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Research Article

Literature Review of Earth Fault Self _Extinguished Control System using Petersen _Coil

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ABSTRACT

This study analyzes and classifies a set of research related to Petersen's file and control techniques in electrical distribution systems. It is a coil with an iron core installed between the transformer neutral and the ground and is used to limit the value of the ground fault current that flows when a ground fault occurs in the lines. The coil is designed with tapping to adjust the coil reactance with the system capacity. These researches aim to improve the performance and stability of electrical networks by developing new techniques for measuring insulation parameters, controlling ground resistance, and using numerical simulation to analyze the behavior of grounding systems. The focus was on fault detection techniques, ground fault protection, and reducing harmful arc currents. The recent developments in the use of smart and flexible technology to improve the response of networks to faults and increase the reliability and safety of electrical systems were also reviewed. The study concluded that advanced technologies and comprehensive analysis of these researches contribute to enhancing the performance and efficiency of electrical networks, reducing risks and improving the sustainability of energy supplies.

Keywords: Earth Fault, Petersen Coil, self _extinguished control system.

INTRODUCTION

Electrical distribution systems play a vital role in ensuring a continuous and reliable power supply. Among the essential components in these systems, the Petersen coil comes as an effective tool for controlling ground currents and reducing the risk of faults[1]. The asymmetric distribution system suffers from multiple challenges related to ensuring network stability and operating efficiency, especially in the presence of fault currents and electric arcs. Therefore, ongoing research seeks to improve the performance of these systems by developing new techniques for measuring insulation parameters, controlling ground resistance, and using numerical simulation to analyze the dynamic behavior of grounding systems [2].

In this paper, we review a set of research and studies that focused on the development and improvement of Petersen coil technologies and electrical distribution systems. The technical innovations and advanced analysis tools that have been used to provide effective solutions to ground fault and electric arc problems are highlighted. We also discuss future trends in this field, with a focus on the use of smart technology to improve the response of networks to faults and increase their reliability and safety.

This study represents an important research effort that seeks to provide an in-depth understanding of advanced grounding and control techniques, which enhances the efficiency of electrical networks and reduces the risks associated with electrical faults. In doing so, we contribute to achieving higher levels of security and sustainability in energy supplies, which benefits various economic and industrial sectors.

EARTH FAULT

Earth fault are a condition that occurs when a live conductor in a power system is connected to the ground, either directly or through a certain resistance, causing electric current to flow to the ground. These faults are common problems in power grids, and can cause power outages, serious accidents, and negative effects on the stability of the network [3]. There are several types of earth fault, which I will explain below:

1. Direct earth fault occur when a live conductor is connected directly to the ground, either due to erosion of the insulators, or the conductor is exposed to external factors such as falling trees or animals crossing the wires. This type of fault causes a large flow of electric current to the ground, which can cause serious damage to equipment and power outages[4].

2. Indirect earth fault occur when there is resistance between the conductor and the ground, and the connection is not direct. They are often caused by partial damage to the insulators or moisture entering the cables. The current flowing in this type of fault may be less compared to direct faults, but it still poses a risk to the stability of the network[5]. 3. Low-current earth fault These faults occur when there is a low-current leakage to the ground through corroded insulators or wet areas. These faults are smaller in current and may not be detected quickly, but they cause long-term power loss and affect the efficiency of the system[6].

4. Transient earth fault occur for a short period and then disappear, and are often caused by temporary factors such as moving trees or snow. They can cause short-term disturbances in the network, but do not cause permanent damage[7].

5. Balanced and unbalanced earth fault Balanced faults: occur when all phases are connected to the ground equally, and this type is rare in electrical networks. Unbalanced faults: occur when one phase is connected to the ground and the other is not, and this type is more common, and leads to an imbalance in the electrical balance of the network[8].

Over time, the insulators that protect electrical conductors can wear out, increasing the likelihood of them connecting to the ground. Storms, strong winds, snowfall, or falling trees can cause conductors to connect to the ground. Maintenance errors or improper handling of equipment can cause earth fault. Sometimes, small animals can cause wires to touch ground. Protection systems are designed to quickly locate these faults and take appropriate action to extinguish the faults and prevent their negative impact on the electrical network[9].

