TECHNICAL WHITE PAPER

HMP-WP-2505

Dynamic Smart Distribution RMU: Circuit Breaker plus Intelligent Terminal

A circuit-breaker-based foundation for distribution network intelligence

ABSTRACT

The new smart distribution network is a dynamic one: dispersed sources, bidirectional power flow, frequently changing operating states, and loads highly sensitive to interruptions — while environmental compliance has shifted from an aspiration to a market-entry requirement. HMP-WP-2504 established that the three premises on which the traditional ring main unit preferred load-break switches — upstream backup, unidirectional flow, occasional operation — are loosening at the same time; HMP-WP-2503 established that the combination of a load-break switch and current-limiting fuses is bounded by being static. Both point in the same direction: the primary switching device of the distribution network will ultimately be a circuit breaker.

As the basic primary device, a circuit breaker combined with self-powered protection can replace the load-break switch plus fuse combination: no DC supply is required, inverse-time or definite-time protection is available, the configuration is simple and maintenance is easy. Where the requirements of a new smart distribution network apply, an intelligent terminal and sensors can optionally be equipped, fed from a PT or a low-voltage supply, forming an intelligent solution applicable to a range of scenarios.

The market does not choose the breaker because it is "more advanced"; two drivers converge. First, environmental trends narrow the technical route of load-break switch and fuse combinations — fewer options and visibly higher cost. Second, the dynamic network's need for local fault isolation and intelligence makes the breaker the necessary choice. Even where intelligence was not planned at design stage, a breaker-based unit can later be upgraded through secondary equipment alone: earlier investment is not lost and lifecycle cost stays under control.

1 Introduction

The selection of a distribution ring main unit (RMU) reached a mature consensus in traditional static distribution networks. The two preceding white papers in this series have set out the background: HMP-WP-2504 explains the historical conditions under which the load-break switch spread widely; HMP-WP-2503 analyses the protection principle and inherent limits of the load-break switch plus fuse combination, together explaining why this scheme became dominant in networks with unidirectional power flow.

The external conditions behind the traditional selection are now changing systematically. As distributed PV, energy storage and charging piles connect in large numbers, the distribution network is shifting toward a dynamic network with bidirectional flow and frequently changing operating states, placing higher demands on local fault handling and supply continuity. At the same time, global greenhouse-gas controls are tightening, gases such as SF_6 are restricted, and the technical route and cost structure of conventional ring-main equipment are affected.

These two constraints — network characteristics and environmental compliance — have updated the criteria for equipment selection. The circuit breaker can serve as a unified primary hardware base, paired with different secondary schemes as required: with self-powered protection, it needs no external secondary supply and can directly replace the load-break switch plus fuse combination; with an intelligent terminal and sensing units, it supports intelligent functions such as local fault isolation and network self-healing.

This paper focuses on the circuit-breaker-type RMU. Chapter 2 reviews the five changes in the dynamic network and the four primary and four secondary requirements they raise; Chapter 3 argues why the circuit breaker is the preferred primary device for dynamic smart networks; Chapter 4 sets out the capability requirements of the intelligent terminal, its two coordination modes and deployment conditions; Chapter 5 verifies the feasibility of the scheme through four overseas and domestic field cases; Chapter 6 draws the conclusions. From the perspectives of network evolution, engineering constraints and whole-life investment, the paper examines the selection logic behind the circuit breaker as the base switching device of the RMU in dynamic smart networks, as a reference for equipment selection.

2 Requirements on the RMU for Dynamic Smart Distribution Networks

"Dynamic" is not a figure of speech but a set of verifiable facts. Setting them out one by one makes it clear which RMU capability each fact ultimately lands on.

2.1 Five Features of the Dynamic Network

Dispersed sources. Distributed PV, wind power, energy storage and V2G electric vehicles connect from the distribution side; fault current is controlled by converters, typically reaching only 1.1 to 2 times the transformer rated current, with direction changing with output and power flow. This magnitude falls precisely inside the division-of-duty blind zone described in Section 2.3 of HMP-WP-2503: the fuse does not melt and the load-break switch cannot interrupt — the fault is real but no device operates.

