TECHNICAL WHITE PAPER

HMP-WP-2503

Static Protection RMU: The Conventional Switch-Fuse Combination

Principles, Applications, Advantages and Capability Boundaries

ABSTRACT

This paper answers one specific question: what a protection scheme built from a load-break switch and a current-limiting fuse inside a conventional RMU (ring main unit) can actually achieve, and what it cannot. The conclusion is clear. It is a scheme formed under particular historical conditions and still in wide use today, whose capability boundaries are set by the word "static": the fuse time-current characteristic is fixed at manufacture, the operation is single-shot, there is no communication interface, and the design basis is the phase-to-phase short circuit.

Three groups of evidence support this judgement. First, the load-break switch cannot interrupt short-circuit current, so the short-circuit current can only be carried by the fuse; the two form a "combination" whose interface parameter is the transfer current[1]. Second, between 1.5 times the transformer rated current and the minimum melting current of the fuse there is a blind zone in which the fuse does not melt and the switch cannot interrupt. Third, in service statistics single-phase earth faults account for the great majority of faults, and the fuse barely responds to them[4].

The paper does not reject the scheme outright. Where capacity is small, no communication is available and cost is the priority, the combination remains a sound choice; what is offered here is an executable boundary list, not a call to "phase it out".

For why this scheme became dominant historically, see HMP-WP-2504; for the technical basis and field evidence of the alternative, see HMP-WP-2505; for the item-by-item comparison with circuit-breaker schemes and the selection method, see HMP-WP-2506.

1 Introduction

In medium-voltage distribution networks, the two most common RMU configurations have operated reliably for decades: on the line side, a load-break switch for sectioning and ring switching; on the transformer side, a load-break switch combined with a current-limiting fuse for the protection of the distribution transformer. The duty of the former is to "make and break load current"; the duty of the latter is to "clear the fault through the fuse in the event of a short circuit and then open all three poles and isolate through the switch".

None of the components in this configuration is complicated, yet together they form a complete protection logic. The key to understanding it is not to look at the switch and the fuse separately, but at the interface between them: who operates in which current range, and what state the system is in afterwards. This paper splits the logic into four parts: structure, zones, applications, boundaries.

The word "static" must first be defined. It does not mean that the equipment is immobile; it means that the protection characteristic does not change with operating conditions. The fuse time-current characteristic is determined by the element material and construction and is fixed at manufacture; a single operation exhausts it, and only replacement restores protection; there is no setting to adjust, no directional discrimination, no communication interface, and no way to tell the faulted phase from the healthy ones. These four features together define the capability ceiling of the scheme and its most fundamental difference from circuit-breaker schemes.

This paper does not discuss the historical origins of the scheme, nor does it carry out a comparative selection against circuit-breaker schemes; the former is covered in HMP-WP-2504 and the technical basis of the alternative in HMP-WP-2505, the latter in HMP-WP-2506. Its task is to explain the conventional scheme itself clearly, so that the comparisons in the following two papers share a common baseline.

2 Composition and Operating Logic

2.1 Capability Boundaries of the Load-Break Switch

A load-break switch is a switching device capable of making, carrying and breaking load current and of making short-circuit current under specified conditions[2]. Its capability list contains one critical "cannot": it cannot break short-circuit current. This limitation is not a design defect but its definition. Precisely for this reason it achieves frequent operation and low cost with an extremely simple arc-quenching structure.

In an RMU a conventional load-break switch is usually built as a three-position device: closed, open (isolated), earthed. All three positions are selected by one operating mechanism and mechanically interlocked to prevent earthing under load or opening the enclosure while live. The advantage of the three-position arrangement is unambiguous status and few operating steps, which also explains why it spread widely through distribution networks.

2.2 The Combination and the Striker Interlock

Connecting the current-limiting fuse in series with the load-break switch in the same phase of the main circuit forms the combination. Current passes through both in turn, the fuse carries the duty of breaking short-circuit current, and the load-break switch carries the duty of breaking load current and of opening the remaining two phases. The mechanical interface between them is the striker: when the fuse melts, the striker protrudes and releases the tripping mechanism of the load-break switch, so that all three poles open together, as illustrated in Figure 1.

