MV - HV AC&DC Circuit Breaker Patent Review

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Abstract:

I propose a novel medium- and high-voltage circuit breaker capable of interrupting both alternating current (AC) and direct current (DC) using atmospheric air as the insulation medium. The breaker employs two opposing moving arms that rotate laterally, with nine disconnection points organized in three parallel branches (three points per branch). Auxiliary circuits—including a superconducting fault current limiter (SFCL), a tuning circuit (coil and capacitor), a fast-acting switch, surge arrestor, and rate-of-rise-of-recovery-voltage (RRRV) control—reduce disconnection time, limit short-circuit current, and suppress discharge voltage. The architecture distributes voltage across multiple disconnection points, enabling high-voltage operation with lower per-point stress, and offers potential environmental, cost, and lifetime advantages relative to SF6- or oil-based breakers. Reported mechanism: disconnection within 5–7 ms, with safety margins from distributed insulation and optimized geometry. The manuscript discusses the technical approach, operating principles, and implications for environmental impact and scalability.

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Keywords: circuit breaker; AC/DC; medium voltage; high voltage; air insulation; SFCL; fast switching; transient suppression; recovery voltage; parallel disconnection points; environmental impact; patent.

Background Art:

High-voltage circuit breakers (with a mechanical disconnection system) operate with gas insulation systems such as sulfur hexafluoride gas or mineral oil. It takes a time ranging from 14 to 25 milliseconds to disconnect the current when a short circuit occurs. In this case, the circuit breaker is exposed to a discharge voltage estimated at approximately 160% of the current voltage of the system at which it operates.
An electrical circuit breaker of this type consists of two parts, one of which is fixed and the other is movable, when a short circuit occurs, the movable part moves away from the fixed part, and gas or mineral oil is forced to extinguish the electrical spark and ensure that the current is interrupted from the electrical circuit, there is also an auxiliary element to the breaker, which is a surge arrestor, to absorb any remaining energy or electrical charges on the contacts of the breakers in the case of alternating current.

As for the case of direct current, some auxiliary circuits are added to the above, such as a coil and a capacitor to convert the direct current to alternating current to ensure that the current reaches a value of zero amps, at which it is easy to disconnect, and a surge arrestor to absorb any remaining energy or electrical charges on the contacts of the breakers. There is also another auxiliary circuit consisting of a capacitor and a resistance to control the rate of rise of the recovery voltage. Knowing that it is difficult and almost impossible to install medium voltage circuit breakers in high voltage electrical systems.

1. Introduction

1.1 Motivation: Environmental and safety concerns motivate air-based insulation concepts for HV breakers, aiming for faster interruption and reduced maintenance.

1.2 Background: Conventional breakers rely on insulating media with environmental risks. The proposed concept uses:

(a) Air insulation for AC and DC.

(b) A multi-stage, parallel-branch architecture with nine disconnection points.

(c) Auxiliary circuits to enhance performance.

1.3 Technical Problem:

Interruption time can be long, and traditional circuit breakers may fail to disconnect large currents because the disconnection contacts overheat, stick together, or melt, potentially causing the breaker to explode.

Medium-voltage circuit breakers cannot replace high-voltage breakers. During disconnection, the breaker is exposed to a discharge voltage that can exceed the system voltage, potentially reaching about 160%.

Oil-based breakers or sulfur hexafluoride (SF_6) gas can leak, leading to malfunction or severe atmospheric pollution. They are also costly. The invention described claims to avoid these issues by using a design where disconnection points, along with breaker arms, can move in multiple directions (up, down, left, right) and use consecutive and parallel branches. This approach eliminates the need for air at very high voltages and mitigates the problems associated with gas leakage and overheating.

Objective: Present the conceptual design, operating principle, expected performance, and potential advantages, including life-cycle benefits and environmental impact, alongside risks and design considerations.

2. Device Concept and Architecture

2.1 Overall topology:

(a) Two movable arms move in opposite directions (up and down) with lateral rotation (45–90°).

(b) Three parallel branches, each with three disconnection points in series (nine points total).

(c)Electrical path from source to load interrupted by coordinated actuation of the points.

