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Modeling and Development of AC Power System Control and Protection with an Application Metal Oxide Varistors (MOV)

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Abstract. This paper presents a comprehensive approach to the modeling and development of AC power system control and protection, emphasizing the critical role of Metal Oxide Varistors (MOVs) in ensuring system stability and reliability. The study explores advanced techniques for controlling voltage and current within AC power networks, addressing challenges such as overvoltage conditions, transient suppression, and fault mitigation. A detailed model of MOVs is developed and integrated into the power system framework to evaluate their effectiveness in protecting sensitive equipment against voltage surges. Simulations and experimental validations are carried out to analyze MOV behavior under various operating conditions, demonstrating their dynamic response and protective capabilities. The results highlight the practical application of MOVs in enhancing power system performance, reducing equipment failure, and improving overall grid resilience. This research provides a foundation for further innovations in AC system control and protection, offering insights for engineers and researchers working in power system design and optimization.

1. Introduction

Power systems face numerous challenges, including voltage surges, transient overvoltage's, and harmonic distortions. These issues can lead to equipment failure, power outages, and economic losses. Effective protection and monitoring mechanisms are critical for ensuring the safe and efficient operation of AC power systems. Metal Oxide Varistors (MOVs), as nonlinear resistive devices, offer a robust solution to mitigate overvoltage conditions. This paper aims to provide a comprehensive framework for integrating MOVs into modern AC power systems(Harnden *et a*l., 1972).

AC monitoring and protection systems are paramount to the safety and efficiency of electrical system. MOVs (Metal Oxide Varistors) is used in this system to protect against voltage surges and transients. AC power system is prone to voltage fluctuations, which can affect the performance and reliability of electrical equipments. Monitoring and protection is of necessity to prevent damages(*BASICS OF POWER SYSTEM , PROTECTION AND INTRODUCTION TO POWER Author : Ajithkannan Sivakumar*, 2024).

This system gives effective protection in case of voltage transient or surges occurrence due to lightning strikes, switching operations or other external factors which can be harmful to sensitive equipment. It aids detecting and isolation of faults in an AC system which is crucial for maintaining operational safety. This involves monitoring parameters such as current, voltage, and temperature to identify any abnormalities or potential faults. Also an important part of this system is the Audible Alarm, which provides a loud and attention – grabbing sound, which can alert operators or nearby individuals in case of abnormal conditions or faults in the AC system. This can help in quickly identifying, addressing issues, and enhancing system safety. The loud sound ensures that people are alerted promptly, allowing them to take immediate action. This can be crucial in situations where quick response is needed especially switching the system from one power source to another. An indicator bulb is install on the system to signal when the main power supply is restored(Amer, 2022).

This research observed that most AC equipment have a short lifespan due to voltage fluctuations, power surges which if not quickly isolated from the system, can causes serious damage to the system. Over voltage conditions cannot be over - emphasized in this country, people losing their electrical Appliances which are expensively purchased which makes them results to using stabilizers that are not always affordable and too cumbersome to use as a protective device even for electrical companies, banks and hospitals(Yageo Group, n.d.).

AC monitoring and protection systems are designed to detect and mitigate abnormal voltage levels, transient over voltages, and voltage spikes. These systems typically consist of various components, such as sensors, monitoring circuits, and protective devices.

Monitoring involves real-time tracking of voltage, current, frequency, and power quality. Advanced monitoring systems use intelligent electronic devices (IEDs) and IoT-based sensors for data acquisition and fault detection(Bo *et al.*, 2016).

2. Design Analysis

Protective schemes in AC systems typically include circuit breakers, relays, and surge protection devices. Overvoltage protection is critical, as surges caused by lightning, switching operations, or faults can damage sensitive equipment.

