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Design and Optimization Strategy for Joint Power Supply and Distribution Systems in Multi-Plant Industrial Parks

Lei Yao

School of Information Engineering, Nanning College of Technology, Guilin, Guangxi Zhuang Autonomous Region, 541006, China

ABSTRACT
The power supply efficiency in industrial parks directly impacts production stability and energy costs for enterprises. Traditional decentralized distribution often leads to redundant equipment configuration, increased transmission losses, and complex multi-site dispatch challenges, undermining overall operational efficiency. When facilities with differing characteristics coexist within the same park, pronounced load fluctuation variations emerge, heightening demands for power supply reliability and increasing energy management complexity. This necessitates establishing a unified power supply and distribution optimization plan. Therefore, this paper explores the design of a joint power supply and distribution system for multi-site facilities, aiming to enhance the economic viability and practicality of industrial cluster power supply and distribution systems.

KEYWORDS
Industrial park; Multi-plant integration; Power distribution system

1 Introduction

Traditional power systems are structured into three major segments: generation, transmission, and distribution. The network distributing electrical energy from high-voltage substations to end-users is termed the distribution system, whose functions include voltage reduction and power allocation. As the terminal segment of the distribution network, the factory power supply system comprises the factory step-down substation, high-voltage distribution lines, workshop substations, low-voltage distribution lines, and electrical equipment. The current model of independent power supply across industrial park facilities presents significant limitations: peak-valley load imbalances cannot be mutually compensated, redundant reserve capacity is duplicated, equipment utilization rates are insufficient, and fault isolation capabilities are limited. However, multi-site joint power supply and distribution integrates substation resources and line corridors to form a unified power network. This approach optimizes overall load distribution and enhances system redundancy. Therefore, this paper will explore the design and optimization pathways for multi-facility joint supply systems, developing an implementable industrial power management solution.

2 Concept of multi-site joint power supply and distribution systems

2.1 Definition of multi-site joint power supply and distribution systems

A multi-site joint power supply and distribution system is a structural configuration within geographically concentrated industrial parks that integrates each factory's independently operated power facilities into a unified power supply network through physical grid connections. This system utilizes dedicated power lines laid between factory sites to directly interconnect the outgoing busbars of each factory's step-down substations, while establishing joint control centers at critical nodes [1]. Its operation relies on foundational pathways formed by physical grid interconnections. For instance, within an automotive manufacturing park, the 35kV substations originally equipped separately for the vehicle assembly plant and engine plant are interconnected via buried 10kV tie cables. This creates an energy exchange pathway between the distribution trunk lines of the two facilities. In practice, the system first consolidates redundant equipment resources within the area, such as eliminating independent diesel generators and standardizing shared power sources across the park. It then merges control authority over substations, transferring power dispatch functions from individual factories to the joint control center. Ultimately, this enables dynamic load balancing across facilities. When monitoring instruments indicate a sudden surge in peak electricity consumption at Plant A, the control center automatically directs surplus power from Plant B to be transmitted via the interconnection cable without manual intervention. This structure fundamentally transforms the isolated state of power systems within traditional supply models, unifying the industrial park into an integrated power supply unit.

2.2 Application scenarios for multi-plant joint power supply and distribution

Multi-plant joint power supply and distribution systems primarily serve production areas experiencing power resource mismatches or critical power reliability demands. Different electricity consumption patterns across production processes create typical scenarios in large manufacturing bases. Take an aerospace components industrial park, for example: the day shift stamping operations at the metal forging plant create a morning peak load, while the high-energy consumption period at the heat treatment workshop concentrates in the afternoon. The joint power distribution network automatically transfers surplus power from the step-down substation to the heat treatment workshop during the forging plant's low-demand period, reducing the park's peak load. For continuous production enterprises like biopharmaceutical parks, power outages exceeding two minutes can kill fermentation tank cultures. Three pharmaceutical plants interconnected via ring circuits form emergency fault bypasses in such scenarios. When a lightning strike caused a short circuit and fire in the formulation workshop, triggering a plant-wide blackout, the control system automatically connected adjacent API plant power within 40 seconds to restore critical equipment operation. In emerging electronics industrial parks, dual-circuit cables can be pre-laid during development phases to establish interconnected backbone networks. For instance, microelectronics parks can bury 110kV shared conduit corridors along main thoroughfares during initial development. When chip factories commence operations, they can directly connect to this unified grid, avoiding redundant construction from individual enterprises applying for external power sources. The commonality across these scenarios lies in creating a closed-loop engineering practice for power sharing and emergency mutual aid. This is achieved by physically connecting the power distribution systems of different enterprises across management boundaries through the physical grid.

