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Analyzing the Impact of SFCL in Evaluating Short-Circuit Current in the Electrical Power System and Artificial based Controlling Techniques

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Abstract: *SFCLs (Superconducting Fault Current Limiters) are cutting-edge electric devices that can minimize faults current levels within first cycles of fault current. SFCL has zero impedance in normal conditions and a significant impedance when there is a fault. This paper includes an analytical and numerical explanation of a suggested method for sentiment classification of a voltage buffers, as well as a simulation of the suggested algorithm's effectiveness. The research used a testing system to study the impacts of SFCL on it by modifying the controlling algorithm for fast fault conditions detecting and mitigating in the relay circuit. The foregoing results show that the suggested ACO-based Optimization controller for relay operations in accordance with SFCL in the circuit is efficient.*

Keywords: power grid, FCL, SFCL, DL_PSO Technique

I. Introduction

We live in a world obsessed with power. Everything around us, from little household gadgets to large-scale factory motors, need power, resulting in an ever-increasing demand for electrical energy. As a result, increasing power generation has always been required to meet energy demands.

In power systems, however, increased generation capacity and increased fault current levels frequently go hand in hand. As a result, a rise in energy demand necessitates an increase in generation capacity while also necessitating a reduction in fault current levels to make the system safe and stable.

Fault current limiters, as the name implies, are used to lower fault currents and hence the risk of power system instability in the event of a fault. It is based on providing a large series resistance in the path of fault currents in the event of a fault, whereas the resistance given in the path of current in normal situations is insignificant.

A power system is an integrated network of components that continually transform non-electrical energy into electricity and convey it from generating sources to loads/users. A power grid has only one essential purpose: to provide electricity to clients as cheaply and reliably as feasible.

Figure 1Transformer like saturated core Fault current limiter

II. SUPERCONDUCTING AND NON-SUPERCONDUCTING FCLS

Fault current limiters (FCLs) are being examined as significant possibilities for installation in electric grid to prevent short-circuit damages and systems upgrades. Non-superconducting and superconductivity FCLs are the most common types of FCLs used in energy systems. Superconductors FCLs have been used in a variety of applications in the electricity network, including renewable energy generating, distribution generating, transmission, and distributing. Non-superconducting versions FCLs have also been used to improve performance characteristics by restricting fault current in numerous branches of the power grid, including generating, transmitting, and distribution. Figure 1.2 depicts the FCL classification system.

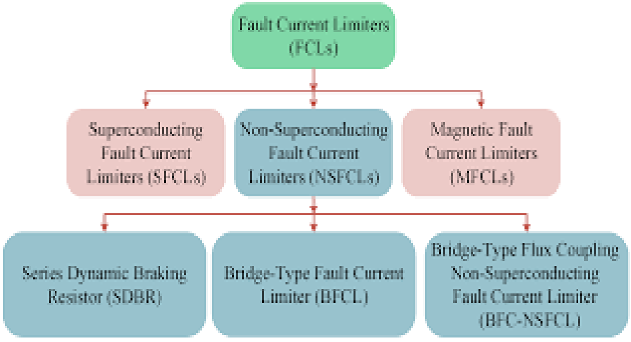


Figure 2Classification of FCL

Superconducting Fault Current Limiter

SFCLs (Superconducting Fault Current Limiters) are cutting-edge electric devices that can minimize faults current levels within first cycles of fault current. SFCL has zero impedance in normal conditions and a significant impedance when there is a fault. Saturated iron care SFCL, inductive SFCL, and resistive SFCL are all examples of SFCLs used for current restriction. Low temperature superconductors (LTSs) and high temperature superconductors (HTSs) can be used to realize each form of SFCL, which has advantages and disadvantages (HTSs). LTSs are used to build saturated iron core SFCLs, whereas HTSs are used to design inductive and resistor SFCLs [2]. A superconducting fault current limiter (SFCL) with a high temperature can be used to reduce short-circuit power throughout a fault. SFCLs have the potential to greatly improve the safety and availability of electrical equipment in power plants. They also play a vital role in expanding the electrical system, as according experts.

Resistive type SFCL

As shown in fig. 1.3, the resistive kind is a superconductivity element coupled in series with networks. It is the most basic form of SFCL. It could be a single low-temperature superconductivity wires or a set of high-temperature superconductivity. The superconductor is in the superconducting state without resistance whenever the energy is normal. The superconductor enters its normal state when the current exceeds the critical current, and it has a high resistance series - connected with the networks. The current will be limited by this resistance.

The superconducting element must be coupled to a parallel resistance. To eliminate hot spots during quenching, modify the limited power, and avoid over-voltages due to its rapid current restrictions, the parallel resistivity or inductive shunt is required. In comparison to inductive SFCLs, resistive SFCLs are substantially smaller and lighter.