2.1 Metal Oxide Varistor (MOV)

MOVs are semiconductor devices that exhibit a non-linear voltage-current characteristic. They are commonly used in AC systems for their ability to suppress voltage spikes and transient overvoltages. MOVs provide a low impedance path for excess voltage, thereby protecting sensitive equipment. MOVs are voltage-dependent resistors that exhibit high impedance at normal operating voltages and low impedance during overvoltage conditions. This characteristic makes them effective in clamping surges and protecting electrical equipment(Wang et al., 2018).

2.2 Types of Metal Oxide Varistors (MOVs)

There are various types of MOVs available, each with its own characteristics. Here are some of the common types:

Zinc Oxide (ZnO) MOVs: These are the most widely used MOVs. They have a high energy absorption capacity and can handle large surge currents. ZnO MOVs have a nonlinear voltage-current characteristic, meaning their resistance decreases as the voltage across them increases.

Silicon Carbide (SiC) MOVs: SiC MOVs have a higher surge current capability compared to ZnO MOVs. They are often used in high-power applications where greater protection is required. SiC MOVs have a higher clamping voltage and can handle higher energy levels.

Ceramic MOVs: Ceramic MOVs are compact and offer good thermal stability. They have a high energy absorption capacity and can handle fast transients. Ceramic MOVs are commonly used in electronic devices and circuits for surge protection.

Polymer MOVs: Polymer MOVs are made of conductive polymers and offer enhanced protection against electrical surges. They have low clamping voltages and fast response times. Polymer MOVs are often used in sensitive electronic equipment(Montano et al., 2004).

2.3 Principle of MOV operation

When the voltage is within the rated limits the resistance of the MOV will be very high and hence all the current flows through the circuit and no current flows through the MOV. But when a voltage spike occurs in the main voltage, it appears directly across the MOV since it is placed in parallel to AC mains. This high voltage will decrease the resistance value of the MOV to a very low value making it appear like a short(Bo et al., 2016).

This forces a large current to flow through the MOV which would blow the fuse and disconnect the circuit from the mains voltage. During voltage spikes the faulted high voltage will return to normal values very soon, in those cases, the duration of the current flow will not be high enough to blow the fuse and the circuit returns to normal operation when the voltage becomes normal. But every time a spike is detected the MOV disconnects the circuit momentarily by shorting itself and damaging itself with high current each time. So, if you find a MOV damaged in any power circuit it is possibly because the circuit went through many voltage spikes (Smith, J., et al 2022).

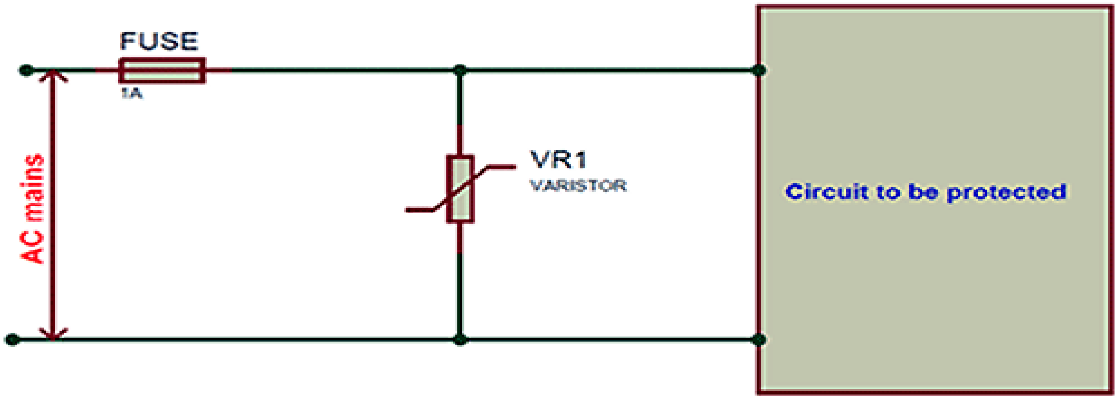

Figure 1: How to use a MOV in your circuit

2.4 V-I Characteristics of Metal Oxide Varistors (MOVs)

It has a strong surge absorption capability. In the 8/20μs waveform, MOV has a flow range from several hundred amperes to several tens of kilo amperes.