Bidirectional power flow. Storage charging and discharging, surplus-power export, and microgrid grid-tied/islanded switching invalidate the unidirectional assumption that "sources are upstream and loads are downstream." Directional criteria, setting groups and coordination must all switch with the operating state rather than being fixed at manufacture.

Frequently changing operating states. The daily cycling of storage pushes switching operations from an annual to a daily basis, so mechanical and electrical life shift from margin to constraint[2]. Maintenance, transfer supply and grid/island switching likewise require repeated operation, with the state after each operation verifiable.

Sensitive loads. High-power charging brings kilowatt-to-megawatt power surges and harmonics; data centres tolerate voltage sags for only a few milliseconds, and the voltage dip during a conventional fault clearance is enough to cause large-scale disconnection and transfer to standby supply. The cost of an outage has changed from "losing a few kilowatt-hours of sales" to "interrupted production and damaged equipment."

Mandatory environmental compliance. Greenhouse-gas controls keep tightening; Regulation (EU) 2024/573 has set commissioning restrictions on fluorinated-gas MV switchgear up to 24 kV. Environmental compliance has moved from an aspiration to a market-entry threshold, directly constraining the technical route of primary equipment (see Section 2.5).

2.2 Requirements on the Primary Equipment

Breaking these features down into requirements on the primary equipment gives four items.

First, full-range breaking capability: from the smallest earth-fault current to the rated short-circuit breaking current, every level must be interrupted reliably. Distributed generation injection complicates the composition of short-circuit current; the equipment must not only meet the rated short-circuit breaking current but also retain effective interruption under DC component and asymmetrical breaking conditions. Otherwise a switching node without full-range breaking can only wait for the upstream circuit breaker to operate, and the outage area expands.

Second, higher mechanical and electrical life: products reaching M2 and E2 classes operate reliably under the higher switching frequency of dynamic networks and need little or no maintenance[2]; they also withstand repeated closing/opening and trial energizing, and will not exhaust their mechanical and electrical life ahead of time under fault-current making, repeated automatic standby-source transfer, and repeated grid/island switching.

Third, stable operating characteristics: stable closing/opening times and speed, and low three-pole non-simultaneity, make protection operation and self-healing restoration times predictable with low dispersion — a necessary condition for intelligent distributed distribution automation.

Fourth, interfaces and an environmentally friendly form: auxiliary contacts, position signals and sensor interfaces, real-time communication with intelligent terminals and remote master stations to support intelligent network operation; meanwhile no fluorinated greenhouse gas, compact dimensions suited to small urban substations and outdoor enclosures.

2.3 Requirements on the Secondary Equipment

Breaking capability in the primary equipment solves only half the question of "whether it can be cleared." Which section to clear, when to clear it, and how to restore afterwards belong to the secondary side. The dynamic network raises four requirements on the secondary side.

Protection must be settable, directional and differential. Settings are no longer a single fixed curve but multiple setting groups preset by operating state, switchable locally or remotely; directional elements must identify flow reversal; differential protection must compare current at both ends, moving selectivity from "separated curves" to "algorithmic judgement."

Fault discrimination must be completed locally. Distributed self-healing requires hundred-millisecond isolation and sub-second restoration; leaving all judgement to the master station exceeds what communication latency and master-station processing can handle. More importantly, isolation must still be completed locally when the communication part is impaired.

Status must be observable and uploadable. Electrical, mechanical and in-enclosure environmental quantities are collected online, serving both fault analysis and condition-based maintenance — replacing "periodic outage maintenance" with "maintenance according to condition."

Interfaces must be integrated with the primary side. The secondary side is no longer an add-on panel, but shares structure, power supply and communication with the switching body, reducing field wiring and commissioning effort. The implications for manufacturing and operation are developed in Chapter 4.

2.4 Reliability, Integrated Cost and Whole-Life-Cycle Management

The dynamic smart distribution network has bidirectional flow and frequently changing states; the direction and magnitude of fault current change continuously with distributed generation switching, placing differentiated reliability demands on the RMU. It must maintain basic insulation and switching capability while being adapted to bidirectional fault breaking, so that existing protection coordination does not fail after network reconfiguration. It must support status awareness and data upload for local fault isolation and network self-healing, and suit unattended scenarios such as supercharger stations, storage stations and suburban networks, with strong environmental tolerance, low fault rate, and fewer field maintenance visits and outage risks. Protection settings and operating logic must be online-settable, so that primary equipment need not be replaced when the network expands or new sources connect.