This interlock solves a real problem. The fuse clears only the faulted phase; if the other two stay in service, the distribution transformer runs single-phased, which can overheat windings, distort voltage and even cause a secondary fault. Three-phase interlocked tripping converts "fuse operation" into "three-phase isolation" and avoids single-phased operation.



Figure 1 — Action chain of the combination: the fuse clears the faulted phase and the striker initiates three-phase tripping[1][2]

Note: "combination" here refers to the division of duties, not the two devices simply stacked together.

2.3 Five Zones on the Current Axis

Spreading the current axis in multiples of rated current makes the scope of the scheme visible. With rated current as the reference, the whole range is cut into five zones, each with a different party responsible, as shown in Figure 2:

Zone A is normal operation, with continuous current through the equipment; zone B runs from 1.5 times the transformer rated current to the minimum melting current of the fuse, typically about 3 times the fuse rated current. In this range the fuse has not yet melted and the load-break switch has no breaking capability, so the fault can only be cleared by upstream protection. This is the so-called "protection blind zone" and the most substantial weakness of the scheme;

zone C runs from the minimum melting current to the transfer current: the element melts first, the striker trips the switch, and the duty of interruption still rests with the load-break switch. Zone D runs from the transfer current to the rated breaking current of the fuse, where the fuse alone performs a current-limiting interruption. Zone E lies beyond the fuse rated breaking current and beyond the breaking capability of the combination itself, so it can only be handled with the upstream circuit-breaker[1].

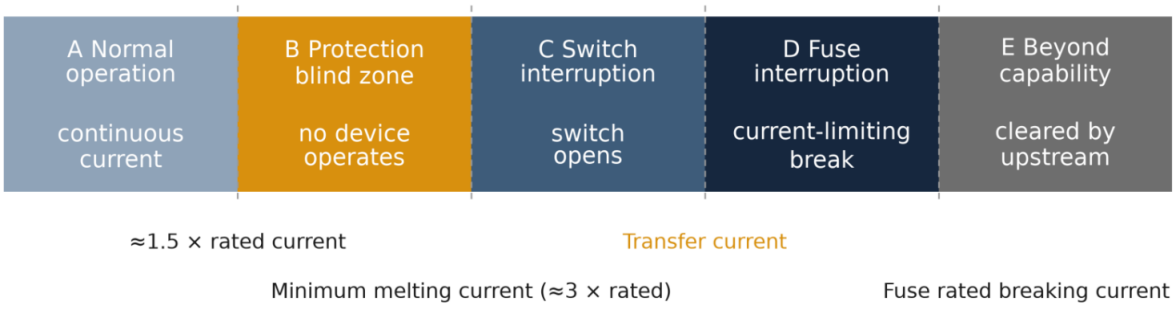


Figure 2 — Five current zones: the switch interrupts in zone C, the fuse in zone D, and zone E relies on upstream coordination[1]

Note: the thresholds vary with fuse type and switch rating, and the positions shown are typical magnitudes; the upper limit of zone E is the fuse rated breaking current.

2.4 Three Criteria for Matching

Whether the combination works reliably depends on three matches. The first is rating match: the fuse rated current must exceed the transformer rated current with sufficient overload margin. The second is range coverage: the minimum melting current must fall within the fault current range that needs protection, otherwise the blind zone is enlarged. The third is transfer-current verification: the load-break switch must be able to break currents below the transfer current, otherwise, once the fuse has operated, the switch side may fail to complete opening[1].

Table 1 Fuse matching and blind-zone calculation for two typical distribution transformers

Check item	400 kVA / 10 kV	630 kVA / 10 kV
Transformer rated current	23.1 A	36.4 A
1.5–6 × rated current	34.6–138.5 A	54.6–218.4 A
Typical fuse rated current	40 A	63 A
Minimum melting current (≈3×)	≈120 A	≈189 A
Blind-zone range	34.6–120 A	54.6–189 A

Note: rated current is calculated from capacity divided by √3 and rated voltage; the minimum melting current is estimated as 3 times the fuse rated current and should be verified against the fuse characteristic curves[1]. This table indicates typical magnitudes only and is not a basis for engineering selection.

