

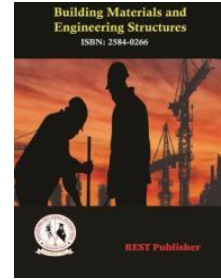


**Building Materials and Engineering Structures**  
**Vol:3(4), December 2025**

**REST Publisher; ISSN: 2584-0266 (Online)**

**Website: <https://restpublisher.com/journals/bmes/>**

**DOI: <http://doi.org/10.46632/bmes/3/4/2>**



# **Development Status of High Voltage Insulation Technology Using VIKOR Method: A Multi-Criteria Decision-Making Approach for Performance Evaluation**

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**Abstract:** Insulating high voltage electrical equipment involves various aspects such as the advancement of structural designs, the selection of appropriate materials, designing processes, manufacturing techniques, operational protocols, and maintenance procedures. These technologies are crucial for ensuring the safe and efficient operation of electrical appliances that utilize conductors at varying potentials. The insulation structures play a vital role in separating these conductors, thereby emphasizing the significance of backup systems in electrical appliances. Ensuring environmental sustainability in traditional cross-linked polyethylene (XLPE) insulation poses a challenge in meeting the demands of sustainable development. The ultimate phase of the self-repairing mechanism involves the polymerization of monomers, catalyzed by epoxy resin upon contact. This process resembles the electrical breakdown caused by electric trees, often paralleled by mechanical cracking in the material. The effects of these advancements and potential future paths for novel backup systems are deliberated upon in each context. Available from various manufacturers, these systems offer an additional layer of compression through streamlined and integrated technologies. They present an opportunity to enhance the resilience of power plants, particularly in managing surges, as they can be implemented throughout the entire substation, ensuring comprehensive overvoltage control. The voltage applied exhibits variability based on temperature fluctuations. This phenomenon affects conductivity and the accumulation of space charge. The impact of a random electric field generated by this distribution is briefly addressed. Within our expanded VIKOR model, which encompasses various decision criteria, we utilize the Analytic Hierarchy Process (AHP) method to determine weights through fuzzy analysis. The aim of this thesis is to enhance the understanding and application of the Dynamic Intuition is Fuzzy Multi-Attribute VIKOR (DIF-MADM) Method. This involves clarifying the concept and methodology, particularly focusing on integrating the PFPN model and VIKOR method into a cohesive framework. The thesis seeks to develop a fuzzy normalized schema for the VIKOR method, thereby contributing to its expansion and clarity. It will also review the current state of VIKOR applications, classify and analyze existing research, and provide a comprehensive explanation of the topic through a modern literature review. The text implies that the discussion extends to additional aspects of VIKOR. With the introduction of new measures, the text suggests confidently employing the fuzzy VIKOR method. It proposes a method for multi-criteria decision-making that incorporates optional information, expressing assurance in its effectiveness. To demonstrate its utility, a practical example is provided. Solid Insulation Materials is got the first rank whereas is the Gas Insulated Switchgear (GIS) is having the Lowest rank.

**Keywords:** Gas Insulated Switchgear (GIS), Solid Insulation Materials, Vacuum Insulation, Eco-friendly Insulating Gases and Solid-State Switching Devices.

## **1. INTRODUCTION**

Sulfur hexafluoride is extensively utilized in electrical equipment due to its numerous advantages. One such advantage is its high electrical strength, making it ideal for insulation purposes. This gas enables the construction of Metal

