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DVR Transient Analysis with Saturated Iron-Core Superconducting Fault Current Limiter

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Abstract: ***The saturated iron-core super conducting fault current limiter exceeds all other fault current limiters in terms of technical performance. Based on the real structure, magnetic structures have been proposed. Simulated current limiting inductance was calculated using the Newton iteration method and the fundamental magnetization curve. Sagging and soaring current levels occurred frequently during the faulting process. Short circuits and voltage fluctuations are two of the most typical grid-related issues.. The use of the SISFCL and DVR in this project resulted in a reduction in the amount of fault current and voltage variation. With the help of Matlab/Simulink and theoretical insights from previous research, we were able to construct an electromagnetic transient simulation model. The transient behavior of these devices during simulation tests demonstrates the accuracy and validity of the suggested strategy.***
Keywords: Analysis of transient electromagnetic waves in a saturated iron core using a Newton iteration method. Fault current limiter (SISFCL), dynamic voltage restorer (DVR), pulse width modulation (PWM).

I. INTRODUCTION

The total electric current load on the transmission system has increased because of a growing need for electricity. As more and more independent power producers have developed, power producers are constantly expanding their power infrastructure (IPPs). Since renewable energy sources and technology have advanced, the number of distributed generation units (DGs) has increased. There is an increase in possible fault current levels as the number of generators increases due to the paralleled connections reducing source impedance.

Power lines, switchgears and protective devices may not be able to withstand short-circuit current levels in conventional systems. If a fault current level exceeds the current interruption limitations of fuses and circuit breakers, the equipment will not be protected. Fault currents can cause conductors and oil-filled equipment to catch fire or explode if they are not properly terminated.

Demand for electricity continues to rise, making it increasingly difficult to keep up.

In the worst-case situation, the CBs' interrupting capacity may be exceeded.

High impedance transformers or air core reactors can also be used to reduce fault current flow in a system re-configuration.

Fault Present Limiters (FCLs) are being considered as an alternative to the current standard way of correcting the problem by many people.

For the rest of this essay, it is organised as follows: Fault Current Limiter for Iron-Core Superconducting Faults described in section II, followed by the Dynamic Voltage Restoresrs in section III, Section IV discusses some Simulation Examples with results, Finally, the key conclusions of this work are summarized in section V.

II. FAULT CURRENT LIMITER FOR IRON-CORE SUPERCONDUCTING FAULTS :

Iron cores, AC and DC superconducting coils are some of the SIFCL's basic components. The dc current drives both iron cores to saturation when a superconducting coil is working normally. during a typical work day, SISFCL's inductance is reduced due to its low permeability saturation area. Whenever a fault develops, two iron core working sites are forced out of saturation. The permeability of the cores has been greatly enhanced in order to reduce the amount of fault current.

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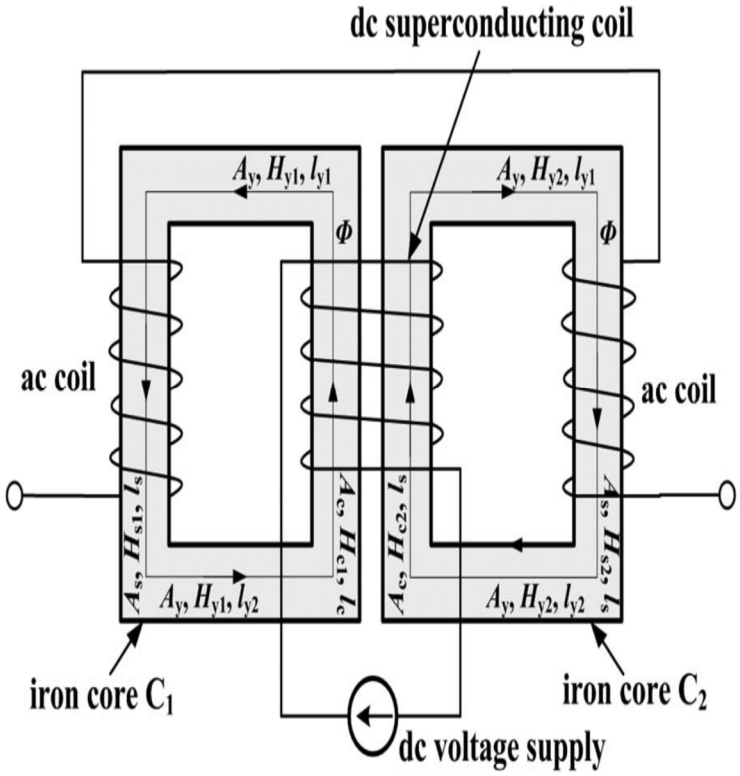

Fig: 1 The saturation state of an iron-core superconducting fault current limiter.