The meaning of Table 1 deserves elaboration. For a 400 kVA transformer, when the fault current falls between 34.6 A and 120 A the fuse will not melt, and the load-break switch can do nothing either. This range corresponds exactly to the small overcurrents and partial inter-turn faults common on the medium- and low-voltage side. The larger the capacity, the wider the blind zone in absolute terms, which is one reason why larger transformers tend towards circuit-breaker protection.

3 Typical Configurations and Applications

3.1 The Three-Bay Structure of an RMU

A typical RMU consists of three bays: two incoming bays and one outgoing bay. The incoming bays perform ring sectioning and switching, the outgoing bay supplies the load. When the outgoing bay feeds a distribution transformer, that bay is configured as a switch-fuse combination. This structure allows one RMU to perform both “network sectioning” and “transformer protection” without additional secondary equipment or auxiliary supply.

3.2 Small and Medium Distribution Transformers

The most typical application of the combination is distribution transformers of 630 kVA and below, particularly oil-immersed types. In this capacity range the transformer rated current is small, and the current-limiting characteristic of the fuse can interrupt the fault current early in its rise, which is favourable for controlling arc energy inside the tank. As capacity increases further, rated current rises, fuse ratings grow with it, the blind zone widens and the current-limiting benefit relatively diminishes.
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3.3 Cable Spurs and Passive Stations

At cable spur ends, temporary supplies, rural distribution areas and similar locations, a reliable DC source is often unavailable and a communication channel is difficult to provide. The combination completes its protection operation without any auxiliary supply, a property of real value in such locations. Equally, in existing networks being reinforced with limited funds and with "keep supply, cut outages" as the main goal, the purchase and replacement cost of the combination has an advantage.

2.4 Three Criteria for Matching

Table 2 Application match matrix for the switch-fuse combination

Application	Suitability	Key reason
≤630 kVA oil-immersed transformer, no communication	Recommended	Fast current limiting, no auxiliary supply, low cost
Cable spur ends, temporary supplies	Recommended	Simple construction, no maintenance, interchangeable spares
Large transformer (>630 kVA)	Conditional	Wider blind zone; requires verification and coordination with upstream protection
Networks requiring local fault clearance	Not recommended	No communication or directional discrimination; selective local isolation is impossible
Networks with DG, bidirectional power flow	Not recommended	Fixed fuse characteristic; cannot follow changes in power flow direction
High-reliability demonstration areas	Not recommended	No response to earth faults; restoration depends on manual fuse replacement

Note: rated current is calculated from capacity divided by √3 and rated voltage; the minimum melting current is estimated as 3 times the fuse rated current and should be verified against the fuse characteristic curves[1]. This table indicates typical magnitudes only and is not a basis for engineering selection.

4 Advantages of the Conventional Scheme

Before discussing the limitations, the advantages must be stated honestly. Otherwise "why is it used so widely" cannot be explained, and the subsequent case for alternatives loses its force.

4.1 Fast Current-Limiting Interruption

The current-limiting fuse interrupts the circuit early in the rise of the fault current, with an operating time typically of the order of 10 to 20 ms, and holds the prospective short-circuit peak to a lower level. For an oil-immersed distribution transformer this means the time for pressure to build up inside the tank is compressed, which helps suppress tank rupture and oil ejection.

4.2 No Dependence on an Auxiliary Supply

The operating energy of the fuse comes from the fault current itself: no DC supply, no relay, no setting or calibration. When station service is lost, communication fails or batteries are flat, it still operates. This "passive reliability" is an important reason for its place in distribution networks.

4.3 Interchangeability and Spare Parts

The fuse is a standardised, interchangeable element with a full range of ratings and ample supply; replacement on site requires no special tools or adjustment. For distribution networks with dispersed locations and long maintenance radii, this significantly reduces operating complexity.

4.4 Construction and Cost

The load-break switch has a simple arc-quenching structure, short contact travel and low operating energy, and both panel volume and cost are lower than those of a circuit-breaker panel. In past distribution construction whose primary goal was "reaching more customers", a per-unit cost difference was amplified into a considerable investment difference.

4.5 Standardisation and Supply Chain

This configuration has developed a complete standards framework and industrial division of labour. RMU manufacturers are numerous and high in capacity, product forms and interfaces are highly consistent, and users have mature routes for procurement, spares and training[7]. This is an "ecosystem advantage" that new technologies cannot replace in the short term.

