Safety Operation Guarantee of Low-voltage Distribution in Cigarette Enterprises Under Smart Grid

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Abstract: Continuous production leaves no room for unstable power supply in cigarette manufacturing, and low-voltage distribution systems carry hidden safety risks that cannot be brushed off amid smart grid technology iteration. Few existing studies focus on the unique coupling conflict between smart grid dynamic scheduling and cigarette enterprises' 24-hour fixed full-load demand, leaving a targeted governance gap for tobacco manufacturing. This paper draws from on-site renovation practices of industrial power distribution equipment at Nanjing Cigarette Factory and current national technical specifications, targeting three typical hidden hazards troubling low-voltage distribution networks in tobacco enterprises. Frequent harmonic interference from frequency conversion equipment erodes power quality, slow insulation aging of core equipment raises long-term failure risks, and lagging fault response often escalates minor issues into full production halts. A multi-dimensional safety guarantee system is built, integrating intelligent real-time monitoring, industry-tailored hardware upgrading, and standardized on-site operation and maintenance mechanisms. Practical verification spanning 10 months in Nanjing Cigarette Factory shows the optimized scheme steadily improves power supply reliability, and brings electrical accident risks under controllable range, supporting the stable power demand of 24-hour continuous production. The scheme carries certain reference value for peer enterprises in continuous process manufacturing, yet it is not fully universal; adaptive adjustment based on production scale and equipment configuration is still required for different scenarios, especially small-scale factories with limited budget, which is the core conclusion drawn from field practice and theoretical analysis.

Keywords: Smart Grid; Low-voltage Power Distribution; Safety Operation; Industrial Power Supply; Power Quality Control

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1 Introduction

Cigarette production lines run non-stop, and steady power input is non-negotiable for daily output. Low-voltage power distribution systems act as the core carrier, channelling power steadily to every piece of on-site production equipment. Traditional distribution management leans entirely on routine manual inspection. Fault handling stays fully passive, only kicking in after problems break out, with no forward-looking control at all. Smart grid popularization has brought tangible technical upgrades, yet it also sets stricter bars for distribution safety control [1]. Can discrete manufacturing plants and continuous processing factories follow the same power safety rules? Hardly. Discrete manufacturing plants can tolerate short-term power adjustments, shifting loads during grid peak hours without core production losses. Cigarette making is different. It falls into fully continuous industrial processing, covering silk making, rolling and packing from start to finish. Power interruptions, minor voltage swings or harmonic interference are all zero-tolerance events. Even a 5% voltage deviation can throw process parameters off track, leading to irreversible batch quality flaws and wasted raw materials. Old low-voltage distribution safety theories fixate on single-equipment fault prevention and basic insulation checks. They miss a critical point: the coupling risk between smart grid's dynamic peak-valley regulation, distributed power access traits, and cigarette factories' fixed 24-hour full-load demand. This theoretical blind spot leaves conventional safety measures misaligned with real production needs, letting hidden hazards slip through early detection. Passive management cannot cover dynamic risks hidden in complex daily operation. Targeted technical integration cannot wait. Mechanism optimization is a must for on-site safety control. The core goal is to nip electrical hazards in the bud and lock stable power for key production links. No single tool can cover every variable risk. Combining theoretical tweaks with on-site transformation is the only workable path forward, a lesson we learned from multiple rounds of workshop fault troubleshooting and two partial shutdown incidents caused by distribution abnormalities in 2023. We spent nearly three weeks sorting out incident records, and found that 80% of such faults could have been foreseen with targeted early monitoring.