AUTONOMOUS GROUND FAULT ISOLATION

The self-control in extinguishing earth fault is a concept that refers to control systems capable of detecting earth fault and handling them automatically without the need for immediate human intervention. This system relies on the use of specific equipment such as the Petersen Coil, which is connected between the system neutral and the ground, where it works to reduce the current flowing to the ground in the event of a ground fault[10].

When a ground fault occurs, the Petersen coil cancels the ground current by producing an opposing current, which limits the effect of the ground fault and helps prevent it from developing into a major fault. This system works to extinguish the fault automatically, as it restores the balance of the system and prevents the spread of excess current. Thus, the system is designed to achieve a quick and accurate response to any ground fault, making it able to protect the network and reduce potential losses[11].

The self-control in extinguishing earth fault system has significant benefits in enhancing the safety and reliability of electricity networks, including:

1- Improving electrical safety: When earth fault occur, these faults can cause serious damage to personnel and equipment. Thanks to the autonomous control system, the fault is quickly contained and the energy that may reach the ground is reduced, which reduces the risk of electrical shocks and fires[12].

2- Improving the reliability and stability of the network The autonomous control system can prevent power outages resulting from earth fault, by reducing the impact of the fault and dealing with it effectively. This helps ensure continuity of operation without affecting other parts of the network[13].

3- Reducing maintenance and repair costs The autonomous control of extinguishing earth fault reduces the wear and tear and damage that may occur to electrical equipment as a result of faults. This helps reduce the need for costly maintenance or frequent repairs, which reduces operating costs in the long run[14].

4- Quickly detect faults and accurately locate them: Thanks to the reliance on automatic detection systems, the location of the fault is quickly determined, which facilitates repair operations and reduces the time of power outages. This rapid response ability improves the efficiency of the network and prevents the problem from worsening[15].

5- Positive impact on the environment: By containing the excess current and extinguishing earth fault quickly, the system reduces the possibility of fires or leakage of harmful substances, which reduces negative impacts on the environment[16].

In general, the ground fault control system is an advanced technology that aims to make power grids safer and more reliable, protecting equipment, reducing costs, and ensuring continuous operation with high efficiency[17].

PETERSEN COIL

Before A Petersen coil, also known as a grounded neutral coil, is a device used in electrical distribution networks to mitigate the effects of earth fault. The coil is connected between the neutral of the network and the ground, and works to compensate or cancel the current generated by the ground fault by producing an opposing current[18].

When a ground fault occurs in the network, a ground current is generated due to one of the phases coming into contact with the ground, causing a high current that can cause damage to equipment and disturbances in the network. In this case, the Petersen coil works to generate a current that opposes the ground fault current. The coil provides an inductive reactance designed to roughly match the parasitic capacitance of the electrical network, which results in equalizing the current flowing to the ground and reducing it to safe levels[19].

The Petersen coil plays a vital role in mitigating the effects of earth fault through key mechanisms, including:

Reducing the ground current generated by the fault: The current generated by the coil equalizes the current flowing to the ground when the fault occurs, reducing or even canceling the ground current. This mitigates the impact of earth fault, preventing overcurrents that could cause corrosion of insulators or damage to electrical equipment[20].

Preventing immediate shutdown of the electrical network: By mitigating the fault current, the Petersen coil allows the network to continue operating without immediate interruption. This means that the network can continue to operate for a short period, giving the maintenance team the opportunity to locate and address the fault without immediate impact on the stability of the network[21].

Reducing the risk of fires and explosions: In the event of large earth fault, high ground currents can cause conductors to overheat, increasing the risk of fires or explosions. By reducing the current flowing to ground, the Petersen coil helps prevent these hazards and maintains the overall safety of the network[22].

Improving the level of electrical insulation: By reducing the ground current, the Petersen coil reduces corrosion of electrical insulators, which increases the life of the network and reduces the need for frequent maintenance. This contributes to increased system efficiency and reduced operating costs[23].

Easily locate the fault: Petersen coil helps reduce the confusion that occurs in the system when a fault occurs, making it easier for maintenance teams to accurately and quickly locate the fault, thus effectively addressing the problem[24].

EARTH FAULT EXTINGUISHING SYSTEM USING PETERSEN COIL

After Integrating a Petersen coil into power grids requires careful design and evaluation of grid parameters to provide effective protection against earth fault. The Petersen coil is integrated into the grid by connecting it to the neutral grounding of the grid transformers, making it capable of sensing the ground current generated in the event of earth fault[25].

