TECHNICAL WHITE PAPER

HMP-WP-2504

Load-break-switch-dominated RMU: the historical choice of the traditional distribution network

How a compromise switch became the standard for six decades

ABSTRACT

This paper addresses a frequently misread question: circuit breaker technology matured long ago, so why did ring main units remain dominated by load-break switches? The answer lies in the order of events. The topology of ring supply came first; the industry then developed a division of duty, load-break switch plus current-limiting fuse, specifically for that scenario.

A load-break switch cannot interrupt short-circuit current, so it is a compromise, while a circuit breaker with full-range interruption is the more complete device. But where terminal nodes numbered in the tens of thousands, where upstream protection already existed, and where there was neither communication nor automation, that completeness had nowhere to be spent and remained pure cost. The compromise rested on a precise split of responsibility: main protection at the substation feeder breaker, transformer protection at the current-limiting fuse, switching and isolation at the load-break switch[1][2][3].

This scheme then led for six decades, not because it was cheap but because it was convenient: simple construction, passive operation, no setting work, interchangeable parts, compact prefabricated units. It also entered standards, drawings and spare-parts inventories, creating a self-reinforcing selection habit[4][5][6].

What changed was the distribution network architecture. Distributed generation and storage made fault current small and directionally uncertain, while high-power charging and data-centre loads brought rigid, frequent switching and tighter voltage requirements. The three premises, upstream back-up, unidirectional high current and occasional operation, loosened together, and reselection of the main switch became inevitable. How circuit breakers take on that role is addressed in HMP-WP-2505.

1 Introduction

In medium-voltage distribution networks the most common RMU configuration has run unchanged for decades: load-break switches on the line side for sectioning and ring switching, and a load-break switch with current-limiting fuse on the transformer side for transformer protection. No component of this configuration is complex, yet it carried urban distribution networks through the entire transition from radial to ring operation.

One point that invites misreading is the causal order. The common account is that load-break switches were cheap, so distribution networks used them, implying that an inferior device was adopted first and justified afterwards. The facts run the other way: the topology and operating regime of ring supply came first, and the industry then developed a switch product for that scenario. This paper sets that causal chain out in chronological order.

The argument has three parts. First, demand preceded the device: ring operation calls for frequent switching, definite status indication, reliable isolation and low cost per unit, requirements that point to an operating device rather than a protective one. Second, the completeness of the circuit breaker had no use at terminal nodes of the time:

completeness was pure cost, so it was not selected. Third, the load-break switch is a device of divided duty designed specifically for this scenario; it gave up short-circuit interruption in exchange for a full fit in cost, size and O&M, and it stayed in use because it was convenient, not because it was cheap.

This paper covers only the logic of that historical choice, not parameter-level comparison. For the principles, blind zones and boundaries of load-break switches and fuses, see HMP-WP-2503; for the technical basis, field evidence and intelligent terminals of the circuit-breaker option, see HMP-WP-2505; for choosing between the two in a specific project, see HMP-WP-2506.

2 The network came first: how traditional ring supply took shape and how it operated

2.1 Origins: from radial to ring

Early distribution was radial: substation feeders ran along the streets and terminated at customers, one line serving one block of load. The structure was simple and cheap to build, but had one fatal weakness: any fault, or any maintenance work on any section, meant shutting the whole line. As urban load density rose and cables progressively replaced overhead lines, the affected area and the cost of an outage grew together, and the radial structure could no longer meet the city's requirement for supply continuity.

Ring supply emerged: a long line was split into sections, ties were placed between adjacent sections, each section ran normally on its own, and on a fault the faulted section was isolated and the healthy ones back-fed through the tie. Outage for maintenance became sectional isolation and rapid transfer; one set of switches and one tie cable bought continuity close to that of a dual supply, at an investment far below a second source. That cost-effectiveness is the fundamental reason ring supply spread quickly through European city networks[1][7].

2.2 Operating characteristics: open ring, manual operation, upstream back-up

Traditional ring operation had three characteristics, and these three determined equipment selection. First, open-ring operation: the ring was built, but the tie point stayed normally open, each feeder still carrying load radially, avoiding circulating current and complicated protection coordination. Second, manual operation: after a fault, field staff went to site to judge, isolate and close the tie, restoring supply to the healthy sections. Third, upstream back-up: clearing short circuits was the job of the substation feeder breaker; terminal nodes only isolated and transferred.