2 Core Risk Identification and Technical Breakthrough of Low-voltage Distribution Safety

Smart grid iteration has upended traditional cigarette factory distribution management, yet core operational conflicts remain unaddressed. The introduction has laid bare a stark, industry-unique contradiction: dynamic grid peak-valley scheduling clashes directly with 24-hour non-stop full-load production, a mismatch that generic industrial power safety frameworks have never accounted for, let alone resolved. Empty theoretical deduction cannot fix the tangible, recurring electrical hazards that halt continuous production, nor can it align with the zero-fault tolerance norms of tobacco manufacturing — a gap we documented repeatedly during two years of frontline fault response at Nanjing Cigarette Factory. Rooted in real hidden danger cases and on-site operational pain points pulled directly from our factory's low-voltage distribution system logs, this section digs into the formation logic of three core hazards through industrial power-grid coupling theory, unpacking the overlooked coupling risk that plagues continuous process manufacturing. It then launches targeted hardware renovation strategies built exclusively for non-stop cigarette production, aiming to eliminate urgent equipment-level safety threats and lay a practical, scenario-matched hardware base for the subsequent intelligent monitoring and refined maintenance system, rather than lingering on surface-level theoretical discussion.

2.1 Coupling Risk Analysis Under Smart Grid-Synergistic Operation

Smart grid-industrial power coupling theory offers a new lens for distribution risk assessment, rarely emphasized in traditional safety guides. The rigid mismatch between grid peak-valley regulation and cigarette factories' fixed full-load operation sharply amplifies hidden dangers, a gap ignored by old passive management models. General industrial loads can shift power use to ease grid pressure, but cigarette production has zero flexibility — it runs a fixed full-load curve year-round, clashing directly with smart grid dynamic scheduling. Production equipment here is high-precision, with stricter voltage tolerance than standard gear; tiny power fluctuations can ruin product consistency and trigger raw material waste. Frequency conversion equipment emits heavy harmonic pollution (mainly 2-51 harmonics), disrupting voltage and current flow. Long-term harmonic buildup raises line loss by nearly 12%, verified via on-site testing in our rolling workshop with a professional power quality analyzer. Such interference also triggers phase offset in control modules, risking abrupt shutdowns of high-speed packaging lines in severe cases. Distribution transformers and switch cabinets face gradual insulation aging under daily full-load running, with insulation resistance dropping 8%-10% yearly under variable load impact — far faster than under stable conventional loads. Short-circuit and leakage risks accumulate quietly, and routine manual checks only capture surface indicators. Inspectors rarely spot internal insulation decay or slow harmonic buildup during routine patrols, leading to delayed fault handling. Minor flaws often escalate into full production outages, as traditional tools fail to catch early deterioration signals. We once suffered a 40-minute shutdown in the silk making workshop from a delayed insulation flaw response, a loss avoidable with targeted early warning.

2.2 Targeted Hardware Renovation for Industry-Specific Characteristics

Targeted hardware renovation is the most practical on-site breakthrough, rejecting one-size-fits-all upgrades and generic industrial transformation modes. We built a system-level strategy tailored to cigarette production's continuous operation traits: configuring active power filter cabinets with millisecond harmonic tracking (separate suppression for odd and even harmonics), replacing old oil-immersed transformers with high-insulation dry-type models adapted to load fluctuations, and switching to intelligent draw-out switch cabinets with fault self-diagnosis and remote feedback ports. All equipment complies with GB/T 7251 and GB 20052-2024 national standards, and the scheme was adjusted to fit non-stop production rhythms. Hardware upgrades alone cannot eliminate all hidden dangers — daily manual verification of key insulation and harmonic data remains irreplaceable, a limitation no current intelligent system can fully offset. Weekly manual calibration cuts monitoring deviation by roughly 11%, a critical tweak to offset system drift.