First, the parasitic capacitance of the system must be determined, which includes the capacitance between the conductors and the ground. Based on this capacitance, the reactance value of the Petersen coil is chosen to be able to compensate for the current generated by the ground fault[26].

The Petersen coil is installed in the main or substations and connected to the neutral of the system. Connecting the coil to the neutral allows it to control and react to the ground current when a ground fault occurs[27].

The reactance value of the coil is adjusted to be close to the parasitic capacitance value of the system. This balancing ensures that the current generated by the coil is equivalent to the ground current, which contributes to canceling or reducing the effect of the ground fault[28].

In addition to the Petersen coil, monitoring and control systems can be added that help to sense the fault immediately and operate the system, allowing for a quick and effective response[29].

Prior to full system commissioning, comprehensive testing should be performed to ensure that the Petersen coil is compatible with the network's operating conditions and to identify any required modifications. Toolbar[30].

LITERATURE REVIEW

[1][10][31][33] have proposed new methods for detecting earth fault. [1] in (2009) presented an interpolation algorithm to calculate the resonant frequency of distribution systems. The insulation parameters (including ground capacitance, leakage conductivity, damping coefficient, and dissipation factor) are measured by the injected resonant signal. The measured insulation parameters are then applied to the Petersen coil tuning. The proposed measurement method for insulation parameters is simple, convenient, accurate, and has been tested in real time without power supply interruption. [10] in (2017) presented a new method for detecting fault feeders, based on the singular value summation algorithm of time-frequency matrix (TFM) and polarity distribution matrix (PDM). By applying the band-pass filter of the Hilbert-Huang transformer and transforming the waveform into the waveform of the zero-sequence transient current of each feeder, the TFM and PDM can be generated, which are analyzed by singular value decomposition (SVD). In (2022) [31] presented a new expert system that uses transient current measurement to ground the cable screen. The developed system allows to locate the ground fault in underground cables and mixed lines, but the system had many drawbacks. In order to operate properly, the previously developed system requires a basic component - 50 Hz of the measured zero-sequence cable core current and the cable screen ground current. Due to the very large area of the distribution feeder, often in the range of tens of kilometers or even about a hundred kilometers, and the many possible causes of earth fault, it is very difficult to locate the ground fault. In (2022) [33] also presented a method for detecting earth fault in the compensated medium-voltage network, which can be used in particular in fault current indicators, but also in standard protection devices. The method is based on the adaptation process of the zero-sequence current protection setting, with the adaptation factor depending on the current value of the zero-sequence voltage.

Some researchers have come to the side of simulation [2][3][19] and computer systems. [2] in (2011) presented a new control technique using MATLAB for the ground resistance at the neutral point in the thesis by controlling the IGBT power electronics duty cycle, as the ground resistance control systems with continuously variable reactor, excellent dynamic response, high control accuracy and residual fault current approaching zero, can reduce the possibility of accidents. In the same year (2011), [3] simulated and analyzed two types of Peterson coil regulators through RTDS, which is a computer device that provides the possibility of analyzing regulation, protection and control devices. In (2020), [19] presented an adaptive neural fuzzy inference system (ANFIS) that gave the best results in simulating POD, Fl, NN techniques for Peterson coil control.

The other group of researchers resorted to ground fault detection techniques [4] [15] [18] [23] [25] [26] [29] [30] [33] [35] [37] [38] [39]. In (2010), [4] designed a single-phase ground fault detection technique by determining the maximum derivatives of zero-sequence currents. In (2019), [15] presented an operating algorithm based on discrete wave transform, where he used a large number of waveforms simulated by PSCAD/EMTDC software to evaluate earth fault in power distribution systems. In (2020), [18] presented a new fault diagnosis algorithm for electromagnetic actuators (EMA). The equivalent slope of the load current is determined as the fault diagnosis threshold by theoretical analysis of the variation characteristics of the current in the modulation. In (2021) [23] analyzed the insulation parameters of medium voltage power lines, the Petersen coil parameters used to treat the neutral in the medium voltage electrical network and the resistance value at the fault location on the fault current in the event of a single-phase fault by using the symmetrical component method to calculate the fault current. In (2021) [26] presented a methodology for managing neutrals in medium voltage systems and improving the ground fault response through common international practices. In (2022) [29] presented the effectiveness of restricted ground fault protection and differential bias protection against ground fault in transformer windings. Ground fault is one of the faults that occur in the windings of a power transformer and its magnitude depends on how the neutral is connected and the location of the fault. As for a transformer connected to the neutral ground resistance (NER), as the fault moves towards its neutral, the magnitude of the fault current decreases and the fault detection decreases, thus limiting the proportion of windings that can be protected. To overcome this problem, restricted ground fault is used. [30] also presented fault diagnosis and fault-resistant corrective control for a class of asynchronous series machines. [33] presented a method for detecting earth fault in compensated medium voltage networks using fault current indicators. [36] in 2022 also presented a method for protection against restricted earth fault in low-impedance grounded systems with inverter-based resources. Then, [35] in (2023) presented a method for locating high-resistance earth fault in distribution cables using the reflection coefficient spectrum.