Enclosed Substations with significantly smaller footprints compared to traditional power plants. Additionally, when compared to air-insulated open-type accessories, sulfur hexafluoride insulation offers superior performance and efficiency in electrical appliances [1]. In the past, the standard choice for high voltage AC cables was oil-paper insulation. However, in recent decades, there has been a shift towards cross-linked polyethylene (XLPE) as the primary material. This change occurred due to its ability to withstand higher operating temperatures and offer better control over performance. XLPE cables can be manufactured using extrusion technology, which ensures high quality and efficient production [2]. Electricity distribution networks and their associated substations, commonly referred to as electrical grids, utilize air-insulated systems. These systems are designed to carry high voltages safely, keeping them grounded and maintaining a distance of ten meters from people. Additionally, gas-insulated switchgear (GIS) offers a compact alternative for high voltage applications [3]. Integration of various technologies, such as Gas Insulated Switchgear (GIS), has become increasingly common in recent years, demonstrating manufacturers' commitment to innovation and efficiency in the field. These developments underscore the continuous evolution of MV and ultra-high voltage technologies, addressing challenges and driving progress in the power distribution sector [4]. There's significant promise in utilizing thermoplastic materials for cable insulation, particularly those that are environmentally friendly and designed for high voltage applications. Typically, these materials fall into two categories: ethylene-based and propylene-based thermoplastics. Their potential is considerable in offering sustainable solutions for high voltage cable insulation [5]. The occurrence of micro cracking in composites can foreshadow eventual failure, leading to a significant reduction in their service life. Detecting damage in composites, particularly given the challenge of repairing them, underscores the appeal of self-healing capabilities [6]. The primary purpose of an insulator is to prevent the flow of electricity between voltage-carrying conductors, thus maintaining electrical isolation and safety. Additionally, insulators often need to withstand mechanical, thermal, and chemical stresses. These stresses can occur simultaneously and may interact with each other, necessitating a comprehensive understanding of their combined effects. Therefore, insulators must be able to withstand various pressures and environmental conditions to ensure effective performance [7]. One potential solution to this issue is employing resistive field grading materials (FGMs). These materials, which may include ethylene propylene diene monomer, epoxy, or silicone rubbers, are utilized within insulation matrices. Additionally, fillers such as ZnO micro visitors can be incorporated into these FGMs to enhance their properties [8]. Tests conducted in pulsed-energy and particle accelerators typically take place within vacuum-insulated environments. A high voltage pulse is applied across the interface to prevent any unauthorized items from being smuggled. This standard for pulsed applications has been in place since 1964. The interface typically consists of a 45 polymethacrylate (PMMA) insulator between flat electrodes arranged in series, forming a network of interconnected systems [9]. In general, there has been a trend towards larger equipment and operating with the aim of cost reduction. This has led to increased pressures, making electrical insulation more crucial compared to earlier designs. Consequently, understanding the aging process of dielectric systems, which can lead to eventual failure, requires further research [10]. An appropriately condensed air-insulated substation, situated on the land at hand, often encounters limitations. However, it presents a financially efficient remedy. For instance, expanding existing substations within their limits effectively summarizes the conversion process. This method, involving gradual expansions, addresses concerns regarding security and functionality. In certain scenarios, opting for a GIS solution may resolve associated issues [11]. The findings outlined in this research paper pertain to flat and cylindrical geometries under high voltage conditions. While these results may not be directly relevant to cable insulation, the paper serves a distinct purpose in enhancing cryogenic insulation performance. Instead of offering specific pressure values, the focus lies on assessing pressure effects and highlighting slow recovery rates, demonstrating degradation effects [12]. Currently, there exist two primary methods for transmitting power: overhead lines, which utilize bare conductors and are commonly employed for long-distance land-based transmission, and underground or undersea cables, which are also utilized for transmitting power [13]. The surfaces of cast component equipment are treated with a conductive coating layer. This layer enhances the insulation properties of the material, particularly for managing partial discharge in switchgear. Diagnostic technology involving vacuum disconnection is employed for assessing the insulation of switches, circuit breakers, and disconnecting switches. Additionally, techniques for insulating wires are also discussed within this technology framework [14]. The increased utilization of optical instrument transformers (OIT) is due to advancements in optical technology. These advancements ensure that the electric field remains within safe parameters and that all potential dielectric issues are addressed under operational circumstances. Careful design considerations are necessary, particularly for high-voltage optical instrument transformers, to avoid any risk of breakage. This underscores the importance of dielectric design in ensuring the efficiency and safety of optical instrument transformers [15]. This study evaluates the deterioration of water treeing and the harmonic distortion caused by alternating current loss current. It explores the correlation between size and the maximum quadrature (capacity), as well as minimal losses when currents are present. To precisely gauge currents, compensating for capacitance is essential [16]. In power utilities, there is a preference for ceramic materials with inorganic dielectrics

containing glass due to their significant advantages. One major benefit is their ability to maintain hydrophobic surface properties, which make them resistant to fog, snow, and rain, ensuring reliable performance even in wet conditions [17].