3 Basic design of joint power supply and distribution systems for multi-plant industrial parks

3.1 System design objectives and principles

The fundamental purpose of designing joint power supply and distribution systems is to establish a technical framework for coordinated management of electrical resources across plant sites. The key lies in forming an operational system that ensures secure sharing and economic optimization. Safety objectives are achieved by establishing power pathways where different plants serve as mutual backups. Should a transformer winding burnout cause a power outage at one plant, pre-laid interconnection cables can deliver electricity from adjacent plants to the affected area, restoring critical equipment operation and ensuring uninterrupted production. Economic objectives demand minimizing redundant investment and idle resources. For instance, replacing individual plants' small-capacity battery banks with a shared energy storage center within the industrial park enhances equipment utilization efficiency through centralized management. System scalability requires standardizing interface technical solutions during the initial design phase, with trunk line capacity determined based on long-term planning values to accommodate future expansion. The process requires comprehensive balancing of line loss control during power transmission, parameter matching adjustments for high/low-voltage equipment, and defining management responsibilities among multiple stakeholders. This ultimately forms a stable, integrated power supply and distribution structure adaptable to dynamic industrial load variations [2].

3.2 System composition and operation mode

The multi-plant joint power supply and distribution system achieves integrated plant energy management through three core functions: physical electrical interconnection, centralized monitoring platforms, and energy resource coordination. Physical electrical interconnection employs metal-clad cables to directly link busbars of dispersed plant substations at the physical level. Key nodes feature high-voltage switchgear with bidirectional switching capability, forming the backbone network for energy exchange. The centralized monitoring platform deploys remote data acquisition terminals to continuously monitor core parameters such as transformer temperatures and line currents across all plants. These data form a closed-loop control chain via dedicated fiber-optic channels. Energy resource coordination integrates the output characteristics of generators, transformer banks, and energy storage devices within the region to create a unified dispatch resource pool [3]. The monitoring platform dynamically adjusts power flow direction during actual operation based on load trend changes. When the automated control system detects a sudden surge in power demand from the coating workshop due to full-speed production line operation, it immediately initiates the power transfer program. This redirects idle power from the adjacent mold factory through pre-set pathways to fill the power gap. The response cycle from command generation to power delivery is controlled within the time limits permitted by production and operational requirements. This operational model establishes a shared power supply entity enabling flexible energy flow while maintaining independent management across factories.

3.3 Key equipment selection and requirements

Equipment selection prioritizes technical compatibility for cross-facility interconnection while ensuring functional continuity under extreme conditions. Interconnection transformers must accommodate voltage fluctuations within the supply radius and employ dry-type cooling for outdoor installation. Their capacity specifications are determined based on maximum load support requirements. Building materials industrial park practice indicates that selecting transformers with impedance-matched windings reduces parallel circulating currents. Protection relay devices must incorporate precise fault identification algorithms to prevent fault propagation. Specifically, multi-level discrimination differential protection units shall be deployed at power transfer points to prevent localized faults from triggering full-area blackouts. Power transfer switches must have mandatory mechanical interlocking mechanisms to prevent erroneous phase-to-phase energization. Cable lines employ flame-retardant, high-purity copper conductors installed via direct burial to mitigate external environmental impacts. Cross-sectional areas are thermally validated based on maximum load short-circuit surge currents with safety margins. All core equipment must feature standard communication interfaces supporting parameter exchange with the central control platform. This ensures system-level implementation of technical objectives: autonomous fault isolation, seamless support switching, and programmatic dispatch operations [4].