Together these three formed a clear hierarchy of responsibility: the substation cleared, the fuse protected the transformer, the load-break switch operated and isolated. Each layer did only its own job and none overstepped. Only with that hierarchy in mind does it become clear why terminal nodes needed no circuit breaker.

2.3 Advanced for its time: high continuity at low investment

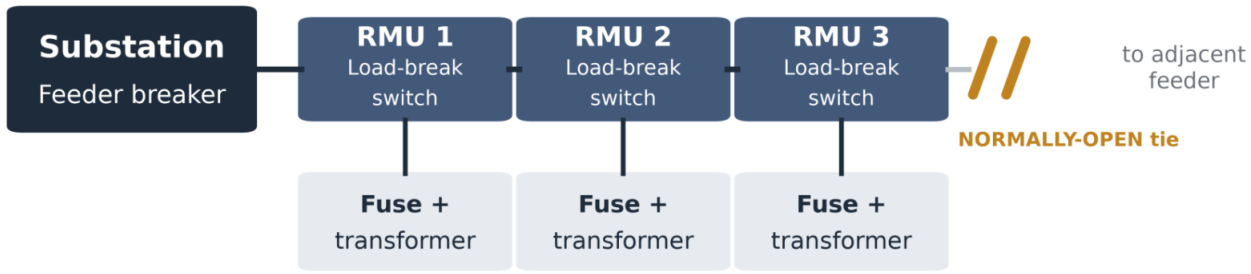
In historical terms ring supply was a real advance. For the first time urban distribution could confine a fault to one section and back-feed the rest; equipment investment was spread across many nodes, so the network could be extended section by section as load grew; and maintenance outages changed from whole-line shutdowns to sectional work, greatly shortening outage time.

More importantly, the structure asked of equipment only that it be adequate: able to break load current, isolate reliably, earth, operate frequently, and run unattended outdoors or semi-outdoors for years. None of these requirements touched short-circuit interruption, because that duty had been assigned upstream. The room for equipment design was thereby opened.

2.4 Three hard requirements handed down to the device

Collecting the analysis, the requirements on a switch at a ring terminal node reduce to three. The first is operating capability: frequent making and breaking of load current, definite status, isolation and earthing. The second is economics: low cost per unit and small size, so units can be deployed in numbers along streets, inside residential blocks and in compact substations. The third is simplicity of O&M: no dependence on DC supply, no setting or commissioning, and long unattended operation.

Note that none of the three mentions short-circuit interruption. That is not an omission but a design choice of the network itself: short-circuit clearing was moved up to the substation and the terminal kept only switching and isolation. The direction of equipment selection was settled at that moment. This topology and the three-tier division of protection are shown in Figure 1.



1. Substation feeder breaker: main protection, phase-to-phase short circuit and overcurrent
2. Current-limiting fuse: short-circuit protection of the distribution transformer
3. Load-break switch: load switching, isolation and earthing; no short-circuit interruption

Figure 1 — Topology of a traditional open-ring network and the three-tier division of protection

Note: "three-tier" refers to main protection at the substation, fuse protection of the distribution transformer, and switching and isolation at the node; the three responsibilities do not overlap.

3 Then came the switch: birth of a compromise product and its division of duty

3.1 What “compromise” precisely means

The industry often calls the load-break switch a compromise, because it cannot interrupt short-circuit current. That is correct but easily misread: compromise here means a narrower functional scope, not lower reliability. In the functions it does own, making, carrying and breaking load current, closing onto short-circuit current, isolation and earthing, it is as reliable as a circuit breaker, and has fewer failure points because its construction is simpler.

Put more precisely: a circuit breaker is a complete switch, a load-break switch is a switch of divided duty. Completeness and division carry no intrinsic ranking; what matters is which one the scenario requires. Where the scenario needs only divided duty, the premium for completeness is pure cost; where it needs completeness, the divided solution becomes the weak link. Chapter 5 of this paper describes exactly how that premise was overturned.