On integrated cost, selection cannot compare only the initial purchase price. Integrated cost includes initial investment, long-term operating energy consumption, inspection and maintenance expenditure, outage losses, spare-parts inventory, and end-of-life dismantling, innocuous treatment of the insulating medium and material recovery. Conventional schemes such as the switch-fuse combination have an advantage in first purchase price, but their protection coordination is limited; network reinforcement often requires replacing the whole panel, and fluorinated insulating media carry compliant-disposal costs. These hidden outlays raise long-term total investment.

Whole-life-cycle management is the core framework that balances reliability targets and integrated cost. It breaks segmented management down and runs reliability control and cost optimization through the entire chain of design, manufacture, commissioning, online monitoring, maintenance and retirement recovery. Digital ledgers and condition monitoring with early warning keep equipment running reliably under changing networks; maintenance is scheduled according to actual health, avoiding both over-maintenance and neglect, extending primary-equipment service life, reducing panel replacement, simplifying spare-parts stock and ensuring compliant environmental disposal. The outcome is the reliability level required by dynamic networks within an acceptable cost range.

2.5 Environmental Compliance

Another constraint comes from environmental regulation. Regulation (EU) 2024/573 imposes a commissioning restriction from 1 January 2026 on fluorinated-gas MV switchgear up to 24 kV, with exceptions only where the procurement procedure demonstrates no suitable alternative[4]. Current industry alternatives include dry-air insulation, atmospheric sealed natural air insulation, nitrogen insulation and solid insulation, while arc quenching widely uses the vacuum interrupter[3].

Environmental compliance restricts fluorinated gases and also changes the design philosophy of ring main units. The reliability, compactness and low cost (simple structure) of conventional load-break switches and combinations rest on the high dielectric strength of SF_6. Once fluorinated gases exit, load-break switch products must change their structural design approach and face greater difficulty in size control and manufacturing cost, weakening their competitiveness relative to circuit-breaker products. These five changes and the resulting capability requirements are summarized in Figure 1.

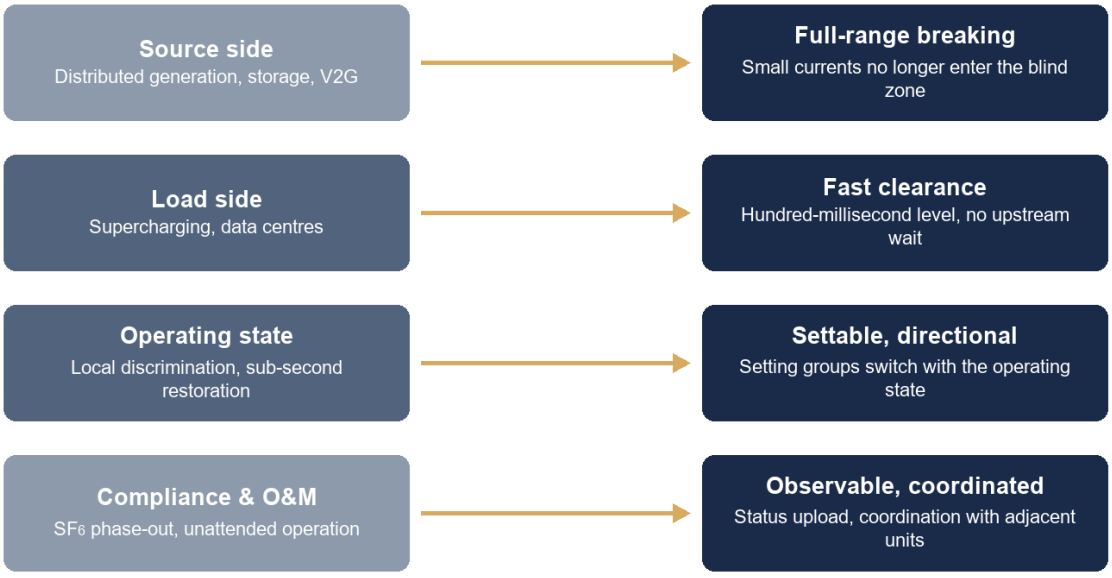


Figure 1 — Key changes of the dynamic network and the capability requirements on the RMU

Note: the figure is a qualitative summary illustrating the requirement cascade; it does not represent the configuration of any specific project.