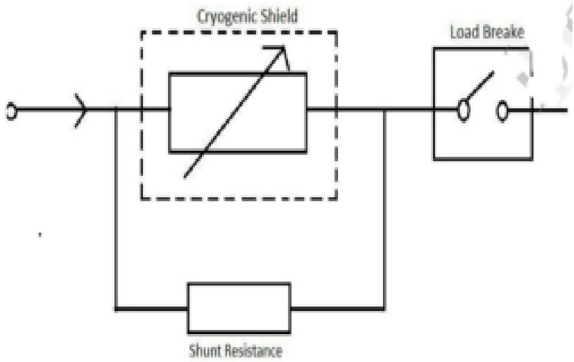


Figure 3Resistive SFCL

III. LITERATURE REVIEW

(Ahmed, 2022) [1]To deal with the problem of increased the expected short-circuit power in the networks, fault current limiters have become necessary. The new difficulty is the explosion in the number of different types of fault conditions limiters as a result of the semiconductors industry in terms rapid growth. It's not easy to choose the right leakage current limiting for the right application. The massive increase in the production of fault current limitation technology necessitates a research of their suitability for future applications, following by a study of the new FCL's impact on the electricity system. This article proposes new classifications for FCLs based on various standards and international guidelines lines. A detailed survey of superconductivity and non-superconducting FCLs was also conducted, with the goal of providing adequate guidance in FCL selections.

(Rao et al., 2022) [2]Three DGs are rated differently in the planned work. Solar and wind power are the primary sources, with fuel cells serving as a backup. The voltage level of the transmission system is 10.5 KV, and it is linked to three-phase distribution power transformers. The loads are fed by the produced three-phase voltages. Three DGs are synchronized with the main grid using Phase-Locked Loop circuits (PLL). Because of the interconnection of scattered generators, abnormal flow is generated, causing the microgrid to be completely destroyed. Type of resistance When compared to circuit breakers, the Superconducting Fault Current Limiter (RSFCL) has a number of benefits, including supply continuity, the ability to restrict anomalous currents within the first cycles, and a short running time. (Fırat Üniversitesi Deneysel ve Hesaplamalı Mühendislik Dergisi Firat University Journal of Experimental And, 2022) By producing a sample R-SFCL in the lab using a 2G HTS (High-Temperature

Superconductor) tape, this study created a dynamic model in MATLAB/Simulink. The limiting analyses for single stage fault is seen using this model. When the simulations findings and the reactions of the samples R-SFCL were examined, it was discovered that they were remarkably similar.

(Song et al., 2021)[3] The employment of a superconducting fault current limiter (SFCL) in voltage source converter-based high voltage direct current (VSC-HVDC) transmission networks to restrict fault currents and safeguard the system in conjunction with DC circuit breakers may increase system security and stability. China created the first transmitting dc Power SFCL, which was used in the 160 kV VSC-HVDC transmission network in Nan'ao. The overcurrent protection unit's electromechanical layout and insulating analyses are described, with the current control unit consisting of 96 bifilar coils built of stainless steel reinforced YBCO tapes. The cooling and insulating medium is liquid nitrogen at 77 K, and the liquid nitrogen is cooled using a closed-loop cryotherapy device consisting of three G-M freezers. The 160 kV DC SFCL prototypes has completed the steady-state latest test of 1 kA, the DC withstand voltage test of 252 kV within 1 minute, the lightning impulse test of 550 kV/1.2 s/50 s, and the operational impulses test of 450 kV/250 s/2500 s. The designed SFCL could generate the appropriate limitation resistant, and the maximal fault conditions time duration might be as long as 60 ms, according to power switching test findings.

(Rehman & Khattak, 2021)[4] The demand for reducing DC fault current and restoring High Voltage DC power systems has grown exponentially during the last three decades. In this article, the DC fault current of a Half Bridge Modular Multilevel Converter (HB-MMC) is examined. Due to its free-wheeling diode, the Half Bridge Modular Multilevel Converter is unable to clear DC fault current, hence DC fault conditions confinement is required. Thyristor based DC fault flow limiter and Saturated Iron Core Superconductor fault current limiter (SI-SFCL) are investigated with Hybrid DC Circuit Breaker for restricting DC fault current and immediate system restoration (HDCCB). A thyristor, a resistor, and an inductance make up the Thyristor-based leakage current limiting. SI-SFCL is made up of three coils: primary, secondary, and superconductivity. The Thyristor-based DC fault current Limiter reduces fault current from 14 kA to 2.5 kA, resulting in an 82 percent reduction in DC fault current, whereas the SI-SFCL reduces fault current from 14 kA to 3.5 kA, resulting in a 75 percent reduction in DC fault current. The restoration time for TB-FCL with HDCCB is 28 milliseconds, and for SI-SFCL with HDCCB is 140 milliseconds. To design and simulate HB-MMC, SI-SFCL, TB-FCL, and HDCCB, a PSCAD/EMTDC is employed.