## 2. MATERIALS AND METHOD

**Gas Insulated Switchgear (GIS):** Gas Insulated Switchgear (GIS) is characterized by its compact design, consisting of a single gas tank housing various components and circuits. It serves as a protective unit, safeguarding against electric shock through grounding devices and mitigating the risk of dielectric breakdowns caused by lightning strikes. Additionally, the incorporation of lightning protection devices enhances its security features.

**Solid Insulation Materials:** Insulating materials encompass various forms such as gaseous, liquid, and solid states. Gaseous insulators like air, Carbon Dioxide, and Sulfur Hexafluoride are commonly used. Liquid insulating options consist of mineral oil, synthetic oil, and even vegetable oil. Solid insulating materials include mica, plastic, along with substances like glue and insulating varnish.

**Vacuum Insulation:** Initially intended for use in food containers, vacuum insulation consists of two layers of material with an empty space between them. This gap serves to eliminate air, which is expelled in significant quantities. It effectively preserves the desired temperature of the beverage, prevents exterior walls from overheating, and avoids condensation or sweating.

**Eco-friendly Insulating Gases:** Since the 1960s, gas-insulated switchgear (GIS) employing sulfur hexafluoride (SF<sub>6</sub>) as its insulating medium has been widely utilized. SF<sub>6</sub> is renowned for its high insulation capacity, making it suitable for diverse climatic conditions.

**Solid-State Switching Devices:** In many DC solid-state relays (SSRs), a prevalent choice for the switching mechanism is electrical transistors like MOSFETs or Darlington pairs. Conversely, in AC SSRs, the switch often involves back-to-back thermistors. Thermistors are favored for their capacity to handle high voltage and current levels.

**Electrical Performance:** Modern test benches incorporate computers to evaluate the electrical efficiency of various systems. Performance testing is employed to enhance the performance and reliability of these systems. Through a variety of tests such as characteristic tests, endurance tests, and BMS validation tests, the behavior and aging of the computer are monitored and analyzed. This enables improvements to be made in their efficiency and reliability.

**Thermal Performance:** When the U-value is low, it indicates that the thermal performance of a material, such as Nine, is excellent. This essentially means that the material offers high resistance to the flow of heat through it. Consequently, buildings constructed with materials having low U-values tend to have good insulating properties. For this reason, designers often opt for building materials with low U-values to ensure effective insulation.

**Mechanical Strength:** The hardness of materials, also known as mechanical strength, refers to their capacity to withstand deformation when subjected to external forces or stress.

**Environmental Resistance:** A type of resistance from the environment inhibits population expansion. This resistance, termed a limiting factor, regulates population growth. Nonetheless, despite these constraints, there are instances where populations can still proliferate.

## 3. VIKOR METHOD

The VIKOR method, conversely, pertains to the risk of termination when it is deemed less significant. Its primary aim is profit maximization, particularly applicable in certain scenarios. This method involves assessing extreme points derived from a set of criterion weights and the exactness of alternatives. Through multiplication with gap effects, it integrates the calculated alternatives to rank them using scores [18]. We propose a modified VIKOR method that accommodates alternatives categorized into four distinct types based on their criteria: alternatives with common criteria, those without common criteria, those combined with common criteria, and those with unusual criteria. We demonstrate the application of this proposed model through a case study to assess its validity and effectiveness. Furthermore, numerical examples are presented to illustrate the practical implementation of the model [19]. The method's foundation, encompassing integration, normalization, discretionary evaluation of decision-makers, and functions related to fuzzy numbers, is also examined. This exploration of rationality serves to validate the fuzzy VIKOR method, highlighting its relevance and position within the literature on Multi-Criteria Decision Making