3.2 Background: urban distribution in the 1960s

In the 1960s the load-break switch and disconnector first entered distribution networks. Only two kinds of switch were then available: circuit breakers, bulky and heavy on maintenance, and simple disconnectors that could only isolate and relied on fuse replacement for transformer protection. The load-break switch and disconnector, and their combination with fuses, were therefore a genuine breakthrough: they opened the way to smaller, cheaper substations and switchgear, and made open-ring operation possible[3].

That breakthrough rested on four conditions of the time, all of them necessary. First, terminal points were extremely numerous and dispersed: a city had tens of thousands of MV terminal nodes, spread along streets, inside residential blocks and at factory gates, highly sensitive to the cost and size of each unit. Second, there was no communication or automation: no channel between switches, no master station in the substation, everything dependent on staff attending site. Third, upstream main protection already existed: the substation feeder breaker cleared short circuits, so terminals needed no duplicate provision. Fourth, the O&M workforce consisted mainly of electricians: able to operate and replace parts, but not to set relays or analyse waveforms.

Together these four conditions pointed to a very specific product definition: as simple as possible in construction, no secondary circuits, manual operation, clear indication of open and closed and earthed status, and no need for maintenance over long periods. The load-break switch was built to precisely that definition[1].

3.3 Why the circuit breaker was not chosen at the time

Since circuit breakers had long been mature, why not fit one at every terminal node? There are five reasons, each grounded in conditions of the time.

First, mismatch of function. The duty of a terminal node was switching and isolation; short-circuit clearing was already carried upstream. The core capability of the circuit breaker, full-range interruption, had no application here; buying it meant paying for something unused.

Second, total cost. The price of a circuit breaker is not only the apparatus but the protective relays, the DC operating supply or energy-taking circuit, the secondary wiring and the on-site commissioning. In an era when protection still occupied separate panels and vacuum interrupters were not yet produced at scale, these items together could multiply the investment in a single terminal node, and with tens of thousands of nodes the difference across a network was enormous.

Third, size and siting. Urban terminal nodes sit beside sidewalks, inside residential blocks and in compact substations, where footprint and headroom are both constrained. Early circuit breakers included operating mechanism, interrupter and secondary panel space in a cubicle clearly larger than a load-break switch cubicle, raising both siting difficulty and civil works cost.

Fourth, time coordination for transformer protection. The current-limiting fuse has an inverse-time characteristic: the higher the current, the faster it operates. When prospective short-circuit current enters the current-limiting range, the element melts within the first half cycle and limits let-through energy, clearing in only 10–20 ms, whereas the breaker with relay of that period typically took 80 ms or more as a whole, and even today can hardly be faster than a fuse in that range. Under the conditions of the time, then, the fuse was not merely cheaper: it genuinely coordinated better[2].

Fifth, the O&M barrier. Half the value of a circuit breaker lies in being settable and communicable. With no master station, no channel and no one able to set relays, neither capability could be realised; what remained was extra maintenance burden: DC supply to look after, relays to calibrate, settings to verify. For the staffing structure of the time that was a burden, not a capability.

The five reasons come down to one sentence: not that the circuit breaker was poor, but that the distribution system was not yet ready to let it do its work. Device capability must match system capability; provision ahead of need is just as much an engineering error.

3.4 Division of responsibility: how a compromise became a workable arrangement

Once short-circuit interruption was given up, that duty had to go somewhere. The solution split it in two: short circuits inside the transformer were taken by the current-limiting fuse in series in the transformer circuit, and short circuits on the line side by the substation feeder breaker. The load-break switch took only the part it does well: breaking and making load current, isolation and earthing.

For the division to hold under fault conditions a mechanical interface was also needed: when the fuse operates, the striker ejects and trips the three poles of the load-break switch together, avoiding the single-phasing condition in which one phase has cleared while the other two keep running[2]. That small linkage is one of the keys to whether the division works at all.

