the aforementioned issues. Superconducting and non-superconducting fault current limiters (FCLs) are the two types of FCLs most frequently employed in energy systems. Recent case studies including the use of superconductivity fault conditions limits in place in various power system components have been published in the literature. Additionally, they are used in systems for generating, transmission, and distribution, as well as when there are renewable energy sources available. High fault currents are a result of the deregulation market system and reorganization of the power system today. This is another reason to be interested in the technology of fault conditions limiters.

Let's examine the various elements of short circuit current to better understand how fault current limiters are used. It consists of a DC offset that is decaying and a symmetrical component. If the fault occurs at zero voltage crossings, they combine to generate an asymmetrical fault current with a highest peak in the first cycle. A device known as a Fault Current Limiter can limit this fault current that is initiated following a power system fault (FCL). As a result, the real fault current can be used with a low power protection system and be limited to lower numbers.

An ideal fault current limiting exhibits various impedance behaviour during both normal and problematic operation of the power system. It functions as a fault current during in the normal operation of power systems, that is, prior to a fault, and as a significant impedance during defective conditions. Power electronics components or superconductivity can both provide this high limiting impedance. It ought to be able to function during the first cycle of fault current as explained, and after the current is reduced, it ought to be able to quickly revert to the normal state. Additionally, it ought to be dependable for several operations and have a longer lifespan. It shouldn't interfere with the relay coordination, though. Finally, the device's size and price should be appropriate.

Typically, there are three types of fault current limiters: series type, shunt type, and solid state diodes kind of. The shorting of a capacitors in a tuned LC parallel resonance circuit is the basic implementation mechanism in series type FCLs. In a shunt kind of FCL, a bypass switching that is typically closed during the proper operation of the power system is operated in parallel to an impedance. On the other hand, the solid state diode type of FCLs uses the current conservation law in a bridge. The significant nonlinearity of superconductivity material makes them extremely helpful for creating FCLs.

IV. Application of FCL in Power System

1) Limit the fault current

When faults develop, the Fault Current Limiter (FCL) is used to limit very high current at high speed. In contrast to a normal reactor, a faulty reactor has designed impedance and a very low impedance. The fault limitation speed is fast enough to limit the fault current in a quarter cycle. This function must also be restored quickly and automatically. Different FCLs have been created, and some of them are used in power systems. The most frequent FCL involves switching from a low to a high impedance circuit. FCL circuits are controlled by circuit breakers and/or power electronics devices. Controlling faulty present level in electrical distribution networks may be possible by connecting a superconducting fault current limiter (SFCL) in series with a circuit breaker downstream. Systems analyses reveal that the SFCL can reduce the voltage sag in addition to limiting the fault current to an acceptable level. After the circuit breaker is activated to clear the fault, the presence of the SFCL could significantly dampen and improve the transitory recovery voltage (TRV). The SFCL is regarded as one of FACTS's cutting-edge devices in the electricity system since it is a potential use of superconductors.

2) Secure interconnector to the network

The use of the SFCL would lessen the strain on the device and provide a connectivity to secure the networks. They can increase the leakage current and increase the stability and dependability of energy systems. The short circuit power can quadruple if the bus-bars are linked via an SFCL. Use of low impedance transformers in series with SFCLs can result in an additional improvement.

3) Reduces the voltage sag at distribution system

If SFCL is implemented in the loop, power distribution network, voltage sags are reduced and fault current is reduced based on the position and resistance value of the SFCL.

So far, a number of strategies have been devised to reduce the fault current. The traditional methods include the employment of high-rupturing-capacity fuses, high-short-circuit-impedance transformers, series reactors, and rearranging power networks. The aforementioned methods, however, are unable to satisfy all needs. Some of them are pricey, while others lack the technical justification to be used at various voltage levels [2]. Embedding fault conditions limits in place into the power system (FCLs) is a different and efficient way to reduce the short-circuit level. FCL is a cutting-edge piece of power equipment that is connected to the power system in series. Under typical circumstances, there is a small voltage loss. However, as soon as the power system problem manifests itself, it instantly restricts the fault current. Furthermore, the use of FCLs enhances power quality, particularly the severity of voltage instability. By strategically placing FCL, it is feasible to regain coordination amongst the protective components in a power grid that has a significant DG penetration.

Academic scholars and businesses present a variety of configurations that are typically divided into SFCLs and NSFCLs in an effort to create FCL with characteristics that are close to optimal. NSFCLs are primarily developed using semiconductors and liquid metals materials. in molten metal. As their name suggests, FCLs use liquid metals like mercury or gallium alloys to perform their fault current limiting job. Power semiconductor switching are implemented in FCL-based semiconductors known as solid-state FCLs (SSFCLs). The various structures for SSFCL technology can be found; they are primarily reported in [9]. Another type of NSFCL is the varied reactors, which operates on the changing of the air gap. In order to implement FCL, superconductivity material is utilized. In the past ten years, researchers have paid increased attention to SFCLs as a result of an important finding in the realm of superconductors. Moreover, field experiments have already verified that SFCLs are technically feasible. Numerous systems have been proposed for the SFCL notion, similar to SSFCL.