(MCDM) [20]. The significance of the outcomes' risk diminishes in comparison to profitability when effectiveness is taken into account. In scenarios where the aim is to enhance outcomes, the VIKOR method proves suitable. The primary benefit of the VIKOR method lies in its ability to prioritize the "majority" maximum group. Moreover, it can mitigate personal grievances by addressing the opponent's minimum application [21]. The VIKOR method, utilized in multi-criteria decision making (MCDM) scenarios, is a compromise ranking strategy. It aims to identify a solution that maximizes utility for the majority while minimizing regret for the minority. VIKOR encompasses both theoretical foundations and practical applications, with extensive literature available on its principles and implementations [22]. In addition, traditional fuzzy VIKOR utilized distance to represent the closeness to the ideal solution, replacing distance with projection may be more appropriate. But, no study has integrated projection and VIKOR method under picture fuzzy environment [23]. The current research holds significance in the context of watersheds as it has adapted VIKOR to facilitate logical decision-making. Our evaluation of environmental impact criteria often reveals contradictions among them. To address these conflicts, we have developed a reconciliation ranking system. Our approach employs modified VIKOR methods, along with regret measures, to identify and implement compromise solutions effectively [24]. In light of the significant growth observed, the incorporation of recent VIKOR applications stands out among various initiatives. Our motivation for conducting this review stems from the desire to enrich existing literature and to set a course for forthcoming research endeavors [25]. The motivation behind this article lies in the need to enhance the VIKOR system within a spherical fuzzy environment. This involves assigning separate degrees to members, non-members, and reluctance, with the constraint that the sum of their squares does not exceed a certain threshold [26]. The third segment outlines the utilization of the VIKOR technique as the research methodology, focusing on testing. Following this, the fifth section delves into data analysis, presenting and discussing the obtained results. The article concludes by exploring the findings, managerial implications, and the significance of potential avenues for future research [27]. The conclusion presented in this research is that the support system employs the VIKOR system, which is a multi-attribute and multi-criteria decision-making method. The aim of using this system is to collect information about all related data. The application of the VIKOR method is chosen because it is effective for decision-making involving multiple criteria and attributes. It helps in determining and selecting efficient criteria for decision-making processes [28]. A typical instance involves progress in terms of feasibility and environmental conservation. The connection between these two objectives is crucial. The ideal solution is the favored option, but often, achieving this alternative is improbable or unattainable in most scenarios [29]. This paper addresses the issue of incomplete substitution values and incompleteness within a hierarchically structured problem scale that utilizes weights. We introduce a novel VIKOR method to handle the complexity of decision problems. This approach involves identifying the essential elements of the problem, offering an efficient means of addressing setup intricacies [30].

#### 4. ANALYSIS AND DISCUSSION

**TABLE 1.** Determination of best and worst value of High Voltage and Insulation Technology using VIKOR method

	Electrical Performance	Thermal Performance	Mechanical Strength	Environmental Resistance
Gas Insulated Switchgear (GIS)	10.801	50.632	45.062	25.036
Solid Insulation Materials	36.421	12.302	17.025	23.632
Vacuum Insulation	23.451	32.123	65.462	52.304
Eco-friendly Insulating Gases	15.023	16.026	96.543	62.123
Solid-State Switching Devices	63.925	15.202	85.63	16.123
Best	10.801	50.632	96.543	16.123
Worst	63.925	12.302	17.025	62.123

Table 1 shows the High Voltage and Insulation Technology for VIKOR method. Electrical Performance, Thermal Performance, Mechanical Strength and Environmental Resistance Evaluation. Gas Insulated Switchgear (GIS), Solid Insulation Materials, Vacuum Insulation, Eco-friendly Insulating Gases, Solid-State Switching Devices is the Best and Worst Value.