5 Inherent Limitations

5.1 Low-Current Blind Zone

As noted in Section 2.3, the range between 1.5 times the transformer rated current and the fuse minimum melting current is the structural blind zone of the scheme. Within it the fault exists, the equipment does not sense it and the switch cannot clear it, so only upstream protection can operate. Once upstream protection operates, the outage area expands from "one transformer" to "a section of a feeder".

5.2 Insensitivity to Single-Phase Earth Faults

The fuse is designed for phase current and barely responds to single-phase earth faults. In real distribution networks, however, single-phase earth faults account for the great majority of faults. Statistics from a CIGRE working group show that about 85% of faults in cable networks occur in cables and about 15% in transformers, with earth faults exceeding 95% and phase-to-phase faults below 5%[4]. This means the case the fuse is genuinely good at, the phase-to-phase short circuit, is only a small part of the whole. On a different basis — all fault types across a mixed urban network, not cable faults alone — a survey in one Chinese city found single-phase earth faults accounting for over 30% of all distribution faults, with accumulated fuse quality problems reaching as much as 60%[5].

5.3 Single-Shot Operation and Restoration Time

After operating, the fuse is scrap and must be replaced on site by maintenance staff. Restoration time therefore depends not on the speed of fault clearance but on travel time, spare availability and work permits. At the stage where reliability indices move to "99.99%" and "99.999%", this step is an obvious weakness.

5.4 Temperature Rise in the Fuse Cartridge and Insulation Ageing

Continuous current heats the fuse, and the temperature inside the cartridge is higher than elsewhere in the panel; long-term operation may age the cartridge and adjacent insulation. Industry surveys have reported cases where fuse overheating melted the insulating cartridge and forced replacement of the whole set[6]. Such problems do not appear at once but accumulate into maintenance burden and hidden cost.

5.5 Not Settable and Not Communicable

The fuse has no settings and cannot be adjusted to load changes; it has no directional discrimination and cannot follow bidirectional power flow; it has no communication interface, cannot report an operation and cannot accept remote commands.
In distribution networks that require "observability, measurability and controllability", these three gaps are structural.

5.6 Difficulty in Achieving Selectivity

The time-current characteristic of the fuse is fixed, and coordination with upstream protection relays and downstream fuses can only be achieved by separating their curves. Where upstream and downstream ratings are close, or several fuses are connected in series, selectivity is difficult to guarantee. The proportion of incorrect fuse operations reported in industry statistics stems precisely from this[3].

5.7 No Testing or Condition Monitoring

The fuse cannot undergo preventive testing and its remaining life cannot be monitored online; the load-break switch is difficult to test for mechanical characteristics and its isolating gap is not visible. Maintenance can rely only on periodic inspection and post-fault checks, which makes the shift from "time-based maintenance" to "condition-based maintenance" difficult.

5.8 Whole-Life Cost

A 63 A fuse typically dissipates about 50 W per element. On that basis the steady-state loss of each three-pole unit is usually 100 to 150 W (upper figure = fully loaded set at about 50 W per element, lower = smaller ratings or partial loading), giving an annual loss of about 700 to 1,050 kWh at 7,000 operating hours per year, or about 28,000 to 42,000 kWh over a 40-year life[8]. These figures are steady-state estimates at full load; light-load conditions fall below the range. Such losses are usually left out of purchasing comparisons but cannot be ignored in whole-life accounting. Adding the labour and outage cost of fuse replacement partly offsets the economic advantage.

6 Capability Boundary List

Table 3 Capability boundary list of the conventional scheme

Capability	Actual performance of the combination	Key reason
Breaking phase-to-phase short circuit	Above transfer current: current-limiting fuse interruption, 10–20 ms	Met
Breaking load current	Performed by the load-break switch	Met
Clearing single-phase earth faults	Essentially no response; relies on upstream	Not met
Coverage of 1.5–3 × rated current faults	Blind zone exists	Not met
Adjustable protection settings	No settings	Not met
Signal transmission and remote control	No communication interface	Not met
Adaptation to bidirectional power flow	No directional discrimination	Not met
Fast restoration after a fault	Fuse replacement on site	Not met
Maintenance-free operation	No secondary maintenance, but periodic verification and replacement required	Partly met

Note: summarised from Sections 2 to 5; the verdicts address the common requirements of new distribution networks and do not represent every operating condition.