The division had its price, and the price was fixed from the outset: three responsibilities independent of one another, so failure of any one falls back on staff attending site. A mis-set upstream relay blackouts the whole section; an oversized fuse lets a transformer fault run until oil temperature or pressure accumulates; the load-break switch can only isolate, not clear, so fault current persists until it does. Under traditional ring operation these costs were acceptable, since the outage area was limited, the repair radius short and load not highly sensitive to continuity; once supply reliability became a performance indicator, they became weak points.

Table 1 Division of responsibility among the three protection tiers

Device	Duty assumed	Duty not assumed
Substation feeder breaker	Clearing of line short circuits and overcurrent; main protection of the network	Current limitation for faults inside the transformer
Current-limiting fuse	Short-circuit protection of the transformer; current limitation in 10–20 ms	Load switching, isolation and earthing
Load-break switch	Load switching, isolation and earthing; closing onto short-circuit current	Short-circuit current interruption

Note: based on the duty definitions of IEC 62271-105 and the analysis in Chapter 3 of this paper[2].

3.5 Summary: putting responsibility where it is cheapest

The ingenuity of the arrangement lies not in outstanding performance of any component but in placing three kinds of responsibility where each was cheapest and best suited: the fuse where fast current limitation was needed, the substation breaker where wide-area clearing was needed, the load-break switch where frequent operation was needed. Total cost fell to a level the time could bear, without losing protective logic.

That is the positive sense the word compromise should carry: not a lowering of standards, but the best allocation of responsibility under constraint.

4 Why the load-break switch option long dominated RMU selection

The reason the load-break switch option became the mainstream is not that it was cheap, cheap holding only against initial capital cost, but that it was convenient, and convenient through the whole process.

4.1 Arc-quenching media: many routes competed, SF_6 prevailed

The arc-quenching medium of the load-break switch went through several routes, each with its own trade-offs. Oil-immersed types relied on gas decomposed from oil to blow the arc and could make and break load current, but the oil degraded, needed filtering and replacement, and carried fire risk; air-blast types used a piston to compress gas, the medium cost nothing, but cylinder and nozzle were real mechanisms with unavoidable wear and maintenance; gas-producing types were simple and cheap but limited in quenching capability and gradually left the mainstream; vacuum had strong quenching and long life, but no visible break, making a three-position arrangement of isolation and earthing in one unit difficult, so RMUs needed an additional disconnector to fill the gap.

The SF_6 route finally prevailed. Not because it beat every other route on every index, but because it solved insulation and arc quenching at once: gas enclosed in a shell served both to quench the arc and to insulate, letting the RMU be compact, fully sealed and low-maintenance, an exact fit to dispersed, unattended ring terminals. According to a 1997 industry survey, the ratio of load-break switches to circuit breakers in European and North American MV networks had reached about 7:3[6].

But the winning option carried its own price. Gas leakage risk never disappears, bringing both insulation risk and the O&M cost of topping up and leak detection. More decisive is environmental compliance: Regulation (EU) 2024/573 prohibits placing medium-voltage switchgear containing fluorinated greenhouse gases (GWP≥1) on the EU market from 1 January 2026, with units of 24 kV and below first, 24–52 kV following from 2030 and above 52 kV from 2032[8], so withdrawal of SF_6 from distribution is settled. How that constraint reaches equipment selection is covered in HMP-WP-2505.

SF_6 is not the only route, however. Siemens 8DJH 12 uses Clean Air, purified air, for insulation and vacuum for interruption; Eaton XIRIA uses natural-air insulation with an over-voltage-free design and likewise vacuum for interruption. Both show that fluorine-free solutions have reached product maturity in the distribution scenarios described in this paper[9][10].

4.2 Fixing of the combined unit

What became the standard product was the combination of load-break switch and current-limiting fuse, not the load-break switch alone. The combined unit puts both devices in one sealed enclosure, completes wiring, testing and sealing in the factory, and goes into service on site once the cables are connected. Construction time fell from months to days and civil works shrank, so the RMU changed from equipment assembled on site into a product that could be moved.

It also fixed a set of interface definitions still in use: transfer current defines where the breaking duty of the switch ends and that of the fuse begins, the striker defines the mechanical linkage between them, and the three-position arrangement defines the sequence of operation and interlock[2]. Once the standard was set, the product form stabilised and the supply chain took shape around it[11].