3 The Circuit Breaker: The Irreplaceable Primary Foundation

The four primary requirements of Chapter 2 all fall on the switching body; these four determine whether the four secondary requirements can be realized.

3.1 Inherent Limits of the Load-Break Switch in Dynamic Smart Networks

By design, the load-break switch is not intended to handle short-circuit faults on its own. Its core duty is making and breaking normal load current; it has a limited short-circuit making capability but cannot interrupt short-circuit current independently.

In a static network, fuse combination provides fault protection in a simple and economical scheme. But in a dynamic smart network with bidirectional flow, frequent operating-state changes, and a need for local fault isolation and network self-healing, the weaknesses of this scheme are continuously amplified:

1. Short-circuit interruption relies on the fuse, which is a single-shot element that must be replaced after operation. Unlike a circuit breaker, it cannot be re-closed after reset and verification following fault clearance, and it cannot support fast automatic transfer and self-healing of the network.

2. The fuse characteristic is a fixed inverse-time curve — static protection that cannot be coordinated and set with digital relays or intelligent terminals. When distributed generation switching and network reconfiguration change the magnitude and direction of fault current, coordination between the fuse, upstream protection and adjacent circuits is easily lost, making it difficult to adapt to a dynamic network.

3. The load-break switch itself has a relatively low mechanical operating life and is not suited to frequent operation. Scenarios such as network self-healing, reconfiguration and repeated switching raise the operating frequency; over long service, the life weakness becomes prominent, and maintenance workload and outage risk rise accordingly. These are inherent, fundamental limits of the scheme, not something removed by better craftsmanship or manufacturing precision. The switch-fuse combination can continue to serve simple, static conventional network scenarios, but it cannot be the base primary switching device for a dynamic smart distribution network.

3.2 The Circuit Breaker: The Preferred Primary Device for Dynamic Smart Networks

The circuit breaker can meet the core requirements of dynamic smart networks because these capabilities derive from the physical structure of the switching body rather than being stacked on by add-on devices; this structure is the underlying primary carrier for network intelligence.

First, it has full-range fault breaking capability, interrupting every fault current from the smallest earth-fault current to the rated short-circuit fault current. Together with protective relays it allows flexible setting and selective coordination between levels, adapting to networks with bidirectional flow and multi-point distributed generation, achieving precise fault isolation and preventing outage expansion — something static fuse protection cannot do.

Second, the circuit breaker can repeatedly interrupt load current and fault current. Selecting a circuit breaker reaching M2 and E2 classes (IEC 62271-100) suits the higher switching frequency of dynamic smart networks, allowing long-term reliable operation with little maintenance under normal conditions.

Third, its operating characteristics are stable and controllable, with low dispersion in closing/opening times. Taking the ASNA (atmospheric sealed natural air) product as an example, opening time is below 30 ms; mechanical characteristics are measurable, and switch status and auxiliary contacts feed the breaker operating state back through interfaces. Stable, predictable switching action is the physical premise for distributed protection, self-healing algorithms and automation logic to take effect. It can therefore be paired with self-powered protection as an alternative to the fuse combination, or equipped with an intelligent terminal for advanced automation such as fault discrimination, remote tripping/closing and auto-reclosing — a flexible, extensible technical path.

The load-break switch and fuse combination were designed for static, unidirectional conventional networks and do not natively possess the full set of capabilities above, so they can hardly support the evolution of dynamic networks. The circuit breaker is the "1"; secondary schemes such as self-powered protection and the intelligent terminal are the "0" that follow. Without this reliable primary base, no amount of intelligent secondary configuration can deliver value. For dynamic smart networks, the circuit breaker is the preferred primary device.

3.3 Conditions for Large-Scale Deployment of Circuit Breakers

It has been established that the circuit breaker's body capabilities match the core demands of dynamic smart networks and make up for the inherent weaknesses of the static switch-fuse combination. The following compares these capabilities with the key limitations of the static scheme summarized in HMP-WP-2503 (Section 6): the breaker scheme covers all the weaknesses, and this capability completion is the technical basis for the selection.