MOV's voltage range is from 18V to 1800V. The voltage accuracy is usually ±10%, which meets the application requirements from low voltages to high voltages:
MOV has various sizes. The diameter varies from 5mm to 53mm;
MOV has a two-way symmetrical breakdown voltage, which is commonly used for the protection of power lines or low-frequency signal lines;
MOV is an aging type device. When it is used for the protection of high-power power ports, it is often used in series with ceramic gas discharge tubes (GDT) or glass gas discharge tubes (SPG) so as to slow down the aging of MOV and extend its service life.

According to ohms law, the V-I characteristic curve of a linear resistor is always a straight line(Yageo Group, n.d.). but we can't expect the same in terms of a variable resistor. As it is in the below image, if there is even a small change in the voltage there is a significant change in current also.

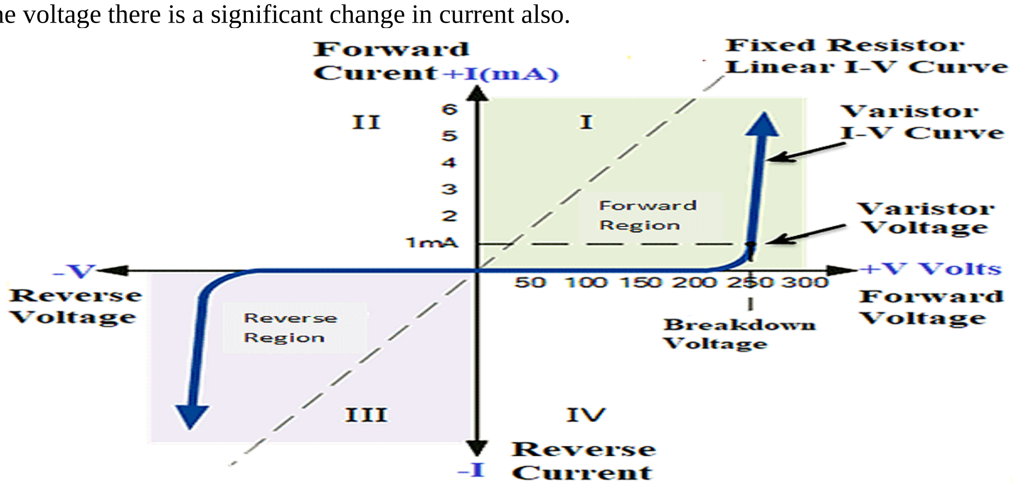

Figure 2: V.I Characteristics of Metal Oxides Varistors (MOVs)

2.4.1 Analysis of MOV's Parameters

Table 1 presents MOV parameter, which outlines valuable parameter that will needful in design and implementation of MOV(Amer, 2022).

Table 1: MOV parameter

Part Number		Maximum Allowable Voltage		Varistor Voltage	Maximum Clamping Voltage		Withstanding Surge Current		Maximum Energy (10/1000μs)		Rated Power	Typical Capacitance (Reference)
Standard	High Surge	V_{AC}(V)	V_{DC}(V)	V_{1mA}(V)	I_P(A)	V_C(V)	I (A) Standard	I (A) High Surge	(J) Standard	(J) High Surge	(W)	@1KHz (pf)
561KD14	561KD14J	350	460	560(504~616)	50	925	4500	6000	125	185	0.6	360

