IJARSCT

International Journal of Advanced Research in Science, Communication and Technology

International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal

ISSN: 2581-9429

Volume 5, Issue 3, November 2025

Impact Factor: 7.67

Leakage Current Measurement & Analysis for Arrester Life Prediction

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Abstract: *The Electricity is a most important resource that is required in day to day life. Due to increase in use of electronics, electricity distribution center has grown in number. Source of electricity is high voltage power stations which are required to protect using surge arrester. Over voltages occurring due to lightening leads to breakdown of surge arresters. This may lead to catastrophic failure. This effect is severe in high voltage power stations. Therefore it is important to protect element which makes the surge arrester. Power dissipation is one of the important characteristic which relates to the breakdown of the arrester. The main cause of power dissipation is the leakage current present in the element. Therefore to overcome the loss due to power dissipation and hence to protect the arrester from failures it is important to measure the leakage current flowing through the basic element which will help to protect the arrester in whole.*

Keywords: Electrical Power stations, surge arreseter, powerloss, lekage current, measurement

I. INTRODUCTION

In modern high-voltage power systems, surge arresters play a crucial role in safeguarding electrical equipment from transient overvoltages caused by lightning strikes or switching operations. These devices, commonly installed in substations, power plants, and railway electrification systems, ensure system stability by discharging surge currents and preventing insulation breakdown or equipment damage. Among various types, Zinc Oxide (ZnO)-based metal oxide varistors (MOVs) have become the preferred choice due to their superior non-linear voltage-current characteristics and high energy absorption capability.

However, the performance and reliability of surge arresters degrade over time due to factors such as aging, pollution, and thermal stress. A key indicator of this degradation is the **leakage current**, which increases as the arrester's insulation weakens. Continuous monitoring of this current not only helps assess arrester health but also enables predictive maintenance, minimizing unplanned outages. Conventional measurement methods, though effective for basic analysis, fail to capture high-frequency harmonics and transient behavior essential for precise fault diagnosis.

To address this limitation, the present work proposes a **microcontroller-based leakage current monitoring system** employing **Fast Fourier Transform (FFT)** for real-time spectral analysis. The system utilizes the **STM32 Blackpill (STM32F401CCU6)** microcontroller for high-speed signal acquisition and processing, complemented by signal conditioning circuits and an LCD display for on-site visualization. This compact and cost-effective design facilitates real-time monitoring, harmonic detection, and improved arrester condition assessment, contributing to enhanced reliability and safety in power transmission and distribution networks.

II. LITERATURE SURVEY

[1] J. Smith and A. Kumar, *"Analysis of Surge Arrester Characteristics for Transformer Protection,"* IEEE Power Systems Eng. Conf., New Delhi,2014.

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Studied surge arrester characteristics for transformer protection. Focused on insulation coordination and overvoltage control.

[2] M. Lee and P. Rao, *"Distribution of Surge Arrester Behavior due to Lightning Induced Voltages,"* IEEE ICHVE, Singapore, 2015. Analyzes arrester response to lightning surges and transient voltage distribution.

[3] K. Tanaka et al., *"Performance Evaluation of ZnO-Based Sheath Voltage Limiters,"* IEEE CEIDP, Tokyo,2016. Compares ZnO and SiC arresters, showing ZnO offers higher energy absorption and reliability.

[4] H. Gupta et al., *"Material Characterization of ZnO Varistors for Surge Protection,"* IEEE Energy & Electronics Conf., Bangalore, 2017. Studies additive effects on ZnO varistor grain boundaries and V–I characteristics.

[5] R. Kulkarni and T. Bose, *"Improved Protection of Distribution Transformers Using Surge Arresters,"* IEEE ICPES, Mumbai, 2017. Proposes improved arrester connection schemes to reduce insulation stress.

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[7] P. Verma and R. K. Sharma, *"Estimation of Surge Current and Life Expectancy of ZnO Arresters,"* IEEE EPQU, Warsaw, 2019. Evaluates surge current effects on arrester life and thermal endurance.

[8] D. Patel et al., *"Enhanced Grounding and Protection Techniques for Transformer Surge Arresters,"* IEEE PEDES, Chennai, 2020. Focuses on grounding improvements for better transformer surge protection.

III. EXISTING SYSTEMS

With the growing use of electrical power distribution at primary voltages, proper surge protection for step-down transformers has become essential. Surge arresters play a critical role in safeguarding equipment by providing overvoltage protection and maintaining insulation coordination. Research studies have analysed surge arrester behavior under lightning-induced voltages, highlighting the importance of ZnO-based arresters due to their high non-linear characteristics and superior performance compared to traditional materials. ZnO elements, composed mainly of zinc oxide with additives like Bi, Co, Mn, and Sb, exhibit excellent voltage-current properties that make them highly reliable for surge protection applications.

Further studies emphasized the role of lightning arresters in protecting distribution transformers, as inadequate connections often result in flashovers despite the arrester's high capability. Effective grounding and improved connection methods were proposed to enhance transformer protection. Additionally, research on high-voltage power systems showed that overvoltages from faults, switching operations, or lightning could reach several times the normal operating voltage, posing severe insulation stress. Surge arresters with variable impedance were recommended to mitigate such surges.