Table 1 Key limitations of the static scheme and the corresponding response of the breaker scheme

Boundary identified in HMP-WP-2503	Response of the breaker scheme
Blind zone from 1.5× the transformer rated current to minimum melting current	Full-range breaking; minimum breaking current far below transformer rated current
Essentially no response to single-phase earth faults	Zero-sequence and differential criteria configurable to clear earth faults
Single-shot operation; restoration by manual work	Repeated operation; automatic transfer with standby source auto-switching
Single-phase fuse operation leads to single-phasing	Three-pole simultaneous tripping; no single-phasing state

Boundary identified in HMP-WP-2503	Response of the breaker scheme
No settings; not settable	Protection settings flexibly switchable with network operating state
Weak communication; hard to observe	Fault waveforms, event records and equipment status uploadable to the master station
Selectivity relies on separated time-current curves	Differential and section protection logic; selective coordination by algorithm
No status awareness; periodic maintenance only	Online status acquisition supporting condition-based maintenance

Note: the left column is based on the capability boundaries summarized in HMP-WP-2503 (Sections 2, 5 and 6); the right column summarizes the breaker body capabilities of this paper.

Having full technical capability is only the precondition; for circuit breakers to be deployed at scale in today's dynamic networks, three engineering conditions must also be met:

First, reliability proven over the long term. The vacuum interrupter has a low current chopping level, generates little decomposition product during interruption, causes low contact erosion and recovers dielectric strength quickly; this is the basis for meeting the stringent M2 and E2 assessments, and it has accumulated extensive service record in medium-voltage distribution networks.

Second, a steadily improving cost structure. Early breaker cost bottlenecks were concentrated in the interrupter chamber and operating mechanism; with scaled mass production and maturing processes of vacuum interrupters, this cost has fallen markedly, while the share of enclosure, sealed insulation and secondary devices in panel cost keeps rising. Full-range breaking is no longer an unaffordable premium; for the quantitative economic comparison, see HMP-WP-2506.

Third, the drive of the environmental route. As SF_6 is progressively restricted and phased out, the arc-quenching solution of mainstream environmental routes has converged on vacuum[3][4]. Against this convergence of quenching media, giving up full-range breaking merely to save cost no longer holds long-term technical rationality.

Overall, as technical capability closes the gaps of the static scheme and the conditions of reliability, cost and environmental compliance mature, replacing the conventional static protection scheme with circuit breakers moves from technically feasible to an engineering-level rational choice.

4 Intelligent Terminal: The Secondary Foundation of Intelligence

The circuit breaker is the primary base of the dynamic smart network, while the intelligent terminal is the core secondary carrier for network intelligence and self-healing coordination. The primary switch provides reliable fault breaking; the terminal handles sensing, discrimination, coordination and execution. Working together, they can fully meet the requirements of the dynamic network.

4.1 Capability Requirements on the Intelligent Terminal

With bidirectional flow, flexible distributed generation switching and frequent state changes, the dynamic network no longer asks the terminal for simple remote signalling and metering; it requires local protection computation and fast decision-making.

The terminal collects local electrical quantities such as switch status, current, voltage and fault records, embeds protection logic, and can independently perform fault discrimination and local tripping according to preset settings. It also provides communication to exchange data and commands bidirectionally with adjacent terminals and the master station.

Its core value lies in pushing protection and self-healing decision-making down to the RMU side, enabling fast local judgement without relying on the master station for fault discrimination, switching action and network reconfiguration. This is exactly the capability required by intelligent distributed self-healing systems for fast fault isolation and rapid restoration of non-fault sections.

4.2 Two Coordination Modes: Centralized Master-Station and Local Distributed

Network intelligence has two implementation approaches: centralized master-station and local distributed.

The centralized mode places judgement at the master station; terminals only collect and execute. The terminal performs local acquisition and basic protection; comprehensive fault judgement and reconfiguration strategy are computed by the master station after aggregating information from network-wide nodes, which then issues closing/tripping commands to the terminals. This mode suits networks that are relatively simple, where self-healing timeliness is not demanding and unified dispatch and management predominate.