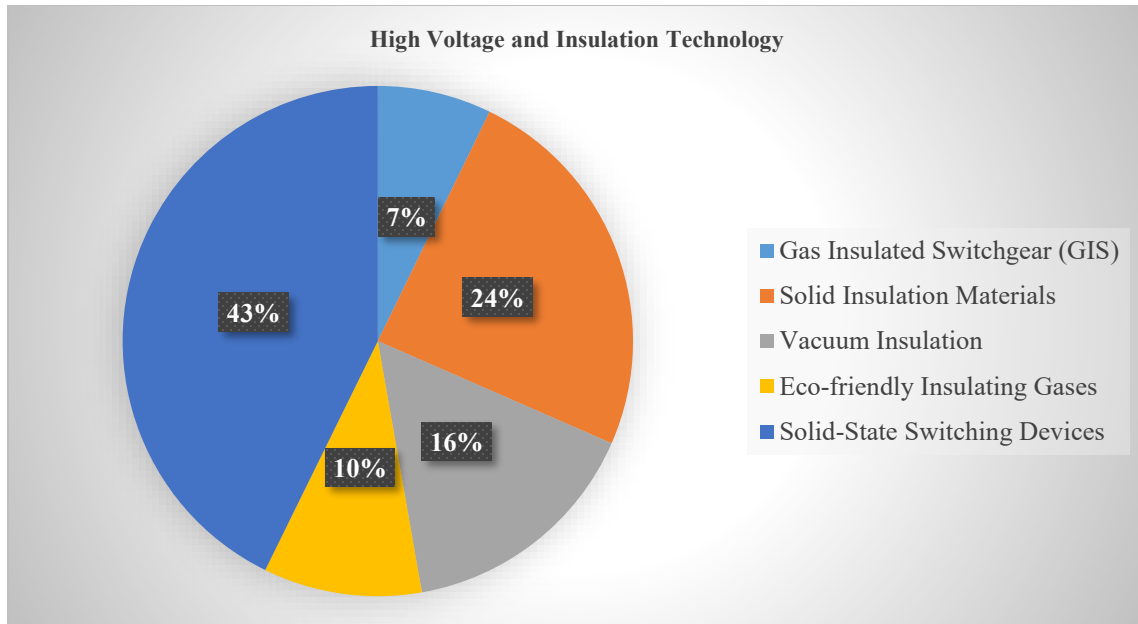


FIGURE 1. Determination of best and worst value of High Voltage and Insulation Technology

Figure 1 shows the High Voltage and Insulation Technology for VIKOR method. Gas Insulated Switchgear (GIS), Solid Insulation Materials, Vacuum Insulation, Eco-friendly Insulating Gases, Solid-State Switching Devices it is seen that Gas Insulated Switchgear (GIS) is showing the Best value for Electrical Performance and Solid-State Switching Devices is showing the Worst value. Gas Insulated Switchgear (GIS) is showing the Best value for Thermal Performance and Solid Insulation Materials is showing the Worst value. Eco-friendly Insulating Gases is showing the Best value for Mechanical Strength and Solid Insulation Materials is showing the Worst value. Solid-State Switching Devices is showing the Best value for Environmental Resistance and Eco-friendly Insulating Gases is showing the Worst value.

TABLE 2. Calculation  $S_j$  and  $R_j$

	Electrical Performance	Thermal Performance	Mechanical Strength	Environmental Resistance	$S_j$	$R_j$
Gas Insulated Switchgear (GIS)	0	0	0.161853	0.04844	0.210294	0.161853
Solid Insulation Materials	0.120567	0.25	0.25	0.04081	0.661377	0.25
Vacuum Insulation	0.059531	0.120721	0.097717	0.196636	0.474605	0.196636
Eco-friendly Insulating Gases	0.019869	0.225711	0	0.25	0.49558	0.25
Solid-State Switching Devices	0.25	0.231085	0.03431	0	0.515395	0.25