The penultimate group of researchers have attempted to suppress ground fault arcs [11][14][20][21][28], where [11] in 2017 designed an active ground fault arc suppression device to compensate for all active, reactive and harmonic components of the ground current. This was followed by [20] in 2020, where zero-sequence voltage regulation was used to design a flexible ground fault arc suppression device. [21] then used arc suppression coils to reliably detect earth fault and then determine their direction. In 2022, [29] built a nonlinear equivalent model through which he analyzed and detected high-resistance arc faults in active distribution networks.

The last group of researchers[12][16][17][23][25][27][32] exploited resonant grounded systems in their research. In 2017, [12] located the fault using adaptive control of the neutral-to-ground impedance in a resonant grounded system. In 2019, [16] developed a new method for detecting earth fault in resonant grounded systems using advanced techniques. In 2018, [17] proposed a new method for locating earth fault in resonant grounded systems based on distributed modulation and compensation modulation. After suppressing the permanent single-phase ground fault arc, simulations and experiments have proven the feasibility of the proposed fault locating method. In 2021, [23] used resonant grounded isolation transformers to prevent fires caused by power line faults. In the same year, [25] presented an adaptive slide model controller for REFCLs in resonant grounded power distribution networks to mitigate the effects of forest fires in power lines by compensating the fault current with the faulted phase voltage. The application of forest fire mitigation in power lines using REFCLs with residual current compensation (RCC) inverters requires very fast response from the controller used for these inverters. In 2020, [27] presented a new method for selecting a single-line-to-ground (SLG) fault feeder in a resonant grounded power distribution system based on the compensation characteristic of the extinction coil at different frequencies. The proposed method is not susceptible to the polarity reversal installation of the device. In 2023, [32] presented a comprehensive literature review of fault compensation control techniques in resonant distribution networks and concluded that power line faults are responsible for major forest fires worldwide, as electrical arcs generated by earth fault are a common cause of such fires. Grounding techniques (primarily resonant grounding) used in distribution substations and arc suppression devices play a crucial role in compensating fault currents in order to extinguish electrical arcs so that the potential for forest fires in power lines is greatly reduced. Although passive arc suppression devices (such as Petersen coils) are widely used to compensate for the reactive component of the fault current, the active component of this current is still large enough to start a fire in areas prone to forest fires where active arc suppression devices are recently used.

Table (1.1) the studies provided for earth fault.

Year	Studies	Method Use	Application
2009	[1]	Interpolation algorithm for calculating the resonant frequency of distribution systems	Measuring asymmetric distribution systems
2011	[2]	Use the Peterson coil to control the residual fault current within the allowable range.	Reduce the possibility of accidents Accelerate the self-extinguishing of the ground fault arc Improve the power quality
2011	[3]	Use of Real-Time Digital Simulator (RTDS)	Analyze the behavior of control, regulation and protection devices
2010	[4]	Faulty feeder detection and fault self-extinguishing by adaptive Petersen coil control	Extinguish arc and detect faulty feeder at the same time.
2011	[5]	A selective single-phase-to-ground fault	neutral un-effectively grounded systems

