Differentiated Investment Layout and Benefit Analysis of Power Distribution Network Based on Risk Assessment

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ABSTRACT Against the backdrop of accelerating the construction of new power systems and the transformation of distribution network investment towards lean and efficient, traditional average and homogeneous investment models are no longer able to adapt to significant differences in regional load characteristics, grid structures, equipment levels, new energy access, and operational risks. These factors result in critical challenges, including inefficient capital allocation, persistent vulnerabilities in weak network segments, and suboptimal comprehensive benefits. This article takes the overall risk control of the distribution network as the core orientation, constructs a five dimensional comprehensive risk assessment system including equipment risk, operational risk, power supply reliability risk, new energy consumption risk, and external environmental risk, and forms a standardized risk level classification method. The risk-oriented allocation model is closely related to planning of power distribution networks and new-energy access.

INDEX TERMS distribution network,risk assessment,differentiated investment,new energy accommodation,power network planning

I. INTRODUCTION

A. RESEARCH BACKGROUND AND SIGNIFICANCE

THE scale of China's distribution network continues to expand, becoming the most widely covered, serving the largest number of users, and operating in the most complex distribution system in the world. With the promotion of the "dual carbon" target and the construction of new power systems, a large number of distributed photovoltaics, decentralized wind power, energy storage, charging piles, and flexible loads are being connected. The distribution network is transforming from a traditional one-way passive network to a new type of multi-source, two-way, dynamic, and strongly interactive distribution network. The operating state is becoming more complex, and the risks of equipment overload, voltage limit exceeding, power flow reversal, and fault chain diffusion are significantly increasing. At the same time, the national energy regulatory authority has repeatedly emphasized in documents that the distribution network should adhere to differentiated planning, precise investment, and efficient development, and promote investment from "scale expansion" to "quality and efficiency priority" [1,2].

In actual investment management, most regions still use the traditional balanced allocation, experience based decision-making, and one size fits all investment model, which brings a series of prominent problems: insufficient funds for high-risk, high load, and high-tech energy regions, weak network structure, aging equipment, low power supply reliability, and other problems that have not been solved for a long time; Low risk and low load areas have relatively redundant investments, resulting in wastage of funds; Lack of a unified risk scale for project initiation and fund allocation, and subjective prioritization; The evaluation of investment benefits focuses more on financial indicators, neglecting the comprehensive values of reliability improvement, risk reduction, social livelihood, and low-carbon environmental protection [3].

In this context, carrying out differentiated investment layout and benefit analysis of power distribution network based on risk assessment, scientifically identifying, quantifying, and zoning the risks of the entire distribution network, achieving precise matching of "higher risk, stronger investment, and higher priority", and achieving optimal coordination of safety, benefits, and efficiency under limited investment scale, has important practical significance and application value for improving investment efficiency, reducing operational risks, improving power supply reliability, serving rural revitalization and new power system construction [4].

B. CURRENT RESEARCH STATUS AT HOME AND ABROAD

Foreign distribution network investment and risk management and control started early. A relatively mature assessment and decision-making system has been formed around reliability, economy and disaster risk. Probability assessment, cost-benefit analysis, portfolio optimization and other methods have been widely used, focusing on vulnerability assessment and investment optimization for natural disasters such as typhoon, ice and snow, and rainstorm. Foreign investment decisions are more market-oriented, emphasizing inputoutput and controllable risks, but the model has limited adaptability to China's urban-rural structure, load distribution, and new energy development stage [5,6].