The SISFCL architecture is rather weakly coupled in this study. The ac and dc coils are two separate components of the framework that can be employed separately (dc superconducting coil). In each of the two iron cores, distinct cross-sectional zones can be identified. Dc superconducting coils, for example, encircle the core, while ac coils connected to the system lower fault current. Because the three single-phase SISFCL models have identical electromagnetic transients, only one scenario is explored in this study. Failure to correctly terminate the fault current could cause conductors and oil-filled equipment to catch fire or explode.

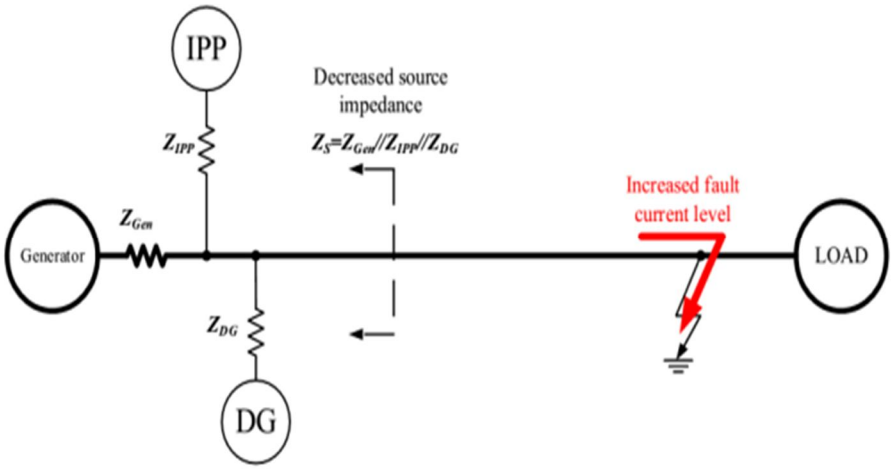

Fig: 2 Paralleling IPP and DG lowers the source impedance of the power system and increases the risk of a fault current.

Circuit breaker upgrades, current limiting reactors, and sequential breaker tripping are all instances of bus splitting that can minimise fault currents. Each strategy's advantages and disadvantages can be summarised as follows: outperforms them all, as demonstrated in the graph below.

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Solution/ method	Advantage	Disadvantage	Relative cost	Relative cost to SFCL
New sub station	Provides for future growth	Expensive andlengthyto install	Most expensive	SFCL is less expensive
Bus splitting	Separate sources of loadcurrent	Separate sources of load current from load centres and undermines system reliability	Highifsplit bus is not installed	SFCL less expensive
Multiple circuit breaker upgrade	Mostdirect solution with no adverse sideeffects	Difficult to schedule outages; bus work reinforcement also needed	High to medium, depending onnumber ofbreakers	SFCL less expensive thanmost multiple breaker upgrades
Current limiting reactor	Easy to install	Voltage drop and power losses	Mediumto low	SFCL cost higher
Sequential breaker tripping	No major hardware installation involved	Expands impactoffault towiderrange of system	low	SFCL cost higher

Table 1

Fig: 3 In contrast to SISFCL, typical techniques As a result of the current state of affairs.

SFCLs (superconductive fault current limiters) have been recommended as a possible method for limiting the excessive power outage.

There are quite a few of them. There are fault current limiters for superconducting systems: quench and nonquench. The quench-type SFCL's superconducting material converts to conductor during a failure [3]. The quench-type SFCL has two issues: delays in fault response and long recovery durations. The SISFCL is a nonlinear SFCL that does not require a quench since the permeability of magnetic cores is nonlinear. Once an issue has been detected and isolated, the SISFCL can respond quickly and reestablish regular operations. See Section 2 for SISFCL's theoretical analysis.