4.3 Four concrete expressions of convenience

Taking convenience apart reveals four concrete capabilities, which answer the three hard requirements of Chapter 2 one by one.

The first is construction and cost: a simple quenching structure, short contact travel and low operating energy make the cubicle clearly cheaper than a breaker cubicle, so that a unit at every node becomes economically viable. The second is passive operation: tripping energy comes from the fault current itself, needing neither DC supply nor relays, so the device still operates when station auxiliary supply fails or communication is lost. The third is no setting and interchangeability: fuses are standardised with a full range of ratings, replacement on site needs no special tools, and O&M reduces to changing a part. The fourth is compactness and prefabrication: several circuits share one enclosure, the footprint is small, and the unit can be factory-built and transported whole.

None of the four is high performance, yet together they make operation simple and smooth: easy to design, easy to tender, easy to build, easy to maintain. In engineering practice, easy often outlives advanced.

4.4 The result of scale: from product to habit

Long and widespread use brought not only installed numbers but a whole system grown around it: typical design drawings, technical specifications for tendering, construction and acceptance procedures, O&M work instructions, spare-parts inventories, crew training materials. When all these documents are written around one configuration, selection ceases to be a technical comparison and becomes process inertia[4][5].

That is both the success of the option and the reason replacement later slowed: changing one device is easy, changing a system is hard. Only with that in mind can the gradual nature of the reselection described later be judged fairly.

Table 2　Basic differences between the two options in traditional ring scenarios

Aspect	Load-break switch + fuse	Circuit breaker
Breaking range	Load current; short circuit limited and cleared by the fuse	Full range, from minimum to rated short-circuit current
Protection characteristic	Fixed current-time characteristic, not settable	Settable, directional, communicable
Secondary dependency	None (striker linkage)	Protection relay plus energy-taking or DC supply
Cost and size per cubicle	Low, small	Higher, larger
O&M mode	Mainly part replacement, no setting	Setting management and condition analysis

Note: only basic differences are listed, to support the argument of this chapter; item-by-item parameters and selection methods are given in HMP-WP-2506.

5 Reselecting the main switch for the new distribution network: why the load-break switch no longer fits

The first four chapters describe a self-consistent system: the network set requirements, equipment was designed to them, responsibility was split precisely, and operation stayed stable for decades. The system rested on three premises: upstream back-up, unidirectional high current, occasional operation. What changes in the new distribution network happens not in the equipment but on the source side, the load side and the operating regime, and it removes all three at once.

5.1 Change on the source side: smaller fault current, uncertain direction

Distributed renewables turn the source from one into many. PV and wind connect to the medium- and low-voltage side through inverters, power flow becomes bidirectional, and fault current no longer comes only from the substation; more decisive is magnitude, since inverter-based sources deliver short-circuit current typically only 1.1 to 2 times rated current, possibly below the minimum melting current of the fuse, landing exactly in the protection blind zone described in HMP-WP-2503: the fault is real, the device does not operate.

Storage and V2G push the change into the operating regime. The value of storage lies in charging and discharging, which is bidirectional power flow; grid-connected and islanded transfer then require protection to change settings and direction with the operating mode. V2G further lets electric vehicles feed power back when needed, so the number of sources and the operating modes move from a fixed few to variable at any time. Meanwhile the daily cycle of storage pushes switching from occasional to frequent, making mechanical life a hard index.

5.2 Change on the load side: rigid, frequent, sensitive

High-power charging brings power surges. Station power rises from tens of kilowatts to the megawatt level, load is random and sharply variable, with harmonics and voltage dips; dense connection rapidly enlarges the area affected by a fault on a single feeder, and the cost of blacking out a block and tracing it by hand is no longer acceptable.

Data-centre load brings sensitivity to voltage. Such load tolerates voltage sags measured in milliseconds, and the dip during conventional fault clearing is enough to take it off the grid at scale and transfer it to back-up supply, producing abrupt, rigid switching. The demand it places on the switch runs both ways: faults must be cleared faster and restoration must be more stable, precisely the part a scheme of one-shot fuse operation and manual restoration finds hardest to meet.