2.2 Insulation medium:

Atmospheric air replaces SF_6/oil; breakdown voltage informs air-gap spacing.

2.3 Disconnection points and geometry:

(a) Each branch contains three consecutive points; branch voltages are shared across points (approx. $V_{system}/3$ per point in idealized conditions).

(b) Gap spacing engineered to minimize arcing and avoid contact during interruption.

2.4 Motion and actuation:

(a) Arms move synchronously; a stabilizing link ensures uniform motion.

(b) Disconnection span: 45–90° for rapid interruption and reduced spark energy.

3. Auxiliary Circuits and Protective Elements

3.1 SFCL (Superconducting Fault Current Limiter):

Type: resistance-type SFCL, inactive in normal operation, active during faults.

Function: reduces initial short-circuit current (e.g., from 25 kA to ≤2 kA for a 500 kV system), enabling rapid interruption.

3.2 Tuning circuit (coil and capacitor) and fast-connecting switch:

Purpose: shape current/enable near-zero current moments to facilitate rapid DC fault interruption.

3.3 RRRV (Rate-of-Rise of Recovery Voltage) control:

LC/RC network to manage recovery voltage and keep discharge voltages within safe bounds (target near 1.05× system voltage during transients).

3.4 Surge arrestor:

Absorbs residual energy and charges post-interruption.

3.5 Per-point auxiliary networks:

Each disconnection point includes its own RC/LC branch to manage local transients and improve arc extinction.

4. Expected Performance and Benefits

Interruption speed: target 5–7 ms for fault extinction; faster or slower with system conditions and actuators.

Voltage stress distribution: splitting across three branches reduces per-point insulation stress and enhances reliability.

DC and AC applicability: tuning circuit and fast-switch enable rapid DC fault interruption via controlled zero-crossing or artificial zero-crossing.

Environmental and life-cycle considerations: elimination of SF_6/oil reduces environmental impact; potential maintenance and longevity benefits from distributed stress and reduced arc energy.

5. Discussion

Technical challenges: synchronization across nine points, high-voltage air insulation geometry, thermal/mechanical robustness, integration of SFCL and tuning circuit.

Comparisons: air-insulated approach offers environmental benefits but requires optimization to meet performance benchmarks of traditional breakers.

Applications and scalability: suitable for HV substations and DC/AC hybrid grids; adaptable via adjusting branch count, gaps, and arm geometry.

6. Materials and Methods (Conceptual)

System voltage examples: per-branch voltage ~ $V_{system}/3$ under balanced conditions.

Electrical field considerations: air breakdown strength ~ 20–30 kV/cm (dependent on pressure/humidity); spacing includes safety margins.

6.1 Conceptual circuit models:

(a) Mechanical actuator dynamics.

(b) Nine series-connected points per branch, three branches in parallel.

(c) SFCL nonlinear impedance.

(d) Tuning LC network with fast switch.

(e) RRRV network and surge arrestor.

7. Advantages

Lower cost compared to sulfur hexafluoride (SF6) gas–based breakers.

Faster current interruption than oil- or SF6-based counterparts.

Lower short-circuit current and discharge voltage experienced during faults versus oil/SF6-based breakers.

Environmentally friendly: uses air as the insulation medium, avoiding air pollution and planetary heating associated with oil or SF6.

Longer life and higher efficiency due to design: moving disconnection points in successive stages and presence of auxiliary circuits reduce exposure to fault currents and discharge voltages.

Capability to handle both alternating current (AC) and direct current (DC) when auxiliary circuits are added.

Breaker design includes successive disconnection points and parallel branches, enabling use across medium to high voltages.

Disconnection arms can move in multiple directions (up, down, left, right), speeding up the disconnection process and reducing electrical sparks.

8. Conclusions

A novel air-insulated multi-point circuit breaker concept for medium- and high-voltage DC and AC applications is presented.

The design distributes system voltage across nine disconnection points in three parallel branches, reducing per-point insulation stress and enabling atmospheric air operation.

Auxiliary circuits contribute to reduced disconnection time (5–7 ms) and lower discharge voltages, with environmental and lifecycle benefits.

Realization requires rigorous multidisciplinary validation, prototype development, and testing under representative fault scenarios.

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