(Shen et al., 2021)[5] The experiment of a resistive-type SFCL in a powered electrical circuits is shown. The experimental perfectly linked the advance finite-element methodology (FEM) SFCL model, demonstrating the model's reliability. After that, a large-scale resistive-type SFCL was modeled using the FEM model and the power application programs PSCAD. The FEM model closely matched the PSCAD model under the identical simulation settings. The FEM methodologyhas the benefit of allowing for precise electromagnetism simulation of superconductivity components. The PSCAD SFCL model has a substantially faster simulation time and can handle all types of energy networks directly. This article presents a new perspective and an all-in-one study to link the experiment, the numerical model, and the power/energy system software design, and how their agreement can help researchers and engineers find useful evidence and developed in response to confidently carry out effective SFCL design ideas for the electrical energy system

(E. Ali et al., 2021)[6] One of the most difficult tasks for protective designers is to safeguard and isolate distribution transformers in the shortest amount of time feasible when internal faults occur. Using a superconductive leakage current limitation is one of the possible ways for reducing fault current in the power system (SFCL). During internal fault situations, the ratios-based transformers differential protection algorithm is tested in the presence of resistance SFCL. In the MATLAB/Simulink environment, a system model under study, including SFCL, is simulated and investigations are carried out. The findings show that the ratios-based differentiated protection strategy is capable of detecting internal flaws in the presence of SFCL.

(Alam et al., 2021) [7]To reduce the impact of failures on voltage source converter high voltage direct current (VSC-HVDC) devices, a fuzzy logic controller (FLC) based variable resistive bridge type fault current limiter (VR-BFCL) is proposed. During contingency, FLC for VR-BFCL dynamic inserts the required current limiting resistant to keep leakage current within reasonable parameters. Based on the fluctuations of direct current (DC) link voltages and point of common coupling (PCC) voltages, the suggested controllers effectively provides changing duties to produce and insert controlled resistant in the system. Simulated for balanced or unbalanced faults are used to prove the efficiency of the suggested controllers. The results show that by regulating fault current through the use of the suitable resistance, oscillations in PCC voltage and DC link voltage may be kept within acceptable limits. The new controllers is also proven to outperform the conventional technique.

(Superconducting Fault Current Limiters for Grid Protection, n.d.)[8] For grid engineers, superconductivity fault conditions limits in place are a revolutionary piece of hardware. It has unique advantages such as ultra-fast current limiting, effective fault conditions reduction, and a tiny footprint. It is non-flammable and environmentally friendly. The basics of devices, potential choices, and recent and advanced breakthroughs in this sector are briefly discussed in this article. A forward-looking examination of potential SFCL application opportunities in the electricity network is also offered.

Ali & Banerjee, n.d.)[9] present a three-dimensional power mapping software for a superconductor that uses a distributed network of Hall sensors. The authors show this in a prototype that is similar to a resistant super conducting fault current limiter (SCFCL). Authors can actually measure the dispersion of current flow in the superconductor and shunted by calibrating the Hall sensor energy. When a fault-like scenario is simulated in the network, Author uses pulsed measurements to determine the percentages of power dispersed across the superconductor and shunted resistors parallel connection. Author creates a real-time three-dimensional mapping of local current average distributions around the superconductor in use in our SCFCL prototypes utilizing Hall array data. Our tests demonstrate that a non-uniform power flow pattern exists around the superconductor employed in the prototype, even at currents less than the critical current. The capacity to monitor the average local current distribution in three dimensions in real time allows for early detection of instability such as hotspot emerging in a superconductor. The authors address the application of this technology to demonstrate not only how it provides early diagnosis and protection against emerging superconductive instability, but also how it provides further flexibility, in the form of a user-settable fault conditions threshold.

(Ghobadpour et al., 2020)[10] Fault in Superconductivity In the presence of distributed generating units, Current Limiter was utilized to restore the missing protective coordinating among fuses and recloser inside the distribution system. Various forms of SFCL equipment, include resistor, induction, and hybrids, are simulated and researched for differential protection in order to assess various SFCL models. The goal of this study is to control the current injected by DGs linked to the radial distribution system using fuse and recloser protections in the absence of DGs with certified protective coordinates among fused and reclosers. Because increase in the size of an SFCL raises its price, the Genetic and PSO Algorithms are used to determine the minimal size of various types of SFCL in terms of maintaining network security coordinating. The result of a simulation run in DIgSILENT® program on an IEEE-34 transport system showed that by employing this optimization strategy, not only can missing protective coordinating of the fuses and recloser induced by the existence of DG be handled, but also SFCL impedance may be reduced.

IV. METHODOLOGY

Increases in the fault present level of electrical network have led to fault current levels that can surpass the switchgear's maximum specified short-circuit ratings. Circuit breakers, triggered by over-current protection relays, are several traditional protective devices used for prevention of high fault current in power systems, notably at power plants.