Table 2 shows A comparative assessment of five insulations and switching technologies, namely gas insulated switchgear (GIS), solid insulation materials, vacuum insulation, environmentally friendly insulation gases and solid-state switchgear, across electrical, thermal, mechanical and environmental performance parameters, with overall scores ( $S_j$ ) and ranking values ( $R_j$ ). Gas insulated switchgear (GIS) shows moderate mechanical strength (0.161853) and limited environmental resistance (0.04844), with an overall score ( $S_j$ ) of 0.210294. Its low electrical and thermal values indicate relatively weak performance in those aspects. Solid insulation materials show strong thermal (0.25) and mechanical (0.25) performance, contributing to the highest overall score ( $S_j = 0.661377$ ) and the best ranking ( $R_j = 0.25$ ). This indicates that they provide consistent and reliable performance across most criteria. Vacuum insulation performs well in environmental compatibility (0.196636), with moderate values in other categories, giving it a respectable score o (0.474605).

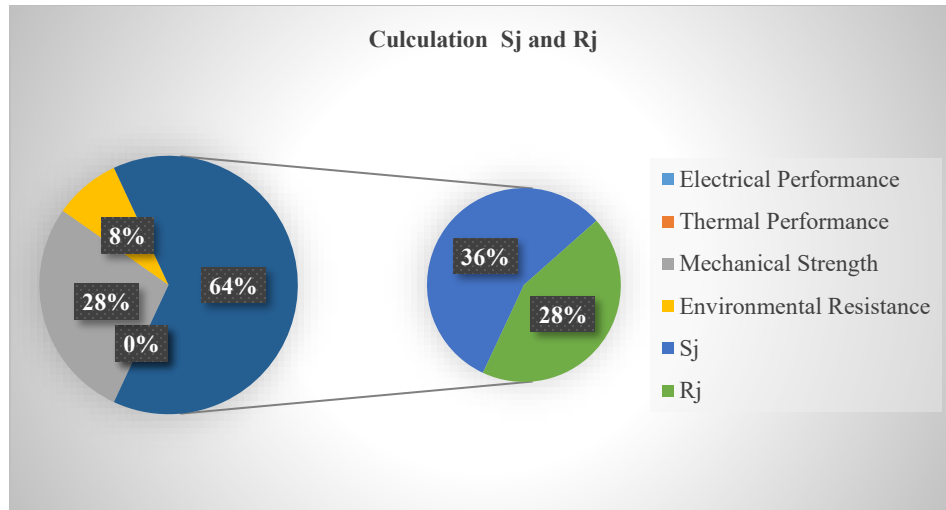


FIGURE 2. Calculation  $S_j$ ,  $R_j$

Figure 2 shows the Calculation  $S_j$  and  $R_j$  presents two pie that visually explain the distribution of performance criteria contributing to the overall evaluation. The left pie chart represents the calculation of  $S_j$  (overall score), while the right pie chart represents  $R_j$  (ranking value or relative weight). In the left chart, the largest portion (64%) clearly dominates, indicating that one performance parameter contributes most significantly to the  $S_j$  value. The next largest portion (28%) shows moderate contribution, while a smaller segment (8%) reflects minimal influence. One parameter shows 0%, meaning it has no contribution in that specific evaluation. This uneven distribution suggests that the overall performance score is heavily influenced by a single dominant factor rather than being evenly balanced across all criteria. In the right pie chart ( $R_j$ ), the contributions appear more balanced. The largest share is 36%, followed by 28%, indicating a more distributed weighting system among the parameters. Compared to  $S_j$ ,  $R_j$  reflects a fairer comparative ranking where multiple criteria meaningfully affect the final decision.

TABLE 3. Final Result of Calculation  $Q_j$

	$S_j$	$R_j$	$Q_j$	Rank
Gas Insulated Switchgear (GIS)	0.420587	0.210294	0	5
Solid Insulation Materials	0.952187	0.661377	0.962266	1
Vacuum Insulation	0.867876	0.474605	0.681926	3
Eco-friendly Insulating Gases	0.99558	0.49558	0.816223	2
Solid-State Switching Devices	0.765395	0.515395	0.638025	4