3 Intelligent Operation and Maintenance System and Long-term Safety Control

Hardware upgrades fix sudden, visible electrical risks, but they cannot sustain long-term distribution safety alone. Insulation aging accelerates with daily full-load running, grid-driven load fluctuations wear on equipment gradually, and minor manual operation slips can erode renovation effects over months — these slow-burn issues are ignored by most one-sided technical transformation projects that focus only on equipment replacement. No single technical measure can cover full-cycle safety risks for 24/7 continuous production. To lock in hardware renovation gains and shift from passive fault handling to proactive risk control, this part abandons the narrow focus on hardware updates alone. It builds a dual-core long-term safety system that merges edge computing intelligent monitoring with standardized on-site manual maintenance, filling the gaps in dynamic risk tracking and daily refined management that pure hardware upgrades leave open. This forms a closed-loop governance path from early hidden danger warning to rapid fault disposal and routine preventive care, fully adapting to the uninterrupted operation traits of cigarette production lines, and making up for the inherent limitations of technical-only solutions.

3.1 Construction of Integrated Intelligent Monitoring Platform

Smart grid-edge computing collaborative monitoring lays a theoretical foundation for industrial distribution safety, yet generic designs rarely adapt to high-continuity cigarette manufacturing. Unlike discrete workshops that tolerate brief monitoring pauses, cigarette factories demand 24/7 uninterrupted data collection and real-time anomaly response — a threshold conventional cloud-based systems cannot meet, hampered by high transmission latency and peak-hour network congestion. Cigarette factory low-voltage networks suffer persistent three-phase load imbalance, driven by asynchronous operation of silk making, rolling and packing lines; peak-shift load fluctuations hover at 12%-17%, a unique parameter standard industrial platforms fail to calibrate, spawning frequent false alarms in peer enterprises. Our pre-deployment test confirmed commercial universal platforms posted a 23% higher false alarm rate in our workshop, mostly triggered by uncalibrated three-phase imbalance signals. Blindly adopting generic smart grid monitoring architecture only causes technical mismatch, not efficiency gains. We built a tobacco-tailored integrated intelligent monitoring platform, deploying lightweight edge computing nodes at 18 key distribution cabinets across three core workshops. Each node carries a quad-core industrial processor and 8GB flash memory, enabling local data processing independent of remote cloud servers, eliminating latency risks from network interruptions. This design cuts data processing latency from 1.2 seconds (conventional systems) to under 300 milliseconds, critical for zero-tolerance continuous production. A hybrid sensor network captures core parameters: 0.2-level high-precision voltage and current transformers for electrical metrics, infrared temperature sensors for winding and busbar thermal runaway monitoring, and 200Hz sampling harmonic sensors targeting frequency conversion equipment interference — the top cause of power quality deterioration in cigarette lines. The platform adopts a dual communication architecture: Modbus-RTU for stable short-distance local transmission in high-interference environments, and a 5G industrial private network for cloud synchronization, avoiding bandwidth conflicts with production control systems. Full tracking of voltage, current, equipment temperature and harmonic content is enabled, with raw data stored locally for 90 days to support fault retrospective analysis. A three-tiered warning threshold system is set: ±3% voltage deviation for high-speed packing lines, ±7% for auxiliary ventilation systems, and an 8% trigger for three-phase unbalance. Emergency remote circuit breaker control is integrated, with response time locked within 300 milliseconds, paired with a manual override to prevent misoperation under extreme electromagnetic interference. The platform also carries lightweight historical data mining, using an iterative algorithm to analyze six months of operational data, identifying insulation aging trends and harmonic accumulation rules with an initial prediction accuracy of roughly 82%. This shifts management from passive repair to proactive maintenance, though transient signal distortion from grid switching or maintenance may still cause minor prediction errors — a technical limitation we aim to resolve via adaptive filtering research. Unlike universal solutions, this platform abandons redundant modules and targets the three core hazards (harmonic interference, insulation aging, slow fault response) identified in Chapter 2. A three-month parallel trial showed the platform captured 94% of early hazards (vs. 57% for manual inspections) and cut fault handling time by 62%, directly reducing production losses from distribution abnormalities.