The local distributed mode places judgement among terminals, with the master station reduced to monitoring and management. Terminals communicate peer-to-peer; relying on intelligent distributed logic and information exchange between adjacent terminals, fault location, faulty-section isolation and automatic transfer of non-fault areas are completed locally. The whole fault-handling process does not wait for master-station commands, acting fast and suiting priority areas with high reliability requirements. At the same time, all operating events and fault records are still uploaded to the master station, which retains monitoring, recording, remote setting and operation-and-maintenance control without leaving unified management.

The two modes can share the same class of intelligent terminal as hardware carrier, differentiated by configuring different logic strategies; they are highly interchangeable.

In dynamic networks more scenarios choose the latter, for three reasons. Latency: against a hundred-millisecond isolation requirement, after communication and master-station processing, the centralized mode can hardly achieve it consistently. Robustness: communication interruption, master-station maintenance and channel congestion all disable the centralized mode, whereas the distributed mode still completes local isolation when the communication part is impaired. Scalability: a new unit only needs to establish relationships with adjacent units, without reworking master-station logic.

4.3 Process-Wide Changes and Requirements of Intelligent Deployment

Adopting the intelligent terminal plus circuit breaker scheme is not merely replacing secondary devices in the panel; it runs through the whole chain of preliminary planning, selection, commissioning and operation, requiring the supporting system to keep pace:

1. Requirements and scheme design: the preliminary stage must investigate network structure, distributed generation capacity, changes in flow direction and customer reliability levels, decide whether to use distributed self-healing or centralized control, and set protection settings, peer-communication logic and self-healing strategy accordingly; the simplistic design approach of conventional static networks cannot be carried over.

2. Product selection: the terminal must match the primary circuit-breaker interface, communication protocol, EMC and temperature/humidity environment class; protection algorithm, fault recording, time synchronization and peer coordination are also verified to ensure primary-secondary integration compatibility and avoid mismatched capabilities between primary base and secondary terminal.

3. Personnel training: design and maintenance staff, beyond the basics of primary switching equipment, must understand protection settings, distributed self-healing logic, communication-link troubleshooting and fault-record analysis; maintenance can no longer rely only on visual inspection and simple fuse-element replacement.

4. Commissioning and operation management: the commissioning stage requires point-to-point testing of peer coordination and joint commissioning with the master station. Routine maintenance adds setting verification, communication-link inspection and fault-record review, building a condition-based maintenance mechanism for digital equipment and continuously tracking protection-strategy updates after network adjustments.

5 Field Applications: Typical Case Validation

In recent years, field cases of circuit-breaker-type RMUs in distribution networks have grown continuously, and technical routes have diversified: early projects mainly used circuit breaker plus self-powered protection as an alternative to the fuse combination; as dynamic smart network construction advances, breaker bases paired with intelligent terminals and primary-secondary integrated self-healing schemes are applied more widely. Drawing on its atmospheric sealed natural air RMU platform, HM Power has delivered benchmark projects across several routes. Four representative projects are selected below, covering basic protection, local differential, distributed self-healing and high-reliability sensitive-load scenarios.

Table 2 Configuration and objectives of four field samples

Project	Year	Primary configuration (sealed at atmospheric pressure)	Secondary configuration	Features
Tesla Supercharger Station, Västerås	2014	Circuit-breaker panel	Self-powered protection	Manual, no auxiliary supply
Gothenburg Smart City	2015	Circuit-breaker panel	Integrated protection relay + RTU	Local isolation, remote master control
Shenyang Hunnan FTZ Self-Healing	2017	7 outdoor switch enclosures (42 breaker panels)	Intelligent terminal (with differential)	Clearance 70 / self-healing 200 (ms)
Bo'ao Lecheng Smart Grid, Hainan	2019	2 breaker-panel sets + 12 outdoor switch enclosures (116 breaker panels in total)	Intelligent terminal (with differential)	Clearance 70 / self-healing 200 (ms)

Note: years are commissioning dates; primary configurations are atmospheric sealed natural air breaker panels / outdoor switch enclosures. "Fault clearance / supply self-healing" are design and assessment targets of the scheme, not long-term service statistics.