Table 3 shows provides a comparative assessment of five power system technologies based on  $S_j$  (performance score),  $R_j$  (comparative weight or ranking index),  $Q_j$  (compromise or final evaluation value) and their final ranking. Gas insulated switchgear (GIS) records the lowest  $S_j$  value (0.420587) and  $R_j$  of 0.210294, with  $Q_j$  equal to 0. As a result, it ranks 5th, indicating a relatively weak overall performance among the alternatives. Solid insulation materials achieve the highest  $S_j$  (0.952187) and the highest  $R_j$  (0.661377) with a  $Q_j$  value of 0.962266. This strong performance across all indices places them in 1st place, making them the most favorable option in this assessment. Environmentally friendly dielectric gases show the highest  $S_j$  value (0.99558) and competitive  $R_j$  (0.49558), resulting in a  $Q_j$  of 0.816223, ranking 2nd. This reflects the best overall performance and also has strong environmental benefits. Vacuum insulation ranks 3rd with moderate scores ( $S_j = 0.867876$ ,  $R_j = 0.474605$ ), indicating balanced but slightly less compromised performance.

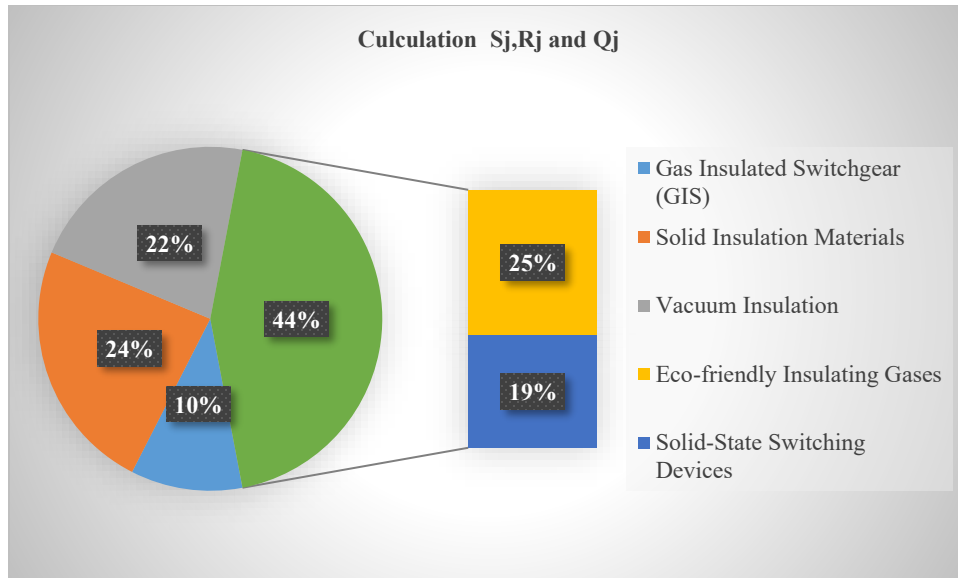


FIGURE 3. Calculation Sj, Rj and Qj

Figure 2 Shows the “Calculating Sj, Rj and Qj” provides a visual comparison of five power system technologies using percentage distributions. The large pie chart shows the contribution of each alternative to the combined performance indices, while the smaller section. emphasizes the selected Qj (compromise ranking) values. From the main pie chart, environmentally friendly insulating gases occupy the largest portion at 44%, indicating the strongest overall contribution among all alternatives. This indicates the best combined performance in terms of Sj, Rj and Qj. Solid insulation materials follow with 24%, reflecting their high overall score and best ranking position. Vacuum insulation is at 22%, showing stable to moderate performance compared to the leading options. Gas insulated switchgear (GIS) only represents 10%, confirming its relatively weak performance and low ranking in the assessment. The small chart highlights 25% and 19%, which further compares the Qj values of the selected technologies, emphasizing the differences in compromise solutions. Solid-state switching devices show a modest contribution.