4 Strategies for optimizing multi-plant joint power supply and distribution systems

4.1 Load forecasting and demand management

Load forecasting requires establishing an energy consumption behavior analysis system covering the entire industrial park. By continuously collecting operational logs of production equipment and electricity metering data across all plants, typical power consumption patterns under different process combinations can be identified. The key lies in extracting repeatable load variation patterns, such as the regular power surges during peak startup periods of large stamping equipment in machinery manufacturing plants. Based on this, a predictive model with adaptive time-series capabilities is constructed to dynamically adjust for non-routine factors like holiday schedule adjustments or order spikes. Demand management requires implementing tiered control strategies and defining non-continuous auxiliary equipment as adjustable load pools. These pools coordinate with central monitoring systems to generate load-balancing directives. When the system detects total park power nearing critical thresholds, it automatically issues delayed-start commands to adjustable equipment—such as instructing packaging workshop conveyor belts to operate half an hour later to reduce peak loads. Transparent response effectiveness evaluation mechanisms must be established during implementation. Regular alignment between actual load curves and predicted trends should be regularly verified, gradually forming a self-improving cycle of enhanced prediction accuracy and optimized control strategies. This provides the integrated power supply and distribution system with precise load trend forecasting capabilities, reducing operational risks triggered by sudden demand fluctuations.

4.2 Power distribution optimization

Power distribution hinges on establishing a dynamic energy dispatch mechanism. It creates a dynamic perception network of the entire grid's energy flow state by leveraging real-time data on transformer load rates, line current values, and node voltage. The distribution model must integrate equipment utilization rates and line transmission losses, while setting priority assurance levels for critical loads such as medical cleanrooms and security monitoring systems. Iterative optimization algorithms automatically generate power support paths for various operational scenarios. For instance, when a power shortage occurs due to the simultaneous startup of induction furnaces in the foundry workshop, the system immediately activates idle transformer capacity from the adjacent electronics assembly plant. Load rebalancing is achieved through pre-configured interconnection channels [5]. Manual intervention retains the authority to modify automated allocation plans, particularly during special production supply periods requiring multi-party coordination to confirm load transfer schemes. The system continuously records the actual execution outcomes of load distribution, performing path optimization and capacity supplementation for supply zones frequently exceeding limits. This prioritizes resolving line overloads and voltage drops during cross-facility support, ensuring the power allocation process meets the individual power demands of production units and maximizes the utilization of overall grid resources.

4.3 Enhancing system reliability and safety

Reliability improvement hinges on establishing equipment redundancy and rapid fault response systems. Parallel power supply circuits with automatic switching devices are deployed on primary transmission lines. Backup channels activate within milliseconds to maintain power delivery upon detecting ground faults or line breaks. For instance, chemical parks implement dual-source automatic transfer systems for hazardous material production lines to prevent safety incidents caused by production interruptions. Safety protection requires implementing a comprehensive coordinated protection strategy. Upgrade relay protection devices across all plants to intelligent equipment with fault direction identification capabilities, ensuring that only the minimum affected equipment units are isolated during a fault. Simultaneously, regularly organize network-wide protection setting coordination and calibration to eliminate the risk of cascading tripping caused by mismatched protection action time limits. Strengthen proactive defense capabilities against system vulnerabilities. Address overvoltage risks from parameter discrepancies in inter-plant grounding systems by installing insulation monitoring and surge absorption devices at connection hubs. Establish cross-plant emergency response mechanisms with standardized procedures covering fault localization, load transfer, and equipment repair. This creates a three-tier defense system: intrinsic equipment protection, collaborative protection systems, and management protocol constraints.

5 Conclusion

This paper identifies three critical capabilities that must be developed for joint power distribution across multiple factories within industrial parks: dynamic load matching, flexible power allocation, and system fault isolation. Practical implementation pathways include achieving demand feedforward control through energy consumption pattern analysis, optimizing power flow based on grid status awareness, and establishing collaborative mechanisms for equipment redundancy and protection. Therefore, engineering implementation departments should immediately develop inter-facility power mutual aid operational protocols, retrofit critical substations with dual power supply access channels, and equip special loads like CNC machining centers with rapid switching devices. Dispatch teams must establish unified cross-facility coordination mechanisms, formulate load transfer priority lists, and define emergency response procedures. Regulatory bodies must refine technical standards for boundary equipment, particularly clarifying protection setting principles for interconnection lines and fault isolation time limits. This enables mutual power support among plants during sudden line failures, ensuring the continuous operation of core production lines. Such measures enhance regional industrial power resilience, reduce overall operational costs, and ultimately transition from single-plant self-sufficiency to multi-plant collaborative mutual support in power supply and consumption.

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About the Author

Lei Yao , Bachelor's Degree, Senior Engineer. Research Areas: Electrical Engineering and Automation, Electric Machinery and Power Electronics, New Energy Development and Application.

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