In the electricity business, voltage swings and short circuit concerns have become a major issue. Voltage sags are common in power systems when a single line to ground fault occurs. The use of sensitive and critical load classes makes a significant contribution. System flaws cause a drop or surge in voltage over the entire power system, or even only a portion of it. Harmonics, voltage transients, and flicker are all issues with voltage quality.

[6] It's impossible to predict when and how long voltage drops of up to 0.9 p.u. will occur. Balanced and unbalanced voltage sags exist, with the former being mostly determined by the voltage loss. Two of the most prevalent causes of voltage sags are large motor loads starting up and power system difficulties. Voltage sags, in particular, are a threat to the power's quality. Voltage swells can last anywhere from a half-cycle to a minute if the frequency is high enough. Voltage sags are more prevalent than voltage spikes caused by rapidly turning off or re-energizing capacitor banks. The system may be shut down or fail as a result of these disturbances, resulting in enormous voltage and current imbalances. As a result, we'll require a specific power device called a dynamic voltage restorer, which we'll talk about in section 3. DVR is your best bet if you're seeking for the best solution for voltage sag and swell correction in a FACT device for the following reasons.

In terms of the fundamental schematic, magnetic circuits C1 and C2 satisfy (1) according to the law of the magnetic circuit, as shown in Fig. 1.

$$H_{s1}l_s+H_{y1}l_y+H_{c1}l_c=N_{ac}i_{ac}+N_{dc}i_{dc}=F_1 \quad (1)$$

$$H_{s1}l_s+H_{y2}l_y+H_{c2}l_c=N_{ac}i_{ac}-N_{dc}i_{dc}=F_2 \quad (2)$$

Each magnetic circuit has three cylinders (ls, ly, and lc): one for the yokes, one for the side cylinders, and one for the core.

$$l_y = l_{y1} + l_{y2}$$

The turns and AC and dc winding currents are both Nac and Ndc, and the rotor core magnetomotive forces are F1 and F2, respectively.

As a result, the turns and currents of the ac and dc windings are represented by Nac and Ndc, respectively, and the magnetomotive forces in the two cores are represented by F1 and F2. According to the equivalence principle, the core can be satisfied.

$$N_{ac}i_{ac}+N_{dc}i_{dc}=N_{dc}i_{\mu 1} \quad (3)$$

$$N_{ac}i_{ac}-N_{dc}i_{dc}=N_{dc}i_{\mu 2} \quad (4)$$

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In this equation, there are two equivalent excitation currents. Because each core's cylinders have a different cross-sectional area, the magnetic field intensity of each iron core is different. For convenience of use, the excitation currents from the two cores can be divided down into three independent component sections.

$i_{\mu 1} = i_{\mu 1.s} + i_{\mu 1.y} + i_{\mu 1.c}$ (5)

$i_{\mu 2} = i_{\mu 2.s} + i_{\mu 2.y} + i_{\mu 2.c}$ (6)

There must also be the following circumstances:

$H_{s1} l_s = N_{dc} i_{\mu 1.s}, H_{y1} l_y = N_{dc} i_{\mu 1.y}, H_{c1} l_c = N_{dc} i_{\mu 1c}$ (7)

$H_{s2} l_s = N_{dc} i_{\mu 2.s}, H_{y2} l_y = N_{dc} i_{\mu 2.y}, H_{c2} l_c = N_{dc} i_{\mu 2c}$ (8)

The nonlinear B-H curves of the three distinct iron cores determine the three identical excitation currents i1.s, i1.y, and i1.c (or i2.s, i2.y, and i2.c). According to earlier study, in Figure 4, we have illustrated the analogous magnetic circuit.