V AC /V DC: it is the AC effective value/DC voltage that can be applied continuously across MOV at a specified temperature. When it is selected, the maximum sustainable operating voltage of MOV V AC /V DC should be greater than or equal to the normal operating voltage of the circuits with a certain margin.
V 1mA: it is the voltage across MOV when a current of 1 mA flowing through MOV. The selection of the varistor voltage should refer to the equation V 1mA =K* Vp, K=(1.5~2). Its aging coefficient, varistor voltage tolerance and power quality should be considered. Vp: it is the voltage peak of the circuit. For example, the voltage peak is 310V for a circuit of 220VAC. The coefficient is taken from the range of 1.5~2. Then the varistor voltage should be selected as V 1mA =K* Vp=310*(1.5~2). The MOV to be selected can be an varistor of 470V~620V. Considering some extreme harsh environmental conditions, the voltage value of MOV can be higher under the premise of protection effects(*BASICS OF POWER SYSTEM , PROTECTION AND INTRODUCTION TO POWER Author : Ajithkannan Sivakumar*, 2024).

3. Methodology

In the circuit design for the AC monitoring and protection system, the system consists of the following section: AC section, DC section, Control section, and output protective section. All these sections are integrating to form a robust circuit that effectively monitors and safeguards the AC system.

3.1 AC Voltage Monitoring and Protection System: Transformer Design

These are the following values for designing transformer:
Efficiency 80%
Magnetic flux density $= B_M = 1 \; to \; 1.2 \; wb/m^2$3.2.1(a)
Current density 2.2 to 2.4 $wb/mm^2$3.2.1(b)
Design
Power rating = 50VA
Primary voltage = 220V
Secondary = 12V
Primary side Calculation: Primary winding current = $\frac{(Voltage\ rating)}{(primary\ voltage)} = \frac{50VA}{220} = 0.23A$
Size of primary conductor = $\frac{Current\ (I)}{Current\ density\ (j)} = \frac{0.23}{2.3} = 0.1mm^2$
Number of turns = turns per volt × volt
Turns per volts = $\frac{1}{4.44 \times B_{\max} \times f \times A}$ 3.2.1©
Area of bobbin = A=2.26inchm^2
Area of bobbin = A= 0.00145161m^2
By putting values
Turns per Volt =2.6 × 230 =600 turns
Total wire length = no of turns perimeter of bobbin = 600× $7inch$ = 4200inch =106m
Volume of conductor = Area × length = 0.1× 10^{-6} × 106m^3
Wight = density × volume
Density of copper = 8960
Wight = 8960 × 1.06 × 10^{-6} = Wight = 100

Secondary side Calculation: Secondary winding current = $\frac{(Voltage\ rating)}{(primary\ voltage)} = \frac{50VA}{12} = 4.2A$

Size of Secondary conductor = $\frac{Current\ (I)}{Current\ density\ (j)} = \frac{4.2}{2.3} = 1.8mm^2$

Number of turns = turns per volt × volt

Turns per volts = $\frac{1}{4.44 \times B_{\max} \times f \times A}$

Area of bobbin = A=2.26inchm^2

Area of bobbin = A= 0.00145161m^2

By putting values

Turns per Volt =2.6 × 12= 32turns

Total wire length = no of turns perimeter of bobbin =32× $7inch =$ 224inch =6m

Volume of conductor = Area × length =1.83×10^{-6} × 6m^3 = 1.098 × $10^{-5}m^3$

Wight = density × volume

Density of copper = 8960

Wight = 8960 × 1.098×10^{-6} = Wight = $0.098Kg$

3.2. Dc Section

This section is powered by power supply from ac circuit which 12v. The 12v fed in to the terminal 4 of LM 555 timer. The 3 terminal of timer which is the out-put was connected to the collector of the transistor, while terminal 8 which is VCC supply was connected to relay, terminal 1 was connected to the ground. The base of the transistor was connected to the diode which makes sure the current flow in on direction and the connected to the line is connected coil of the relay and the emitter of the transistor was connected to the ground. Whenever there is power supply to the Dc circuit relay will be energized and then from normally opened to normally closed terminal, this leads to initiation of operation of alarm which the timer control to ring for 5 seconds. The second buzzer only server as back up for the main buzzer which is in the ac circuit. The dc will only ring when the Ac buzzer is not available.