V. LITERATURE REVIEW

(Naveen & Jena, 2018)provides a review of the problems and coordination techniques for microgrid protection system. Due to its capacity to provide clients with extremely efficient, dependable, and affordable power, microgrid has grown more appealing. Additionally, the microgrid is adaptable enough to function in both grid-connected and islanded modes. Based on these operation modes, the fault current's size and direction are changed. The range of the inverter-based source fault conditions is 2 p.u. To use the traditional protective schemes, the islanded distributed generation with inverter-based sources are insufficient. To ensure the safe and dependable operation of microgrids, extensive research has been conducted in this area. This article discusses the problems and coordinating techniques for microgrid overcurrent protection.

(Sahebi et al., 2017)The level of fault current is rising as Distributed Generations (DGs) become more prevalent in power systems, which causes various systemic issues. Devices called Fault Current Limiters (FCLs) are appealing solutions to these issues in transmission and distribution networks. The signals used for difference application of power transformers may be significantly impacted by the utilised FCLs, which causes these protections to malfunction. It appears that in order to evaluate the effectiveness of differential protection algorithms in the presence of FCLs, a thorough analysis is required. This study looks into how FCLs affect the differential protection of power transformers. In order to distinguish between internal fault current and magnetizing inrush current with and without the presence of FCL, the performance of a few well-known distance protection algorithms is assessed.

(Badakhshan & Mousavi G., 2018)To meet the ever growing demands for electrical energy, power infrastructure must be improved and expanded. System capacity is increased as a result of system design and the addition of distributed generation (DG) units to the power systems. As a result, the network's short circuit current is constantly rising. Superconducting fault current limiters (SFCLs) have gained a lot of attention worldwide since the discovery of high temperature superconducting (HTS) materials. SFCLs come in a variety of forms. An important class of SFCLs is the flux-lock type due to its properties in fault current limitation. The purpose of this work is to provide an in-depth analysis of the research projects and applications of flux-lock type SFCLs in energy systems.

(Elsherif & Zaggout, 2014)Several technology have been used in international power systems to decrease energy loss, voltage regulator problems, the capital cost of the entire system, and increase the amount of power delivered to urban areas and from offshore farms. These techniques include distributed control techniques and carefully sourced and operated distributed generation (DG). However, these methods could lead to additional network problems like instability, problems with voltage control, and rising network capital costs. It is possible to employ High Temperature Superconductor (HTS) cables to solve these problems in transmission or distribution systems since they show zero resistance when chilled to the boiling point of liquid nitrogen (77Keliven).As a result, this study analyzes superconductive power systems, including the accomplishments made in the DC and AC superconductive energy systems, and it describes the tools and techniques that were employed.

(Zhang et al., 2018)aims to illustrate the state of current research in several related fields and examine the suggested protection solutions in order to aid researchers in understanding DC microgrid protection. The main areas for future research are highlighted in this paper in order to address the protection concerns and further the development of the Micro grid. The creation of novel safety devices that are based on computer technologies to provide looser protection limitations and the improvement of suitable protection systems are the future directions for protective research. Also explained is the new idea of a coordinated method for controlling and safeguarding DC microgrids.

(*A REVIEW ON SUPERCONDUCTING FAULT CURRENT LIMITERS IN RESTRUCTURED*, 2021)The fundamentals of fault conditions limiters and their various variants are discussed. Analysis of the literature is examined in relation to the use of superconductivity fault conditions limits in place to improve power system transient stability, power quality, safety systems, and fault ride through capacities. Finally, the study also reports on the few identified research gaps.

(Bakhshi et al., 2021)In order to safeguard more electric aircraft (MEA) from fault current, recent techniques that have been provided must be reviewed. This essay provides a general review of potential flaws that could develop in more electric aircraft's electric power system. Additionally covered are different functionality and fault limitation techniques. The research also focuses on the key issues for raising the distribution system's dependability in MEA based on safety mechanisms including fuses, circuit breakers, and fault current limits in place. The recommendations are evaluated in order to improve MEA's power grid performance.

(Patil & Bhole, 2017)Although adding distributed generation (DG) to a distribution system raises the fault present level reducing voltage level of common-coupling, the energy quality of the system is still improved (PCC). Therefore, fault ride-Through (FRT) capacity needs to be improved in order to prevent the unexpected tripping of DG units from the power system during voltage sag in an unfavorable state. An overview of distributed generation and how it affects the performance of distribution systems is given in this study. This paper's innovative aspect is its examination of the idea of FRT requirements and several techniques for improving FRT capacity.