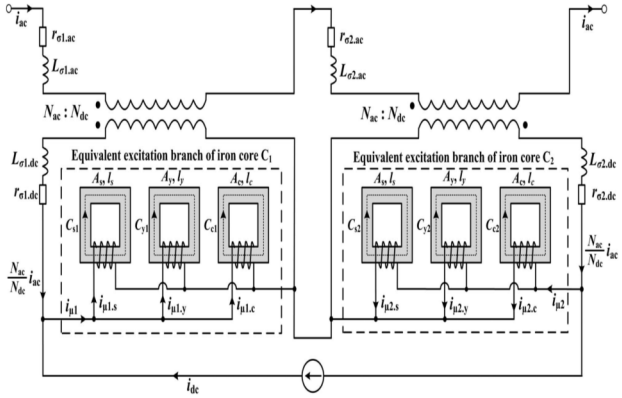

Fig: 4 A magnetic circuit is formed when two iron cores are connected together.

There are three current-limiting inductors in the SISFCL, each with a value of Lμ.

$L_{\mu} = L_{\mu 1} + L_{\mu 2} = (L_{s1} // L_{y1} // L_{c1}) + (L_{s2} // L_{y2} // L_{c2})$ (9)

Fig. 4 A coiled iron core is shown in [2] with its equivalent inductance L.

$$L = \frac{N^2 \mu A}{l}$$ (10)

Turns (N) of the coil Cross-sectional area, average travel distance, and permeability are all factors to consider here. It is required to accurately predict the magnetic permeability of each iron core in order to calculate current-limiting inductance L. There are a number of ways to implement the SISFCL electromagnetic transient simulation. To determine MMF F1 and FF2 at any time, all four necessary parameters must be known in advance of the simulation. The magnetic flux of C1 and C2 iron cores can be approximated using nonlinear equations based on the MMF values of F1 and F2. S1, s2, y1, y2, and C1 and C2 can also be extracted from the fundamental magnetization curve of the core iron. Finally, the current-limiting inductance L can be calculated using the equation (9).

Fig. 5 shows a Matlab simulation programme in action. Newton's method can be used to compute the flow.

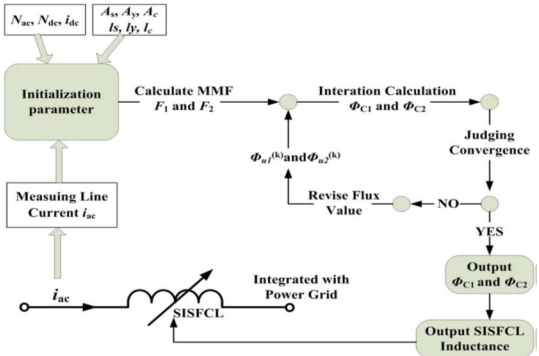

Fig: 5 Implementation of a Matlab/Stateflow algorithm. The parameters for the transmission line were culled from [6].

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A nonlinear equation solution and magnetic circuit analysis were used to simulate SISFCL transient performance during short-circuit failures. In the simulation, the values of Ndc are 660, Ac, 0.8 m2, Ay, and 0.40 m2. Single-phase-to-ground failure was discovered in under 0.1 seconds. Magnetic forces F1 and C1 and magnetic flux C2 were depicted in Figure 5 for SISFCL's two iron cores. Magnetic flux in the two iron cores before the fault was discovered was roughly 3.96 105 (A • turns) and 1.298Wb. By utilising a variable inductor, which changes in response to current, the model diagram depicted in Figure 6 can be reproduced Low impedance during normal operation and prominent function when a defect make the switch an essential component of any control logic design. We employ a random number generator to change our inductance depending on the severity of the malfunction..

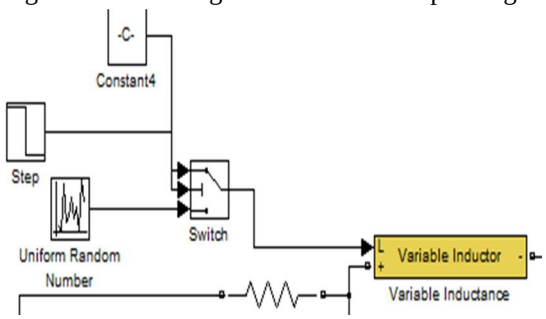

Fig: 6 Using a control circuit in Simulink, the model's inductance may be varied.