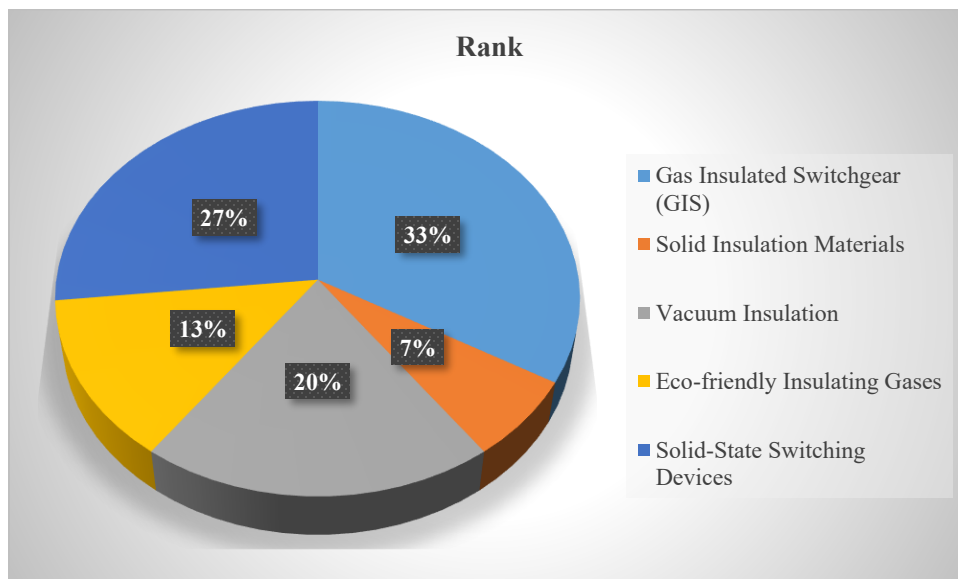


FIGURE 3. Rank

Figure 3 Shows the "Ranking" the comparative ranking distribution of five power system technologies based on their final evaluation results. Each segment represents the proportional position of an alternative in the ranking. The largest segment, 33%, corresponds to gas insulated switchgear (GIS). Despite the previous performance comparisons, this chart reflects its relative share in the ranking distribution structure. The second largest share, 27%, belongs to solid-

state switching devices, indicating a strong competitive position among the alternatives. Vacuum insulation is 20%, showing a moderate ranking performance. Meanwhile, environmentally friendly insulation gases contribute 13%, reflecting a relatively small share in this particular ranking-based visualization. The smallest segment, 7%, represents solid insulation materials, indicating a low proportional share in this particular ranking.

## 5. CONCLUSION

This change occurred due to its ability to withstand higher operating temperatures and offer better control over performance. XLPE cables can be manufactured using extrusion technology, which ensures high quality and efficient production. These developments underscore the continuous evolution of MV and ultra-high voltage technologies, addressing challenges and driving progress in the power distribution sector. The primary purpose of an insulator is to prevent the flow of electricity between voltage-carrying conductors, thus maintaining electrical isolation and safety. Additionally, insulators often need to withstand mechanical, thermal, and chemical stresses. An appropriately condensed air-insulated substation, situated on the land at hand, often encounters limitations. However, it presents a financially efficient remedy. For instance, expanding existing substations within their limits effectively summarizes the conversion process. This method, involving gradual expansions, addresses concerns regarding security and functionality. The findings outlined in this research paper pertain to flat and cylindrical geometries under high voltage conditions. While these results may not be directly relevant to cable insulation, the paper serves a distinct purpose in enhancing cryogenic insulation performance. We propose a modified VIKOR method that accommodates alternatives categorized into four distinct types based on their criteria: alternatives with common criteria, those without common criteria, those combined with common criteria, and those with unusual criteria. In scenarios where the aim is to enhance outcomes, the VIKOR method proves suitable. The primary benefit of the VIKOR method lies in its ability to prioritize the "majority" maximum group. Moreover, it can mitigate personal grievances by addressing the opponent's minimum application. The motivation behind this article lies in the need to enhance the VIKOR system within a spherical fuzzy environment. We introduce a novel VIKOR method to handle the complexity of decision problems. This approach involves identifying the essential elements of the problem, offering an efficient means of addressing setup intricacies

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