5.1 Tesla Supercharger Station, Västerås, Sweden (2014)

High-power charging-pile loads impose higher demands on fault clearance and protection coordination. The project uses circuit breakers directly as switching nodes, with no load-break switch or fuse; protection is provided by self-powered protection, placing the protection node close to the load and preventing end faults from spreading upstream. The scheme needs no external secondary supply; it draws power itself for instantaneous, overcurrent and earth-fault protection as well as transformer non-electrical protection, and the primary equipment meets the SF_6-free environmental requirement. It satisfies current equipment needs while leaving an upgrade path: when the network is later upgraded and more intelligent functions are required, an intelligent terminal can be fitted directly, allowing smooth evolution toward an intelligent network[1].

5.2 Gothenburg Smart City Project, Sweden (2015)

This Gothenburg "green smart distribution network self-healing system" project uses a circuit-breaker-type RMU. Local protection employs an integrated protection relay, with an IPC earth-fault protection terminal to detect low-current earth faults; connection to the master station is through an RTU (Remote Terminal Unit), achieving local fault isolation, terminal data upload, master-station comprehensive assessment and remote controlled self-healing. Faults are discriminated and tripped locally by the protection terminal; the master station handles network-wide status monitoring, event record collection, comprehensive assessment, remote self-healing and operation management, forming a "local protection + master-station control" collaborative architecture — a common scheme for centralized smart distribution networks.

5.3 Shenyang Hunnan FTZ (Free Trade Zone) Self-Healing Network Project (2017)

As a local high-reliability supply demonstration project, it uses atmospheric sealed natural air breaker RMUs plus intelligent distributed terminals based on fibre-optic differential protection to form intelligent ring-network nodes; several nodes are linked hand-in-hand to form ring supply feeders. Terminals are connected by fibre; the load side of each node uses overcurrent protection logic, while the line side uses longitudinal differential and busbar differential protection.

When a line fault occurs, differential protection starts and rapidly opens the circuit breakers on both sides of the fault point to clear and isolate it. Meanwhile, terminals communicate peer-to-peer; once isolation is confirmed, the tie breaker in the ring closes per setting, restoring supply to non-fault areas and completing transfer supply. Fault handling does not depend on master-station commands, achieving fast isolation and restoration. All operating events and record data processed by the terminals are synchronously uploaded to the master station for unified operation management.

The project was completed and met its design targets; one year after commissioning it won the gold award of the 4th State Grid Youth Innovation Competition, verifying the field capability of the circuit-breaker plus distributed self-healing scheme in complex urban networks, and resolving the pain point where conventional distribution automation schemes struggle to achieve fast local fault isolation and self-healing supply restoration for non-fault areas.

5.4 Smart Grid Project of Bo'ao Lecheng International Medical Tourism Pilot Zone, Hainan (2019)

The Bo'ao Lecheng medical pilot zone is an international advanced medical demonstration area with extremely high reliability requirements. The project uses a "two switching stations + two ring feeders" network; primary equipment are atmospheric sealed natural air breaker RMUs, and secondary equipment are intelligent distributed terminals based on fibre-optic differential. The outgoing feeders of the two stations form an open-ring network through multiple nodes; both rings constitute intelligent distributed self-healing systems, markedly improving local fault isolation and fast restoration, supporting high-level reliability and minimizing outage impact on medical operations — a benchmark dynamic-network scheme for sensitive loads.

5.5 Case Summary

All four cases use circuit breakers as the primary switching device, with different secondary configurations matched to actual customer needs. The Västerås Tesla Supercharger Station uses self-powered protection: low initial investment, meeting basic protection needs while retaining an upgrade path to a smart network. The Gothenburg Smart City project uses local relay protection plus centralized master-station control, with some fault isolation and restoration capability, but relatively long restoration time. The Shenyang Hunnan and Bo'ao Lecheng projects use intelligent distributed self-healing systems, completing local fault discrimination and isolation and restoring non-fault areas without master-station participation. The four cases cover the range from basic protection to distributed self-healing, offering replicable schemes for smart distribution network construction.