5.3 Change in operating regime: from being able to isolate to being able to decide on site

These changes finally land on the operating regime. Distributed self-healing requires fault isolation in the 100 ms class and restoration in seconds; waiting for the upstream substation is no longer acceptable. A fault may lie downstream of distributed sources, so direction is reversed, or the current may be too small to start upstream protection, and upstream back-up no longer holds. At the same time, dense distributed resources require nodes able to observe their state and coordinate, otherwise neither self-healing nor optimisation can begin[12].

5.4 Collapse of the three premises and the direction of reselection

These three premises were not an oversight of designers but technical facts of the network at the time: short-circuit current supplied only from the substation in one direction, several times rated, and switching counted in operations per year. While the premises held, the division of responsibility was both economical and safe; once they fail, the same division turns from adequate to inadequate. Set against present conditions one by one, the three have failed together.

Table 3 Conditions under which the three premises held and why they now fail

Premise	Why it held in traditional networks	Why it fails in new networks
Upstream back-up	Fault current large and unidirectional; the substation feeder breaker is certain to start	The fault may lie downstream of distributed sources, so direction is reversed; current may be too small to start
Unidirectional high current	Load unidirectional and fault current several times rated; the fuse current-time characteristic coordinates deterministically	Inverter-based sources give only 1.1–2 times rated fault current, inside the fuse blind zone
Occasional operation	Annual operations counted in single digits; mechanical life designed for occasional duty	Daily storage cycling, V2G and charging load raise operations by an order of magnitude

Note: based on Chapter 3 of this paper and the analysis in HMP-WP-2503; "today" refers to typical conditions of the new distribution network.

When all three premises fail together, the basis of the division disappears. This is not to say the load-break switch was badly made; the network assumptions it was designed against no longer hold.

Terminal nodes therefore need to recover the capability of a complete switch: to interrupt fault current over the full range, to be set according to the operating mode, and to coordinate with neighbouring nodes. The circuit breaker returns to the terminal position of the distribution network, not because it is more advanced, but because the constraints that once made it unnecessary have disappeared one by one.

It should be noted that the circuit breaker is only the first step. Replacing the load-break switch with a breaker while omitting settable protection, reliable communication and verifiable state awareness leaves the node merely a more expensive switch. Interruption capability and decision capability must arrive together before the network truly gains self-healing and assessability[13]. Technical detail and field evidence for both steps are given in HMP-WP-2505. These changes and the switch requirements derived from them are summarised in Figure 2.

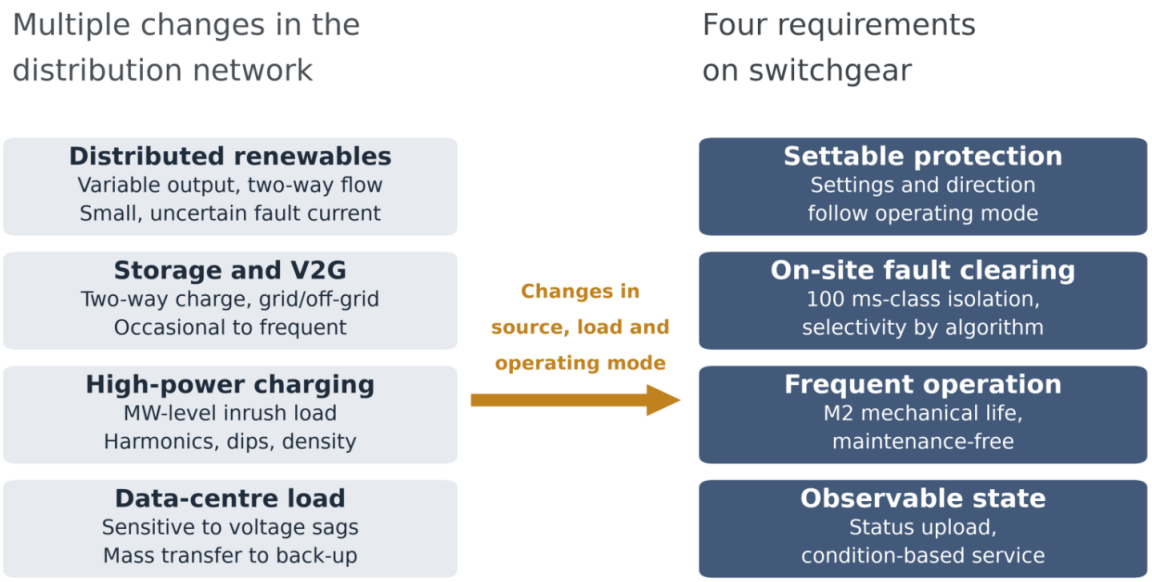


Figure 2 — Multiple changes in the distribution network and the four requirements they place on switchgear