III. DYNAMIC VOLTAGE RESTORERS

The major function of this DVR is to detect voltage decreases and then inject the desired voltage amount in series with the supply using an injection transformer. In most cases, it's placed at the point of common coupling between the supply and the critical load feeder (PCC). The DVR can also handle voltage sags and surges, line voltage harmonics, transient voltages, and fault current limits.
For a DVR, the IBT, control and protection systems for harmonic filter storage devices are shown in Figure 7. power supply that converts DC to AC.

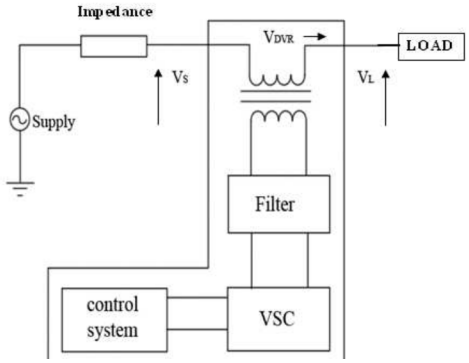

Fig: 7 DVR's basic structure

The DVR has three modes of operation: protection, standby, and injection/boost.
This can be caused by a short or considerable inrush current. bypass switches must be used in isolation from other systems in order to divert current away from the DVR and protect it from overheating (will be closed).
Devices enter standby mode when the VDVR is set to zero. The converter shorts the booster transformer's low-voltage winding during standby mode. In this mode of operation, the primary of the transformer receives the whole load current, and the semiconductors are not switched.
Virtual Disk Recorder (VDVR) mode 0: Injection/Bosser To compensate for supply voltage fluctuations, the DVR activates the booster transformer in the Injection/Boost mode.
PWM and PID controllers are used to control a voltage source converter (IGCT) in the simulink diagram of a dynamic voltage restorer. When used in conjunction with power electronics and a tiny DC reactor, voltage loss in the FCL circuit can be greatly reduced. A switching pulse is generated when the relational operator compares the reduced PCC voltage to a reference voltage value, which is detected by sensors.

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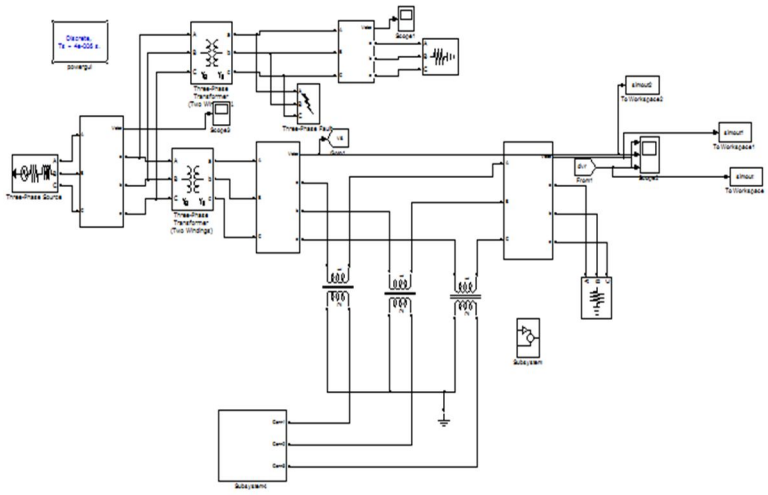
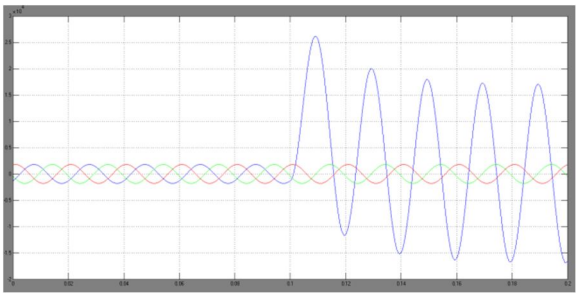


Fig: 8 Simulink can be used to model the DVR.