The Superconducting Fault Current Limiter (SFCL) is a cutting-edge electric device that can reduce faults present level within first faults current phase. The use of a fault current limiter (FCL) would indeed ease the strain on connected devices, but it would also provide a link to increase the power system's reliability. In power distribution systems, a superconductivity fault current limiter (SFCL) in conjunction with a downstream circuit breaker can provide a viable method for limiting fault present level. We need a mechanism to forecast the efficiency of the SFCL in a particular circumstance in order to incorporate the SFCL into electricity grids.

Resistive-type SFCL When the transportation power surpasses the significance level, a resistive-type SFCL directly leverages the transition from superconductivity to resting condition that a superconducting (SC) material shows [3].

In reality, it represents the non winding constructed of superconductivity wire or tape that really is parallel linked to a resistor or inductive external shunt. During a malfunction, the external shunted provides an alternative path for the current, lowering the superconductor's Joule heating. From the standpoint of the electricity system, a resistor external shunted is desirable since it does not delayed the current's negative approach but does not reduce the program's transient response

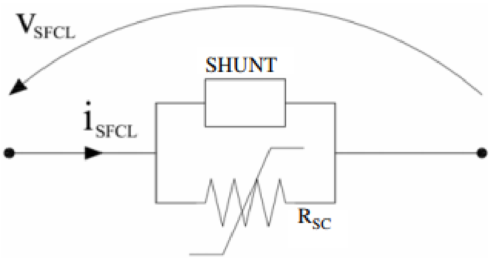


Figure 4Circuit scheme of a resistive-type SFCL.

Figure 3 depicts the circuit of a resistive-type SFCL. The paralleled equivalent of the superconductor and the normal conductive matrix or shunt-layer gives the nonlinear resistant RSC. Even after complete transition, the persistence of the electrical resistivity materials only allowed for a small value of resistance values.

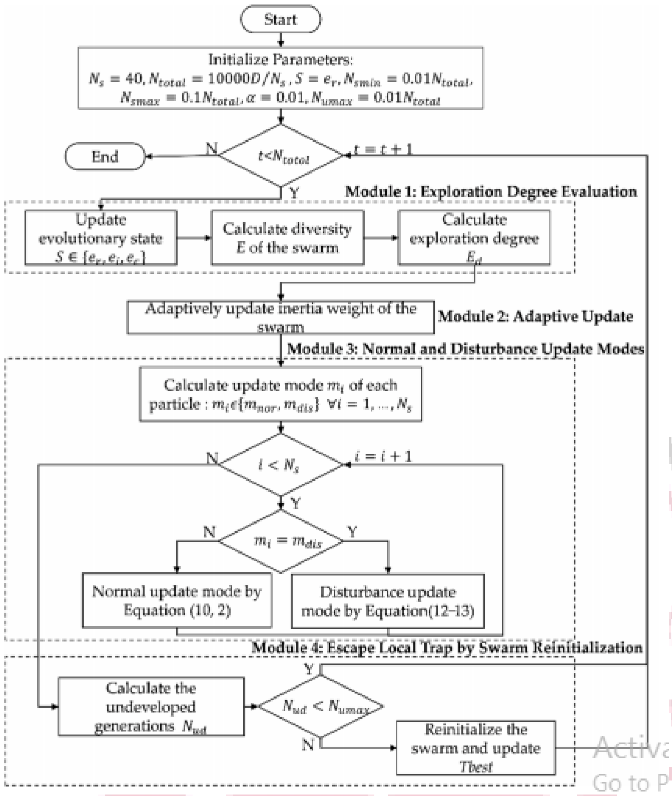


Figure 5 Proposed DL_PSO technique.

V. Results

This paper includes an analytical and numerical explanation of a suggested method for sentiment classification of a voltage buffers, as well as a simulation of the suggested algorithm's effectiveness.

CASE 1: System modeled without SFCL

In this situation, the testing process is unaffected by any SFCL device or algorithms type. The systems relay activates when it detects a large current flowing during a fault event. The breaker cuts the load off from the power supply. The program's ability to autonomously recovery from a fault is being investigated.The graphs of voltage or current output are examined in the following figures