7 Conclusions

First, the combination is not an outdated design but a self-consistent scheme: by dividing duties so that "the switch handles load and the fuse handles short circuits", it buys reliable phase-to-phase short-circuit protection and operation without auxiliary supply at the lowest structural complexity.

Second, its capability boundaries are set by four static features: a fixed characteristic, single-shot operation, no communication and a phase-to-phase design basis. These four cannot be removed by local improvement; only a change of protection method can change them.

Third, where capacity is small, no communication is available and cost comes first, it remains the most economical choice; but where local fault clearance, adaptation to bidirectional power flow and highly reliable restoration are required, it has reached its ceiling.

Fourth, whether a scheme is "outdated" should not be judged by whether it is still in use but by whether it meets the requirements of today's networks. That is exactly the question the next paper answers: why this configuration became dominant, and whether those conditions still hold today.

A Appendix A — Glossary

- Load-break switch: a switching device capable of making, carrying and breaking load current and of making short-circuit current under specified conditions, but not of breaking short-circuit current.
- Switch-fuse combination: an assembly of a load-break switch and a current-limiting fuse in which the fuse breaks the short-circuit current and the switch breaks the current in the remaining two phases.
- Transfer current: the current at which the duty of interruption in a switch-fuse combination passes from the load-break switch (tripped by the striker) to the fuse. Below this value the load-break switch interrupts; above it, up to the rated breaking current of the fuse, the fuse interrupts with current limitation[1].
- Minimum melting current: the lowest current at which the fuse melts reliably, usually about 3 times its rated current and varying with type.
- Striker: the mechanical triggering element that protrudes when the fuse melts, used to trip the load-break switch.
- Current-limiting fuse: a fuse that interrupts the circuit before the prospective fault current reaches its peak, thereby limiting the short-circuit peak.

- Protection blind zone: the current range in which the fuse has not yet melted and the switch is not capable of interruption.
- Time-current characteristic: the curve relating melting time to current for a fuse, fixed at manufacture and not settable.
- Three-position switch: a switch structure in which the closed, isolated and earthed positions are selected by one operating mechanism and mechanically interlocked.

B Appendix B — References (with original sources)

- [1] IEC 62271-105, High-voltage alternating current switch-fuse combinations. International Electrotechnical Commission (IEC).
- [2] IEC 62271-103, High-voltage alternating current load-break switches. International Electrotechnical Commission (IEC).
- [3] CIRED 1997, paper 4.2.1: distribution of fault types and fuse operation statistics in distribution networks. International Conference on Electricity Distribution (CIRED).
- [4] CIRED Working Group WG03: distribution network fault statistics (cables 85%, transformers 15%; earth faults >95%, phase-to-phase <5%). International Conference on Electricity Distribution (CIRED).
- [5] Special survey report on "no fault leaves the customer" work in distribution networks. A municipal power supply company of State Grid (internal document).
- [6] EPTC technical report on solid-insulation ring main units. Electric Power Transmission and Distribution Technology Collaboration Network (EPTC).
- [7] Li Jianji, "Development of the Ring Main Unit" and "Development of the Medium-Voltage Ring Main Unit". Industry journal papers.
- [8] Study on SF6 emission reduction and alternative technologies for 12 kV distribution switchgear. HM Power (Guangdong) Co., Ltd. (internal document).

C Appendix C — Further Reading

- This paper is the first in the series on transformer protection methods. To understand why this configuration became dominant historically, and whether the constraints of that era still hold today, see HMP-WP-2504, "Load-Break-Switch-Dominated RMU: The Historical Choice of Conventional Distribution Networks".
- For the technical basis and field evidence of the alternative, see HMP-WP-2505, "Dynamic Smart Distribution RMU: Circuit Breaker plus Intelligent Terminal"; to go straight to the selection comparison, see HMP-WP-2506, "Transformer Protection Selection: Static versus Dynamic Smart Solutions".



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