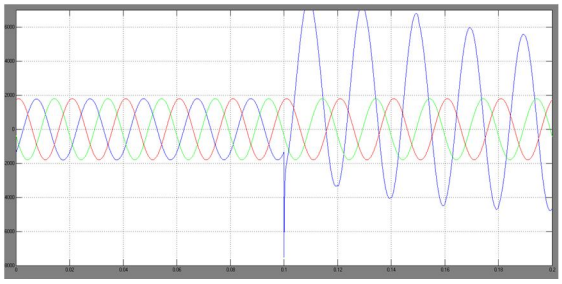
IV. SIMULATION RESULTS AND ANALYSIS

A. Current Limitation

In the case of a single phase to ground fault, as shown in the simulation results in fig. 9(a), our proposed sisfcl is not present in the system. By adding SISFCL, the fault current is capped at nearly 7k amps (b). As depicted in the diagrams, there are two waveforms: the MMF and Flux waveforms.



(a)



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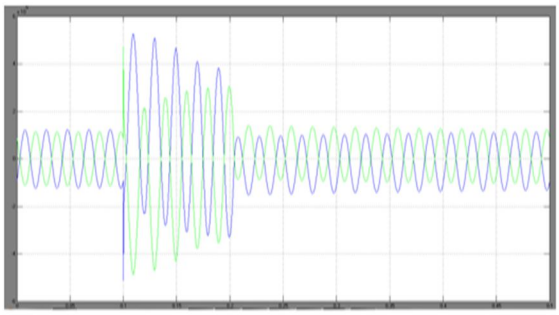

(c)

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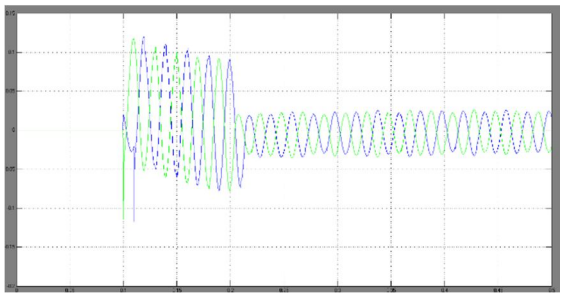
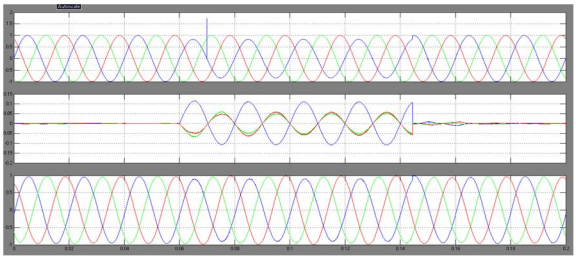


(d)

Fig: 9(a) MMF waveform (c) Flux waveform (d) LG fault with0ut SISFCL (b) LG fault with SISFCL (c)

DVRs are able to handle a wide range of fault conditions, as demonstrated by the simulation results shown in Fig. 10.



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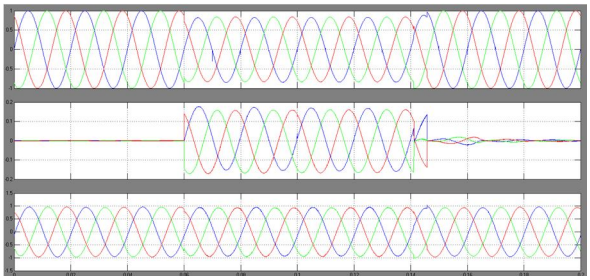

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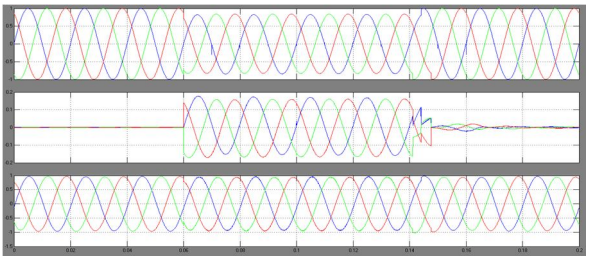

(g)

Fig: 10 (e) Single line t0 gr0und fault with DVR (f) LLL fault with DVR (g) LLLG fault with DVR.

V. CONCLUSION

SISFCL transient behaviour was studied using a new equivalent magnetic circuit derived from the mmf and flux relations of two iron cores. Using Newton's iteration method, flux and current limiting inductance can be calculated. During faults, voltage swings were frequently seen, and DVR was provided as a remedy.