Fig. 1 Existing Analog surge counter

IV. PROPOSED SYSTEM

The proposed system aims to continuously monitor the leakage current of a Zinc Oxide (ZnO) surge arrester to ensure it operates within safe limits. As the arrester ages or degrades, leakage current increases, which can be detected early through this system. It measures and displays real-time voltage, current, and power on a 16×2 LCD, helping engineers easily assess arrester health. Additionally, the system performs signal analysis to detect harmonic components—

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especially the 3rd harmonic—to identify non-linear behaviour or internal faults. The data will be presented in both numerical and graphical formats, supporting predictive maintenance, reducing manual inspections, and improving the overall reliability and safety of the electrical system.

Fig. 2.Experimental setup

V. SYSTEM ARCHITECTURE

The system architecture for the proposed leakage current monitoring setup of a ZnO surge arrester consists of several key stages working together to ensure accurate measurement and analysis. The process begins with a **series resistor**, which converts the leakage current from the surge arrester into a proportional voltage signal. This voltage then passes through a **2nd-order Butterworth low-pass filter** that serves as an anti-aliasing filter with a cutoff frequency of 220 Hz and an attenuation rate of –40 dB/decade. The filter removes unwanted high-frequency noise, providing a clean voltage signal within a range of approximately –1.05 V to +1.05 V.

Next, the filtered signal is fed into a **level shifter circuit** based on a summing amplifier, which adds a DC reference voltage (Vref = 1.65 V) to shift the signal into the 0–3.3 V range suitable for the microcontroller's analog input. The conditioned signal is then processed by the **STM32F401CCU6 microcontroller**, which performs analog-to-digital conversion with a 12-bit resolution and a 0–3.3 V input range. The microcontroller also carries out **Fast Fourier Transform (FFT)** operations with a 1 kHz sampling rate and 1024-sample FFT size to analyze harmonic components of the leakage current, particularly the 3rd harmonic that indicates non-linear behavior or insulation stress. The microcontroller stores the measured data in its 512 KB flash memory and communicates the results through GPIO pins.

Finally, the processed parameters such as voltage, current, power, and frequency components are displayed on a **16×2 HD44780 LCD** in real time. This display allows engineers to easily monitor the surge arrester's condition without complex instruments. Overall, the architecture effectively integrates signal conditioning, digital processing, and user display to provide a reliable, real-time health monitoring system for surge arresters.

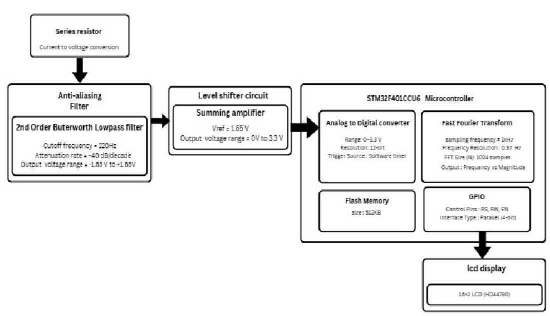

Fig. 3.block diagram

DOI: 10.48175/IJARSCT-29855

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VI. RESULTS AND DISCUSSION

The LTspice simulation results validate the effective performance of the designed analog front-end circuit for surge arrester leakage current monitoring. The transient analysis across the sensing resistor confirmed accurate current-to-voltage conversion, producing a clean 50 Hz sinusoidal signal of ±0.6 V, consistent with theoretical calculations. The 2nd-order Butterworth low-pass filter provided a smooth output with an amplified amplitude of ±1.05 V and a gain of approximately 1.74, while effectively eliminating high-frequency noise and harmonics.

The level-shifting stage successfully added a 1.5 V DC offset, shifting the waveform to a range of 0.45–2.55 V—well within the STM32 ADC's 0–3.3 V input limit—without distortion. The AC analysis verified a cutoff frequency near 200 Hz, with a flat passband and a roll-off rate of –40 dB/decade, confirming ideal Butterworth behaviour. Additionally, higher harmonic attenuation results showed a significant reduction, with the 9th harmonic suppressed by –12.54 dB and the 12th by –17.47 dB.

Overall, the simulation results demonstrate that the circuit accurately filters, amplifies, and level-shifts the leakage current signal, ensuring reliable and distortion-free input for digital sampling and further analysis in the proposed monitoring system.

VII. CONCLUSION AND FUTURE WORK

The project *"Leakage Current Measurement & Analysis for Arrester Life Prediction"* successfully developed a compact and intelligent system for real-time monitoring and analysis of leakage current in surge arresters. The system accurately detects current waveforms and harmonic components that indicate insulation degradation or faults. It integrates an analog front-end (current-to-voltage conversion, 2nd-order Butterworth filter, and level shifter) with an STM32F401CCU6 microcontroller that performs real-time FFT analysis using the CMSIS DSP library. Measured parameters such as leakage current magnitude and dominant frequencies are displayed on a 16×2 LCD, providing reliable and noise-free readings.

The hardware and software were validated through LTspice simulations and experimental testing, confirming accurate current detection, stable FFT performance, and strong noise immunity. The system achieved key technical goals such as clean signal conditioning, real-time digital analysis, custom PCB design, and low power consumption.

Future improvements may include IoT/cloud integration for remote monitoring, higher FFT resolution using DMA, and the use of AI or ML algorithms for predictive fault detection. The system can be expanded to multi-channel measurements, enhanced with graphical displays or web dashboards, and integrated with IEC 61850 smart grid standards. Further optimization for power efficiency, miniaturization, and automated protection mechanisms will make it more suitable for industrial and field applications.

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