Field practice confirms that, as the primary base of the dynamic smart network, the circuit breaker can flexibly match multi-level demands from basic protection and local differential to distributed self-healing. The scheme can meet current needs for environmental retrofitting and replacement of static protection, and also support the continuous evolution toward a dynamic smart network with bidirectional flow and variable operating states; it is feasible and replicable.

6 Conclusions

First, the five changes of the dynamic network come down to four primary requirements: full-range breaking, longer mechanical and electrical life, stable operating characteristics, and interfaces with an environmentally friendly form. These four can only be borne by the switching body, on which the four secondary requirements are built.

Second, the switch-fuse combination is the solution for static networks: short-circuit breaking relies on a single-shot element, the protection curve is fixed at manufacture, and mechanical life does not suit daily cycling. This is not insufficient margin but a principle boundary that process improvement cannot remove.

Third, the circuit breaker is the preferred choice because the four capabilities come from one physical structure, and the conditions for scale deployment are mature: the reliability of vacuum arc quenching has long been proven, the cost structure keeps improving, and the environmental route has converged on vacuum. Once the primary base is selected, the secondary side can be configured in stages following the network's pace.

Fourth, secondary configuration is an option, not a grade. Self-powered protection solves the problem of replacing the combination with a breaker without a secondary supply, and carries no intelligence functions; the intelligent terminal handles local discrimination, coordination and self-healing, which can be completed locally among terminals or issued by the master station after aggregating multi-node information. The two paths share the same breaker base; the choice depends on network structure, reliability requirements and maintenance capability. Deployment requires simultaneous build-up of scheme design, product selection, training and operation management. Initial cost is higher than the static scheme, but the primary equipment is reusable long-term and the secondary side can be upgraded in phases, giving a more controllable whole-life cost; for the quantitative comparison, see HMP-WP-2506.

A Appendix A — Glossary

- Dynamic smart RMU: an RMU with a vacuum circuit breaker as the primary breaking element and an intelligent terminal, featuring settable protection, local fault discrimination and coordinated transfer with adjacent units.
- Primary foundation: the full-range breaking capability and the controllable operating mechanism; all secondary judgement, coordination and sensing capabilities are built on this base.
- Full-range breaking: the breaker's ability to interrupt reliably across the entire range from minimum breaking current to rated short-circuit breaking current.
- Self-powered protection: a protection device that draws energy from the primary circuit and needs no DC supply; functions mainly inverse-time overcurrent and instantaneous overcurrent, replacing the protection role of a fuse, and is not an intelligent configuration.

- Intelligent terminal: a terminal integrating protection, control and measurement, communication and edge computing, supporting differential, directional and status awareness; the secondary configuration for dynamic networks.
- Primary-secondary integration: a design in which primary switch and secondary device share structure, power supply, communication and interfaces, reducing field wiring and commissioning effort.
- Setting group: multiple protection settings and directional configurations preset by operating state, switchable locally or remotely.
- Distributed self-healing: a self-healing mode in which terminals discriminate faults locally and coordinate with adjacent terminals to complete isolation and transfer, without relying on the master station.
- Differential protection: a protection method that compares current magnitude and phase at both ends to detect internal faults; selectivity is determined by algorithm.
- Status awareness: online acquisition of electrical, mechanical and in-enclosure environmental quantities to assess equipment health.
- Condition-based maintenance: scheduling maintenance timing and content according to online status quantities, replacing fixed-period outage maintenance.
- Whole-life-cycle cost: a cost basis covering initial investment, operating energy consumption, operation management and recycling/disposal.
- Atmospheric sealed natural air insulation: an insulation method in which live parts are placed in a sealed enclosure containing air at atmospheric pressure, with no pressurization or gas top-up required.
- M2 class: a stringent mechanical-life assessment class requiring mechanical characteristics to remain satisfied after the specified number of operations.
- E2 class: a stringent electrical-life assessment class.

B Appendix B — References and sources

- [1] Circuit breakers together with self-powered protection improve transformer protection in secondary substations: application of self-powered protection in secondary substations. Conference paper (2016).
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C Appendix C — Further Reading

- For the structure, operating logic and capability boundaries of the replaced scheme, see HMP-WP-2503; for why this configuration became dominant historically and whether those constraints still hold today, see HMP-WP-2504; for project-level trade-offs and panel comparison, see HMP-WP-2506.



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