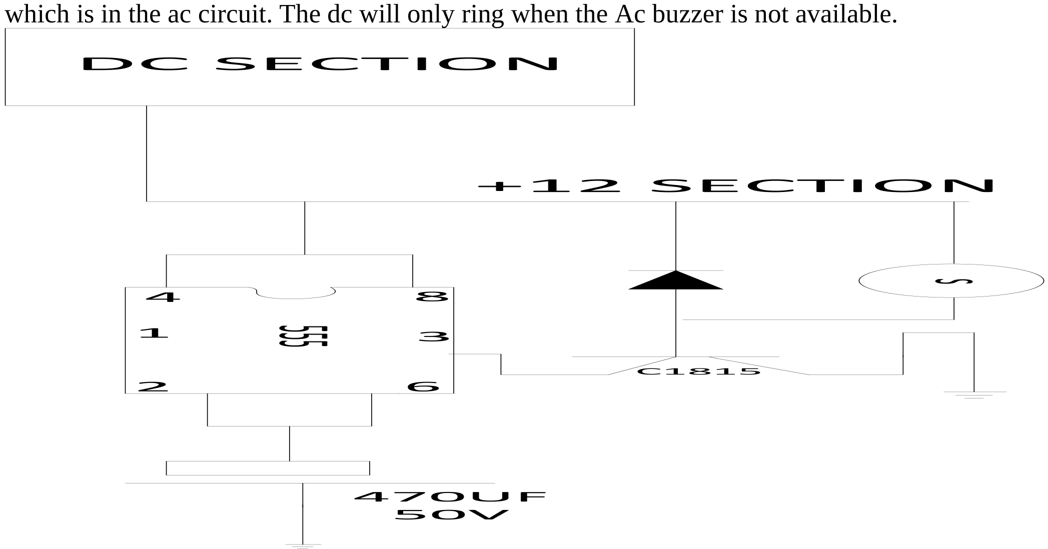

Figure. 3. Dc section circuit of Ac voltage monitoring and protection system

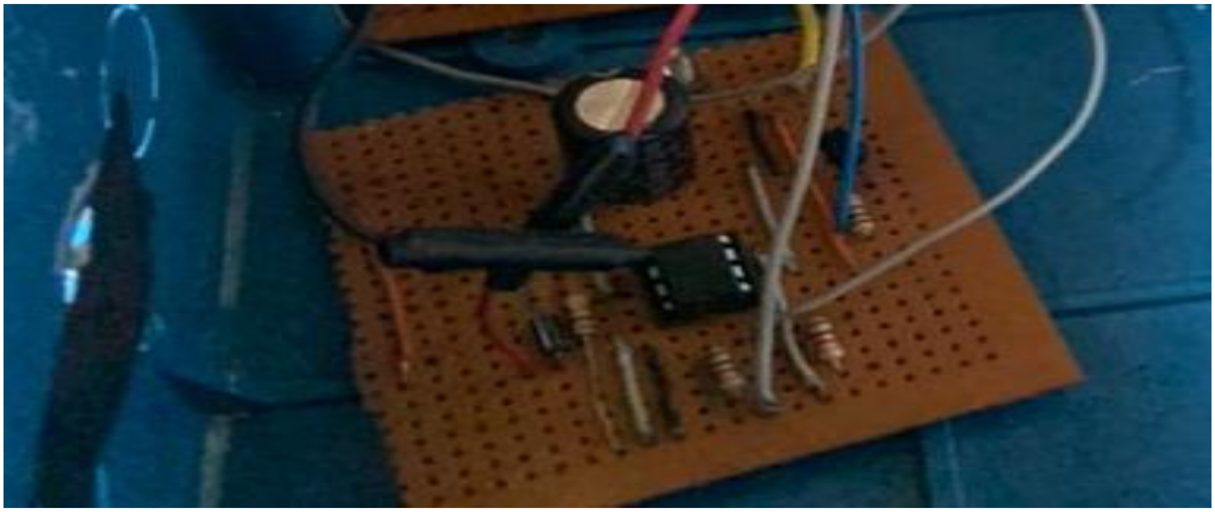

Figure 4. Circuit development

3.3 Control sections

This section consists of three relays, each of these relays are present in the other three sections of Ac voltage monitoring and protection system. The relay present in Ac section in-charge of controlling the timers of the ac section and dc section is while the other two relays in out-put section, one is in the control of voltmeter and other acts more like automatic switching device that will be to switch from main power supply when that is not available to generator pow supply and then automatically switch back to main power supply that is being restored (Brown, L.,*et al* 2023)..

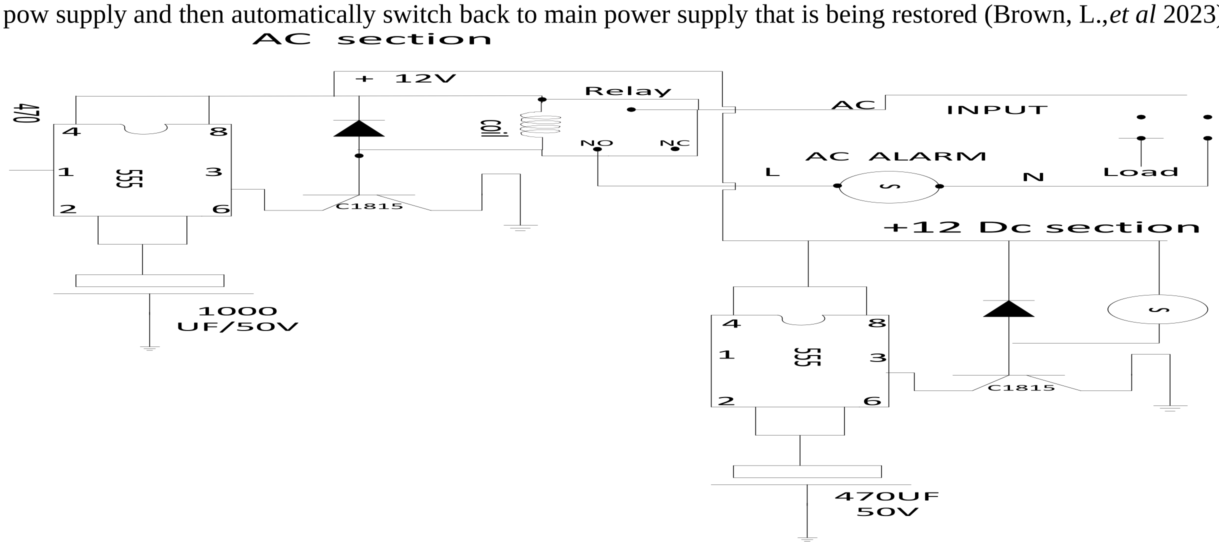

Figure. 5: Control circuit

3.4 Determine the value of the components mathematically

Given that R= $\frac{(Us-0.6)hFE}{Relay\ coil\ current}$

Where: R = base resistor of the transistor

Us = Source or the trigger voltage to the base resistor

H_{fe} = forward current gain of the transistor,

Supply (Vs) is = 12V, the coil resistance is 400 ohms, and Relay current I = $\frac{12}{400} = 0.03\ or\ 30mA$

H_{fe} =150

Applying the above values in the actual equation we get

R= $\frac{(Us-0.6)hFE}{Relay\ coil\ current}$

$R = \frac{(12 - 0.6) \times 150}{0.03}$ = 57000 ohms or 57k, closest value being 56

Evaluation of the system performance

The evaluation of an AC Voltage Monitoring and Protection System involves analyzing its ability to ensure accurate voltage measurement, efficient fault detection, and reliable protection mechanisms. Key performance metrics include precision in voltage sensing, response time to abnormal voltage conditions, and the effectiveness of the system in mitigating damage caused by voltage irregularities.