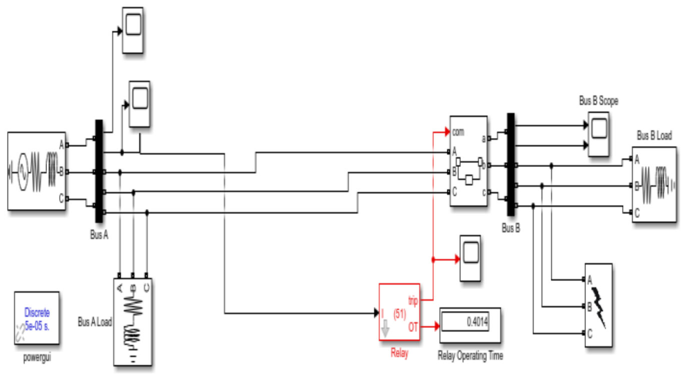


Figure 6TEST SYSTEM MODELED WITHOUT SFCL

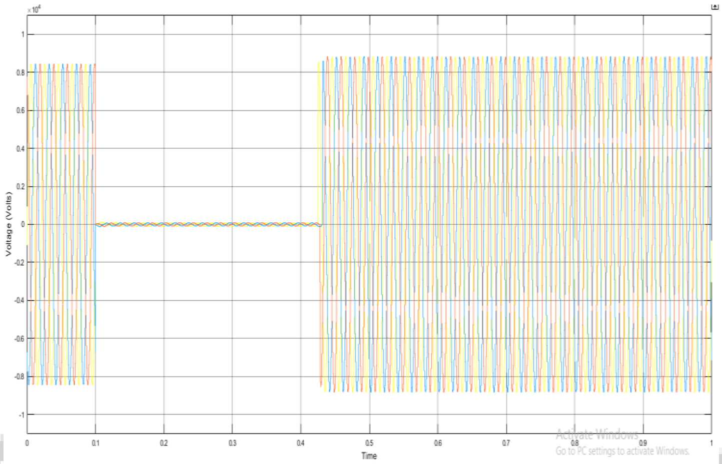


Figure 7Voltage output from the system having no SFCL

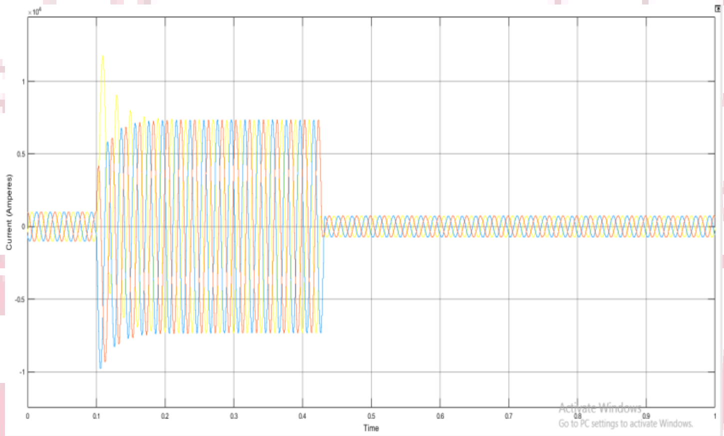
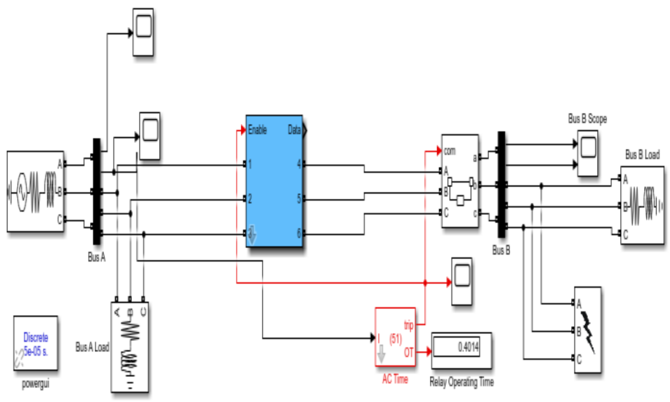


Figure 8 CURRENT OUTPUT FROM THE SYSTEM HAVING NO SFCL

CASE 2: System modeled with SFCL and Relay circuit without AI technique



Figer:9 System modeled with SFCL and Relay circuitwithout AI technique

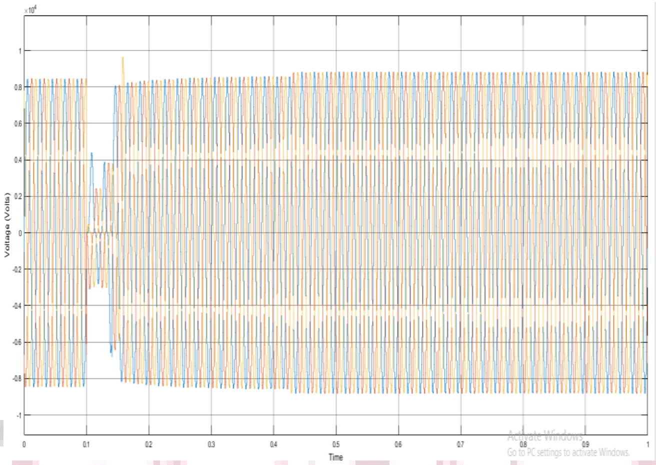


Figure 10 Voltage output from the System modeled with SFCL and Relay circuit without AI technique