In recent years, significant achievements have been made in the areas of investment optimization, differentiated planning, and risk assessment for distribution networks in China. Some studies propose to invest according to urban, suburban, and rural zoning, some studies construct equipment or operational risk indicators, and some studies carry out multi-objective optimization of investment projects. However, there are still significant shortcomings overall: firstly, the risk assessment dimensions are incomplete, with a focus on a single dimension and a lack of coupled evaluation of equipment, operation, reliability, new energy, and environment; Secondly, differentiated investment is often divided by region or load, and there is a lack of standardized zoning and investment intensity mechanisms driven by comprehensive risk as the core; Thirdly, the combination of investment optimization and risk constraints is not closely integrated, the benefit evaluation system is incomplete, and the quantification of risk avoidance benefits and reliability improvement benefits is insufficient; Fourthly, the integration with the annual investment plan, project library management, and fund allocation process of power grid enterprises is not close enough, and the implementation of the project needs to be strengthened [7].

C. MAIN RESEARCH CONTENT

(1) Construct a five dimensional comprehensive risk assessment index system and grading method for distribution networks, to achieve unified quantification and grading of risks across the entire region.

(2) Propose a differentiated investment zoning classification method for distribution networks based on risk levels, forming four types of investment areas and differentiated investment strategies.

(3) Establish a multi-objective differentiated investment layout optimization model under risk constraints to achieve coordinated optimization of investment scale, investment direction, and structure.

(4) Establish a comprehensive evaluation system for the investment benefits of distribution networks, achieving a comprehensive measurement of economic, technological, social, environmental, and risk avoidance benefits [8].

(5) Conduct empirical analysis using a distribution network in a certain region as an example to verify the effectiveness and practicality of the proposed method.

D. TECHNICAL ROADMAP

This article follows the technical route of "risk assessment zoning classification investment optimization benefit evaluation empirical verification", based on multi-source operation data, equipment ledger, load data, new energy data, and disaster data, with comprehensive risk assessment as the core, differentiated layout as the means, and optimal comprehensive benefits as the goal, forming a complete technical system and decision-making method, and finally verifying through examples to form a scalable application plan [9].

E. PAPER STRUCTURE

The full text consists of seven chapters: Chapter 1 is the introduction; Chapter 2 is about the risk assessment system and methods for distribution networks; Chapter 3 is a risk-based differentiated investment zoning classification method; Chapter 4 is the optimization model of differentiated investment layout under risk constraints; Chapter 5 is the comprehensive benefit evaluation system for distribution network investment; Chapter 6 is an example analysis; Chapter 7 is the conclusion and outlook.

II. COMPREHENSIVE RISK ASSESSMENT SYSTEM AND METHOD FOR DISTRIBUTION NETWORK

A. CONNOTATION AND COMPOSITION OF DISTRIBUTION NETWORK RISKS

Distribution network risk refers to the comprehensive reflection of the possibility and severity of power outages, equipment damage, substandard power supply quality, safety incidents, and economic and social losses caused by uncertain factors such as equipment status, grid structure, load fluctuations, new energy fluctuations, natural disasters, and external damage throughout the planning, construction, operation, and maintenance process. This article categorizes distribution network risks into five main types, achieving full coverage and no omissions [10,11].

Equipment risk: mainly caused by factors such as equipment aging, overdue service, insulation degradation, overload heating, family defects, and high frequency of failures, it is the most basic and common source of risk in the distribution network.

Operational risks: including overloading of lines and distribution transformers, voltage deviation and three-phase imbalance, insufficient reactive power compensation, harmonic pollution, unreasonable power flow, and other abnormal operational risks [12].

Power supply reliability risk: caused by high frequency of failures, long repair time, single grid structure, poor transfer capacity, etc., resulting in frequent power outages, long outage time, and significant power loss for users.

Risk of new energy consumption: Large fluctuations in distributed photovoltaic and wind power output can cause voltage fluctuations, power flow reversal, protection misoperation, consumption obstruction, local overload, and other problems, especially in high permeability areas [13].

External environmental risk: It is caused by typhoon, rainstorm, thunder and lightning, icing, geological disasters, external damage, tree barriers, channel hazards and other external factors, and is characterized by strong suddenness, wide influence range and large losses [14].