Accuracy of Voltage Monitoring: The system must provide real-time voltage readings with minimal error, ensuring precise monitoring across various operating conditions. Calibration and testing against known standards are critical for verifying its accuracy.

Fault Detection and Response: The system's ability to detect over-voltage, under-voltage, or voltage surges promptly is crucial. A fast response time ensures timely activation of protection mechanisms, minimizing the risk of damage to connected equipment.

Protection Mechanisms: The system should efficiently disconnect the load or activate other protective measures when voltage anomalies are detected. Its reliability in repeatedly performing this function under different conditions is a key performance indicator.

System Reliability and Robustness: Evaluation includes testing the system under various environmental and electrical conditions to ensure consistent performance. This includes handling transient events and maintaining functionality during power surges.

Energy Efficiency: The system should consume minimal power during operation to avoid adding unnecessary load to the circuit it monitors.

Ease of Integration and Maintenance: The system's design should support easy integration into existing setups and allow for straightforward maintenance or upgrades.

Overall, the performance evaluation ensures the AC Voltage Monitoring and Protection System meets safety standards, operates reliably under real-world conditions, and provides long-term protection for electrical systems and appliances. Figure 6 present laboratory test on the system developed with variarc

Figure 6: Testing of the system with variarc

4. Conclusion

In conclusion, this study highlights the critical role of modeling and development in AC power system control and protection, particularly through the application of metal oxide varistors (MOVs). By integrating MOVs into system design, we demonstrated enhanced system reliability and protection against voltage transients and overvoltage conditions. The proposed methods and models offer a practical framework for improving the stability and resilience of modern power systems, paving the way for further advancements in high-performance electrical networks. The system was tested using variarc equipment with a voltage range between 0V and 270V; the performance was excellent, and the response to the switch at high voltage to prevent the system from surge was perfect. Future work may explore optimizing MOV deployment strategies and integrating emerging technologies to address evolving power system challenges.

References

Amer, M. (2022). *Techniques for Power System Protection and Control*. *17*(1), 1–6. https://doi.org/10.9790/1676-1701010106

BASICS OF POWER SYSTEM , PROTECTION AND INTRODUCTION TO POWER Author : Ajithkannan Sivakumar. (2024). *September*.

Bo, Z. Q., Lin, X. N., Wang, Q. P., Yi, Y. H., & Zhou, F. Q. (2016). Developments of Power System Protection and Control. *Protection and Control of Modern Power Systems*, *1*(1), 1–8. https://doi.org/10.1186/s41601-016-0012-2

Harnden, J. D., Martzloff, F. D., Morris, W. G., & Golden, F. G. (1972). Metal-Oxide Varistor: a New Way To Suppress Transients. *Electronics*, *45*(21), 91–95.

Montano, R., Edirisinghe, M., Cooray, V., & Roman, F. (2004). Varistor Models - A Comparison between Theory and Practice. *Lightning Protection (ICLP), 2004 International Conference On, September*.

Wang, G., Kim, W. H., Lee, J. H., & Kil, G. S. (2018). Condition monitoring and deterioration analysis of metal oxide varistor. *Journal of Electrical Engineering*, *69*(5), 352–358. https://doi.org/10.2478/jee-2018-0051

Yageo Group. (n.d.). *Applications of Metal Oxide Varistors (MOV) in Power Supply*. 1–8.

Smith, J., & Johnson, A. (2022). AC Monitoring and Protection Systems: A Comprehensive Study. *International Journal of Electrical Engineering, 15(3), 45 – 60*.

Brown, L., & Davis, M. (2023). Metal Oxide Varistors:

Principles and Applications in AC Monitoring and Protection Systems. IEEE Transactions on Power Systems, 28(2), 78 – 92.