Note: the four boxes on the left cover changes on the source side (distributed renewables, storage and V2G) and the load side (high-power charging, data-centre load); the change in operating regime is described in 5.3; together the three constitute the "multiple changes". The four items in the right column are the switch requirements derived from them. The figure is a qualitative summary and does not prescribe configuration for a specific project.

6 Conclusions

First, in sequence, the topological demand of ring supply came before the load-break switch product that fitted it. Read the order backwards and "making do with an inferior device for sixty years" becomes inexplicable.

Second, the load-break switch is not an inferior article unable to break short-circuit current; it is a dedicated design that trades that duty for cost and O&M advantage. The circuit breaker is the more complete switch, but completeness misplaced where it is not needed is nothing but cost.

Third, the real reason it led for six decades was not cheapness but convenience: easy to design, easy to build, easy to maintain. Cheap holds only against initial cost; convenience runs through the whole process, entered standards and procedures, and became self-reinforcing inertia.

Fourth, the change comes from the network architecture, not from the switch. On the source side fault current is smaller and its direction uncertain; on the load side rigid, frequent and sensitive consumption patterns have appeared; the operating regime demands on-site decisions and coordination. The three premises, upstream back-up, unidirectional high current and occasional operation, disappear together, and reselecting the main switch becomes a necessity rather than a preference.

Fifth, reselection has two steps: the circuit breaker settles whether full-range interruption is possible, the intelligent terminal settles whether to interrupt, where, and how to restore supply afterwards. Doing only the first discounts the return on investment; doing only the second builds on air. The complete scheme for both steps is given in HMP-WP-2505.

Further reading: for the structure, operating logic and capability boundaries of this scheme itself, see HMP-WP-2503, Static-protection RMU: the traditional solution of load-break switch and current-limiting fuse combination; for how the circuit-breaker option enters the RMU, including vacuum interruption, self-powered protection, intelligent terminals and distributed self-healing, see HMP-WP-2505, RMU for the dynamic smart distribution network: circuit breaker plus intelligent terminal.

A Appendix A — Definitions of terms

- Ring supply: a supply arrangement in which a distribution line is divided into sections with ties between adjacent sections, each section running normally on its own, and on a fault the faulted section is isolated and back-fed through the tie.
- Open-ring operation: an operating mode in which the ring tie point stays normally open and each feeder still carries load radially, avoiding circulating current and complicated protection coordination.
- Load-break switch: a switching device able to make, carry and break load current and to close onto short-circuit current, but unable to interrupt short-circuit current.
- Combined unit: the combination of a load-break switch and a current-limiting fuse; after the fuse interrupts the short-circuit current, the striker trips the three poles of the switch, completing isolation and earthing, while load current in the remaining two phases is broken by the switch.
- Transfer current: the maximum current a load-break switch in a combined unit can break; above that value the fuse takes over the breaking duty.
- Striker: the mechanical triggering element ejected when a fuse operates, used to trip the three poles of the load-break switch.
- Current-limiting range: the range of prospective current in which a fuse melts within the first half cycle and limits let-through energy; below that range its characteristic is inverse-time.

- Division of responsibility: a design method that allocates protection and switching duties to different devices or layers according to economics and technical fit.
- Inverter-based source: a distributed source connected through a power-electronic converter, whose fault current is controlled and typically only 1.1 to 2 times rated current.
- V2G: Vehicle-to-Grid, electric vehicles feeding power back to the grid, so that charging facilities also become dispatchable sources.
- Distributed self-healing: a self-healing method in which terminals decide on site and coordinate with neighbours to isolate and transfer, without relying on a master station.

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