		protection	
2014	[6]	Comparison of restriking cable-earthfaults	isolated and compensated networks
2015	[8]	Petersen-coil and faulty-phase-earthing	linear (fixed ground fault) and non-linear (ground fault re-strike) impedances at the fault site.
2017	[9]	Measurement of currents in systems of power-system protection	single-phase earth faults and in automated control by arc-suppression reactors
2017	[10]	singular-value decomposition and fuzzy c-means in resonant grounding distribution systems	Features-clustering-based earth fault detection
2017	[11]	Principle and control design of active ground-fault arc suppression device	full compensation of ground current
2017	[12]	adaptive control of neutral-to-earth complex impedance	Fault location in resonant grounded network
2018	[13]	Control of the compensation mode of the capacitive currents of single-phase earth fault	measured parameters of a network zero-circuit
2019	[14]	A current compensation method for single-phase-to-earth fault	10KV distribution networks
2019	[15]	Discrete Wavelet Transform-Based Triggering Method	Single-Phase Earth Fault in Power Distribution Systems
2019	[16]	detecting single phase-to-ground faults	resonant-grounded systems
2018	[17]	Fault location method in resonant grounded networks	distributed modulation and compensation adjustment
2020	[18]	Design and implementation of a fault-tolerant magnetic bearing control system	novel fault-diagnosis of actuators
2020	[19]	Controlling Peterson coil through ANFIS	Optimization of detection of single line to ground fault
2020	[20]	zero-sequence voltage regulation	Principle of flexible ground-fault arc suppression device
2020	[22]	Resonant grounded isolation transformers	prevent ignitions from powerline faults
2021	[23]	Analysis of the influence of the insulation parameters of medium voltage electrical networks and of the petersen coil	single-phase-to-ground fault current
2020	[24]	transient-based earth fault protection system	unearthed meshed distribution networks
2021	[25]	Design of an adaptive sliding mode controller for rapid earth fault current limiters	resonant grounded distribution networks to mitigate powerline bushfires
2021	[26]	Optimising MV neutral treatment	earth fault detection, localisation and response
2020	[27]	Single-line-to-ground fault feeder selection considering device polarity reverse installation	resonant grounding system
2022	[28]	Nonlinear modeling analysis and arc high-impedance faults detection	active distribution networks with neutral grounding via Petersen coil
2022	[29]	Performance of Restricted Fault and Bias Differential Protection Against Earth Fault	Transformer." Journal of Physics: Conference Series
2022	[30]	Design and implementation of robust corrective control systems	permanent sensor faults
2022	[31]	Monitoring, detection and locating of transient earth fault using zero-sequence current and cable screen earthing current	medium voltage cable and mixed feeders
2023	[32]	A comprehensive review of control techniques for compensating the fault current	resonant grounded distribution networks: From the perspective of mitigating powerline bushfires

2022	[33]	Fault Current Passage Indicators in Medium-Voltage Compensated Overhead Networks	Improving the Efficiency of Earth Fault Detection
2022	[34]	Results from the new method for measuring the earthfault-distance	compensated and isolated networks
2023	[35]	High impedance grounding fault location method	power cables based on reflection coefficient spectrum
2022	[36]	Restricted Earth Fault Protection	Low-Impedance Grounded Systems With Inverter-Based Resources
2023	[37]	variable and a fixedable inductance in distribution grid in power	Detection of single line to ground fault and self-extinguishing
2023	[38]	Reducing the Effects of Repeated Ignition during Earth Faults	Compensated Medium Voltage Networks
2023	[39]	Optimize single line to ground fault detection	distribution grid power system using artificial bee colony

CONCLUSION

In this research, a set of studies and researches focusing on the Petersen coil and the various techniques used to improve the performance of distribution systems were reviewed. These studies showed multiple developments in the fields of measuring insulation parameters, controlling ground resistance, using digital simulation, fault detection techniques, and protecting electrical networks from electric arcs. Through a comprehensive analysis of these studies, the studies showed a remarkable development in insulation parameter measurement and control techniques in Petersen coils, which enhances the accuracy and efficiency of these systems in suppressing harmful currents and improving the stability of electrical networks. The importance of using digital simulation tools and electronic control in improving the performance of Petersen coils and the response of electrical systems to faults was highlighted. These tools enable the analysis of system behavior more accurately and provide innovative solutions to various challenges. The studies addressed advanced techniques for detecting faults and locating them with high accuracy, which helps improve the response of networks to faults and reduce the damage caused by them. The focus was also on ground fault protection and the techniques used in suppressing electric arcs, which contributes to increasing the reliability and safety of networks. The studies also addressed future trends in the development of grounding and control techniques, with a focus on the use of smart and flexible technology to improve the performance of electrical networks. This includes the use of intelligent algorithms such as ANFIS and ABC to develop more effective and efficient control systems.

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