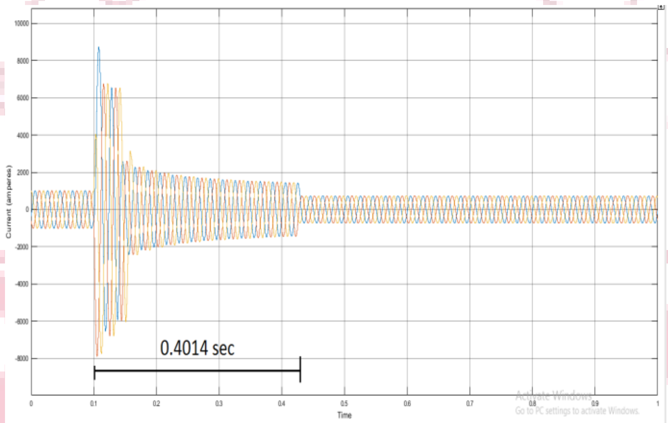


Figure 11 current output from the System modeled with SFCL and Relay circuit without AI technique

CASE 3: System modeled with SFCL and Relay circuit with PSO technique

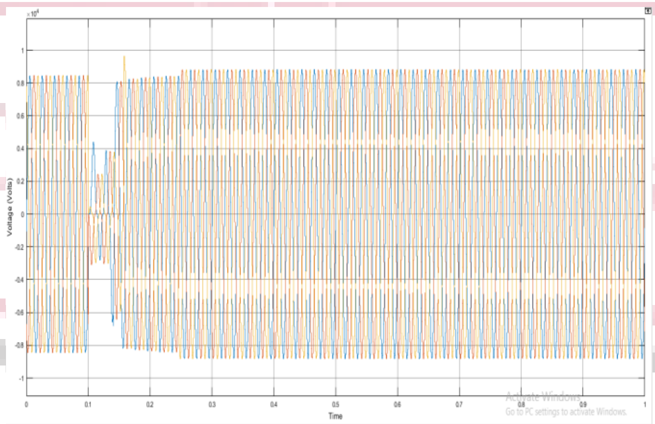


Figure 12Voltage output from the system modeled with SFCL and Relay circuit with PSO technique

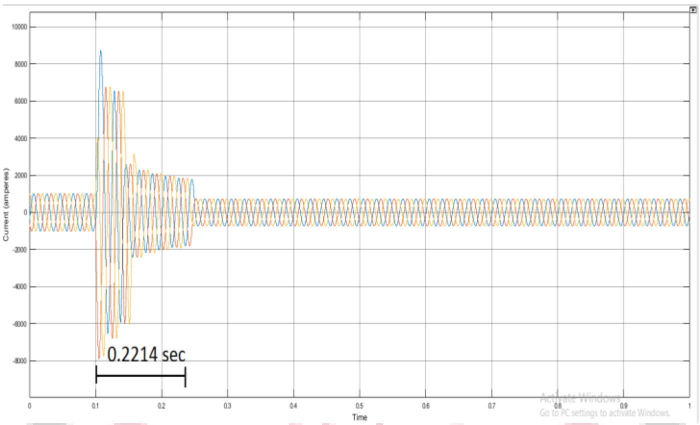


Figure 13Current output from the system modeled with SFCL and Relay circuit with PSO technique

CASE 4: System modeled with SFCL and Relay circuit with ACO technique

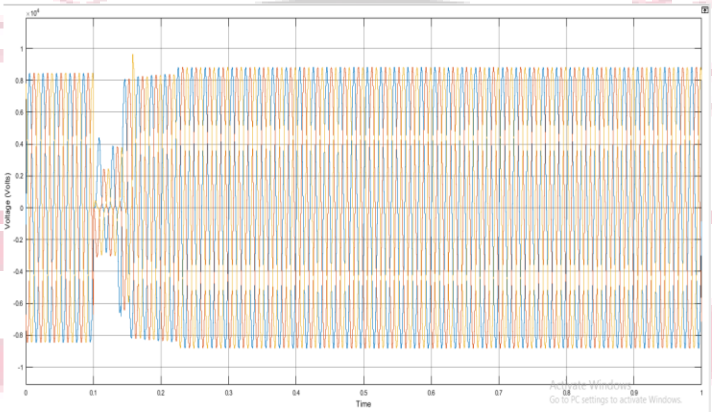


Figure14Voltage output from the system modeled with SFCL and Relay circuit with ACO technique

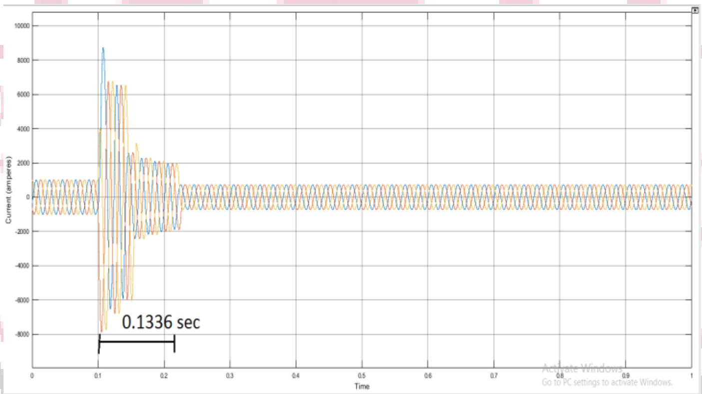


Figure 15 Current output from the system modeled with SFCL and Relay circuit with ACO technique

Outputs with IEEE 9 bus system.