(Abu Samah & Wan Abdullah, 2010)The application of a superconducting fault current limiter (SFCL) to control fault current in a power grid is suggested in this research. The defects that are asymmetrical are examined. The bus that provides the maximum fault current at the main location and the feeding position has the SFCL integrated into it. Purely resistive and Purely inductive SFCL are the two varieties. To demonstrate its viability and capacity, simulations were run using MATLAB programs and Simulink version 7.5 and evaluated on 11 bus IEEE devices.

(Kosa et al., 2020)An RL-Indirect SFCL model is presented in this study (RL-I-SFCL). SF 12100 superconductivity tape has been used. Researchers solely looked at the fault's stable state. Our investigation was fruitful. With this solution, they can effectively protect the grid, switchboards, and the superconductivity cable. Due of the ease of use and potential for safety, they would like to help the industry establish an SFCL using this unique model solution.

(Didier et al., 2015)This study compares induction and resistive superconductivity fault current limiters (SFCL) from the perspectives of current limiting and power system transient stability. To reduce the amplitude of fault conditions in a power system, many SFCL kinds can be applied. The two most popular are inductive type and resistive type (rSFCL) (iSFCL). The two SFCLs have differing effects on the power system, according to the results. However, it appears that the resistive SFCL is more suited to limit the fault current and boost the power program's transient response in the event of a short circuit.

(Barzegar-Bafrooei et al., 2019)In this work, different superconducting fault current limiter (SFCL) topologies will be thoroughly reviewed. In terms of technical advances, there are three categories for SFCL types: quench type SFCL, non-quench type SFCL, and composite type SFCL. Some of the investigated structures are resonance-type SFCL, hybrid-type SFCL, magnetic-shielded iron core-type SFCL, transformer-type SFCL, flux-lock-type SFCL, saturated iron core-type SFCL, and superconductivity fault current limitation transformers. The structures have been thoroughly examined in terms of technological viability, operating theory, and recent developments. The study is based on material that has been published in papers, reports, and other internet resources. It is anticipated that this study will give researchers and businesses a solid base on which to build their knowledge of various SFCL types. It would be beneficial to contribute to ongoing research on the creation and application of SFCL for actual energy systems.

(Okakwu et al., 2018)Due to the rise in power consumption, the fault present level of a linked electricity network have generally increased. If effectively mitigated, this increase in fault conditions may exceed the switchgear's maximal rated. Numerous standard protective devices, including series reactors, fuses, high impedance transformers, etc., are expensive, result in higher power loss, impair the stability of the power, and may eventually degrade reliability and operating flexibility. Due to its customizable means of reducing fault current within the first cycles of fault current, reduced weight, and zero impedance during normal operating conditions, the superconductivity fault current limiter (SFCL) provides a flexible alternatives to the usage of conventional protection systems. The many SFCL principles and their uses in energy systems are reviewed in this essay.

(Alam et al., 2018)As more and more power electronic devices are integrated into power systems, their complexity is increasing. Limiting the fault currents is crucial for the stability and reliability improvement of such devices as well as their protection. Numerous fault current limiters (FCLs) have been used in power systems because they quickly and effectively restrict fault current. This essay offers a thorough assessment of the literature on the use of various FCL types in energy systems. Following are some examples of uses for both superconductivity and non-superconducting FCLs: (1) use in generation, transmitting, and distribution channels; (2) use in AC/DC systems; (3) use in the integration of renewable energy resources; (4) use in distributed generation; and (5) use to improve reliability, stability, and fault ride though capacity. Several FCLs' modelling, effects, and control mechanisms for power systems are provided with examples of their actual use in various nations. It is suggested that the structures, locations, and control designs of FCLs be modified in order to increase their performance in power systems. In order to incorporate the continuing research advances in practical systems, industry and researchers working on system stability concerns can benefit greatly from this review study.

(Naderi et al., 2018)The fixed speed wind turbine lacks some key characteristics of the doubly-fed synchronous generators, which has made this technology more widely used in energy systems. One of the key topics in regard to the new grid code requirements is the improving of fault ride-through capacity due to partial rated back-to-back conversions in the doubly-fed induction machine. Numerous experiments have been conducted to improve the doubly-fed inductive generator's ability to ride through faults. One method used to control the current levels and safeguard the switches of the back-to-back converters from over-current damages is the use of fault conditions limiter devices. In this study, a review of fault conditions limiting systems used in doubly-fed induction generators is conducted based on their fault current limitation properties. As a result, series dynamic brake resistors and fault current limiters are generally taken into consideration

VI. CONCLUSION

The definitions and impacts of power quality issues were covered in this essay. We also covered the Fault Current Limiter (FCL) and its uses in the power system. One method used to control the current levels and safeguard the switching of the back-to-back converters from over-current damages is the use of fault current limitation systems. Many researchers have sought to minimize the power distribution malfunction. In order to incorporate the continuing research advances in practical systems, industries and researchers working on power system stability concerns can benefit greatly from this review study. The many SFCL principles and their uses in power systems are reviewed in this essay.

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