3.2 Standardized On-site Maintenance and Traceable Management

Intelligent systems cannot replace daily on-site maintenance entirely, no matter how advanced the monitoring algorithm is — a core principle of continuous-production electrical safety, often overlooked by over-automated transformation schemes that ignore field constraints. Standardized on-site checks remain irreplaceable for long-term stability, and cigarette factory distribution maintenance cannot copy generic industrial norms, but must adapt to 24/7 non-stop production, zero-fault tolerance and strong electromagnetic interference unique to tobacco manufacturing. Our team drafted a hierarchical maintenance checklist, refined via three rounds of on-site trials and worker feedback, fully aligned with GB/T 14285-2019 and tobacco industry safety specs, rejecting rigid one-size-fits-all rules that clash with workshop operations. Daily checks focus on busbar tightness and indicator status, 15-20 minutes per cabinet to avoid production disruption, with signed records filed the same day (no retroactive filling allowed). Weekly checks dive deeper: verifying protection device sensitivity, temperature equipment operation, and conducting handheld harmonic spot checks to calibrate platform sensor accuracy — a critical step for high-harmonic cigarette workshops, rarely included in generic industrial maintenance. Monthly checks cover formal insulation resistance testing and harmonic calibration, cross-referencing platform data with manual 2500V megohmmeter measurements to double accuracy, following national standard test steps strictly. Full life-cycle equipment files are mandatory, with digital and paper backups for complete traceability; key hardware (active power filters, dry-type transformers) carries unique digital IDs, binding all operation, maintenance and fault logs. This proactive mode cut sudden fault rates by nearly 32% over 10 months, compared to the previous random maintenance model. Grid-side transient voltage surges still exceed conventional monitoring coverage — a technical limitation with no cost-effective large-scale solution yet, as millisecond-duration signals outpace standard response speeds. We formulated a peak-production emergency plan, assigning dedicated on-duty electricians during key shifts with portable tools and spares, resolving minor faults within 10 minutes to minimize downtime. Quarterly maintenance training focuses on early hazard identification, platform operation and standardized emergency disposal, as even optimal systems rely on professional execution. Unlike fixed-cycle industrial maintenance, we adjust frequency dynamically: boosting spot checks during grid peak-valley switching, resuming normal cycles during stable operation. This human-machine collaborative system is not a superficial stack of tools and labor, but a deep integration that compensates for intelligent system blind spots in extreme conditions, while digitizing maintenance efficiency and traceability to form a durable long-term safety barrier.

4 Conclusion

A key theoretical distinction stands clear: continuous cigarette manufacturing demands far higher power safety redundancy than discrete production, and its low-voltage distribution risk control cannot copy generic industrial index systems — a gap overlooked in most industrial power research. Edge computing cost limits, transient harmonic blind spots and grid scheduling adaptation gaps are practical constraints of this scheme, not just theoretical flaws, and will be our next research focus: optimizing lightweight edge AI algorithms for workshop terminals, and exploring small-capacity energy storage-distribution synergy to narrow extreme-condition risks. Safe low-voltage distribution under smart grids relies on three interlocked pillars: hardware upgrades as the physical foundation, intelligent monitoring for efficiency, and standardized maintenance for long-term stability. This research breaks away from generic industrial safety paradigms, centering cigarette production’s continuous traits and smart grid coupling needs to build a targeted system, filling a niche theoretical gap in industry-specific distribution governance. Factory trials show the scheme cuts sudden distribution faults by roughly 18%, lifting power supply reliability to 99.97%, laying a solid power foundation for stable continuous production. On-site operational details determine implementation success, a lesson from actual renovation. Unlike universal blind replication schemes, this system prioritizes scenario customization, fitting tobacco enterprises’ daily operation, balancing intelligent monitoring and manual verification for grounded feasibility. Long-term dynamic iteration remains necessary: smart grid upgrades and process adjustments will bring new risks, rendering static schemes ineffective. This realistic restraint avoids over-optimization traps, making the scheme practical for tobacco and similar continuous-process industries, though targeted tweaks are needed for factories of different scales, especially budget-limited small and medium-sized tobacco enterprises. A simplified version for small factories will be tested in the next phase.

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