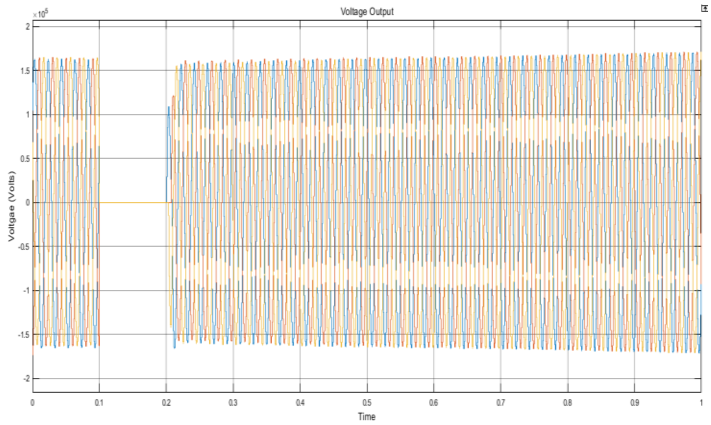


Figure 16Voltage output at the line where fault is generated in the grid system.

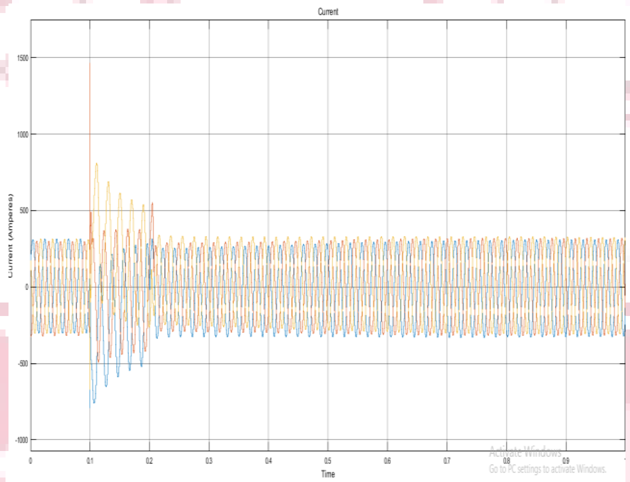


Figure 17Current output at the line where fault is generated

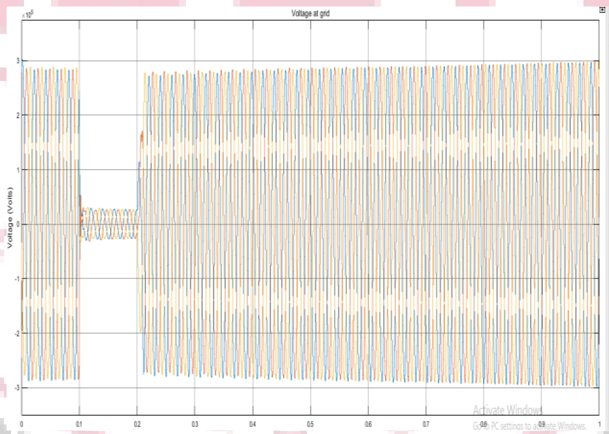


Figure 189Voltage at the grid connection terminal after using SFCL after step up from transformer

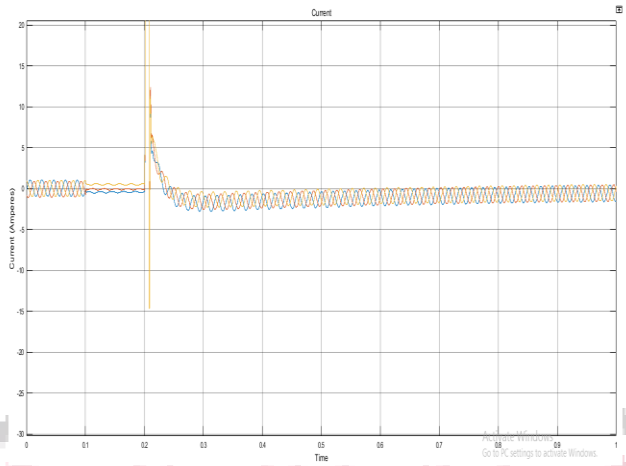


Figure 19 Current at the grid connection terminal after using SFCL after step up from transformer