Fault current limiters SISFCL and DVR were determined to be the most successful in lowering shunt currents, while DVR was the most efficient in rectifying voltage variations in their category. This method has been demonstrated to be accurate because to SISFCL and DVR. In real-time applications, the SISFCL and DVR combo can be used to construct both current and voltage controllers.

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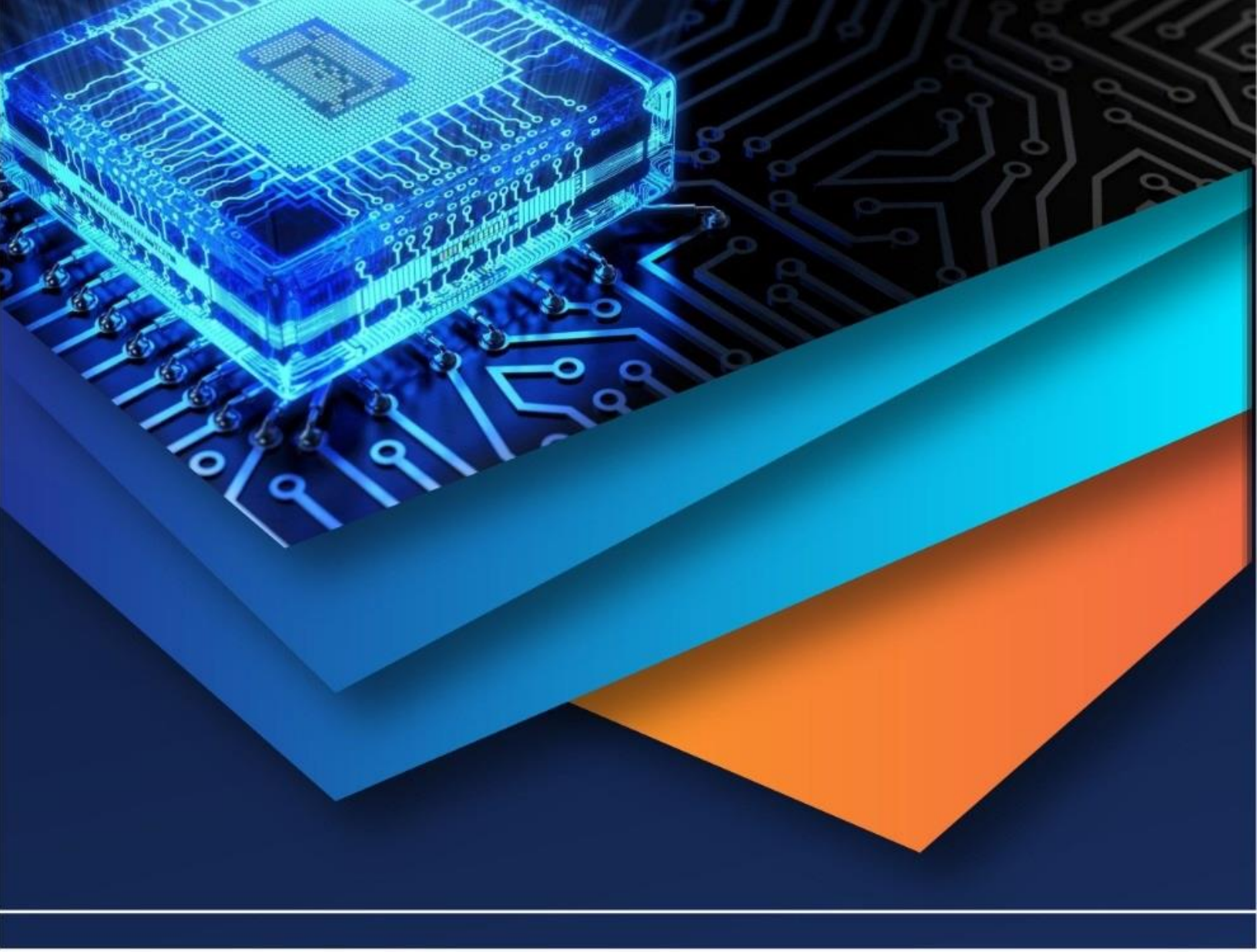

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