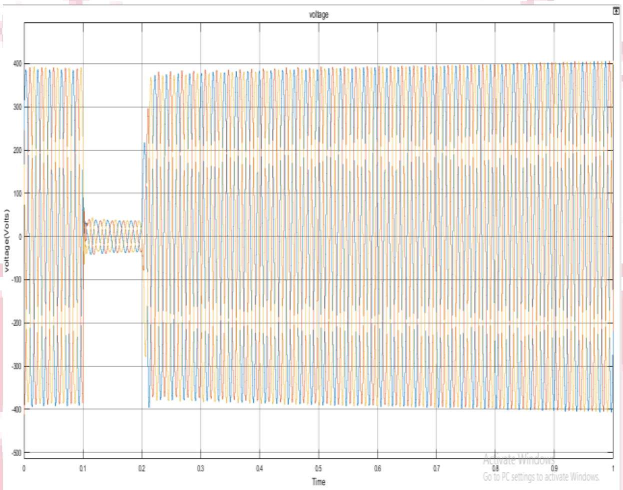


Figure 20Voltage at the renewable energy source terminal with sfcl.

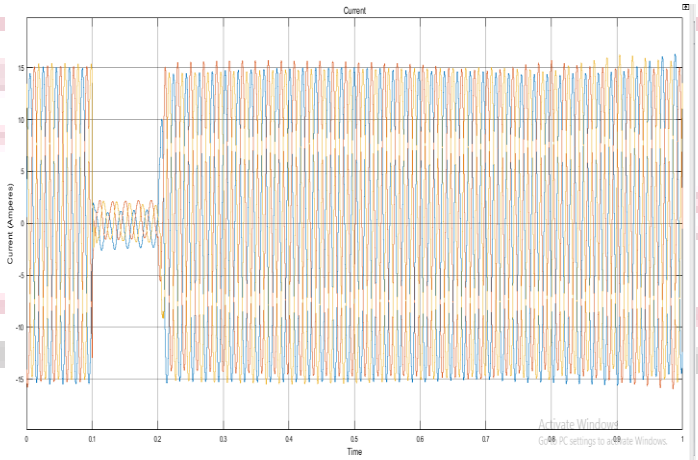


Figure 21Current at the renewable energy source terminal with sfcl

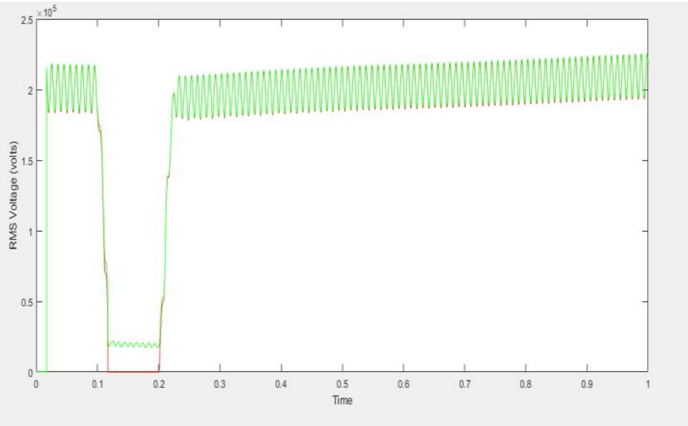


Figure 22 Voltage output at the line where fault is created and voltage at the bus where source is integrated with the grid

VI. CONCLUSION

The fault present level in an interconnecting electricity network have increased as energy consumption has increased. If not appropriately mitigated, the fault may surpass the switchgear's maximum rated. 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.
When a problem develops in a simple high voltage (HV) electricity system, we propose resistive SFCL (IEEE 9 bus system). The short-circuit energy in the electrical power system is evaluated using a time domain method, and artificially based controlled techniques are suggested to meet the goal.
The research used a testing system to study the impacts of SFCL on it by modifying the controlling algorithm for fast fault conditions detecting and mitigating in the relay circuit.
The work of the AI-based approaches is summarized in the table below.

Table 1Test System and control Algorithms with regards to operating time

Test System and Control algorithms	**Operating time { seconds }**
without SFCL	0.4014
with SFCL but without AI technique	0.4014
with SFCL and with PSO technique	0.2214
with SFCL and with proposed ACO technique	0.1336

The foregoing results show that the suggested ACO-based Optimization controller for relay operations in accordance with SFCL in the circuit is efficient. Even if no AI-based technology is utilized and the operational period remains the very same, the very first 2 test systems conclude that the system with SFCL decreases faults current rise and prevents the voltages from dropping to zero. Whenever the test system is simulated for 1 second in the MATLAB/SIMULINK environment, the power is restored to its actual levels in a short space of time, reducing the running time and making the process more efficient. The IEEE 9 bus network with renewable energy resources is then integrated with the this technology.

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