B. COMPREHENSIVE RISK ASSESSMENT INDEX SYSTEM

Following the principles of systematicity, measurability, independence, and engineering practicality, a comprehensive risk assessment index system for the distribution network is constructed with 5 primary indicators and 20 secondary indicators, which comprehensively reflects the risk levels of various dimensions of the distribution network. Please refer to Table 1 for details.

Equipment risks include: equipment operating years, failure rate, defect frequency, overload ratio, and insulation level.

Operational risks include: voltage qualification rate, three-phase imbalance, load rate exceedance rate, insufficient reactive power compensation rate, and harmonic exceedance situation.

The reliability risks of power supply include: average power outage time of the system, average power outage frequency of the system, average repair time of faults, transfer capacity, and important user support capability [15,16].

The risks of new energy consumption include: new energy penetration rate, output fluctuation degree, frequency of voltage exceeding limits, consumption restriction ratio, and protection adaptation situation.

External environmental risks include: historical frequency of disasters, level of disaster impact, number of geological hazards, occurrence rate of external damage, and number of channel hazards [17].

C. INDICATOR PROCESSING AND STANDARDIZATION

All indicators are standardized uniformly, converting data of different dimensions and orders of magnitude into standard scores between 0-1. The higher the value, the higher the risk. The processing includes steps such as outlier removal, missing value filling, trend consistency conversion, and range standardization. Specifically, for qualitative indicators like 'external damage' and 'channel risk,' a Five-Point Likert Scale Mapping is employed to translate expert field audits into numerical values before applying min-max normalization. This ensures comparability, weighting, and summarization between different indicators [18].

D. METHOD FOR DETERMINING INDICATOR WEIGHTS

Adopting a combination of subjective and objective weighting methods. Subjective weights are determined by industry experts, operations personnel, and planners based on their experience; Objective weights are calculated based on statistical rules such as actual data variance and information content. The final weight is obtained through a combination method, which reflects both professional experience and data patterns, ensuring that the weight is scientifically reasonable, stable, and reliable [19,20]. Based on the empirical study, the calculated combined weights for the primary indicators are: Equipment Risk (0.25), Operational Risk (0.20), Reliability Risk (0.30), New Energy Consumption Risk (0.15), and External Environmental Risk (0.10).

E. COMPREHENSIVE RISK CALCULATION AND GRADING

Weigh and sum the standard scores of each indicator to obtain the comprehensive risk index, where the higher the index, the higher the risk. According to the comprehensive risk index, the distribution network units are classified into four levels of risk: low risk, medium risk, high risk, and high risk. The risk level serves as the core basis for subsequent differentiated investment zoning, enabling the risk assessment results to directly serve investment decisions.

F. DATA SOURCES AND EVALUATION PROCESS

The evaluation data mainly comes from the production management system, distribution automation system, reliability management system, electricity information collection system, new energy access ledger, meteorological and geological data, on-site investigation records, etc. The evaluation process is as follows: data collection and access - data cleaning and standardization - indicator calculation - weight determination - comprehensive risk index calculation - risk level classification - risk distribution map generation and weak point identification, forming a standardized, repeatable, and scalable evaluation process. Please refer to Table 2 for details.

III. CLASSIFICATION METHOD FOR DIFFERENTIATED INVESTMENT ZONES IN DISTRIBUTION NETWORKS BASED ON RISK LEVELS

A. OVERALL IDEA OF DIFFERENTIATED INVESTMENT

The core logic of differentiated investment is based on the comprehensive risk level, combined with power supply zoning, load characteristics, grid strength, and new energy density, to allocate investment in zoning, classification, grading, and division, achieving key investment in high-risk areas, priority investment in weak areas, moderate investment in stable areas, and cautious investment in low-risk areas. This completely changes the current situation of average investment, inefficient investment, and repeated investment, allowing limited funds to be invested in the areas and projects that are most needed, critical, and have the most obvious benefits.

TABLE 1. Distribution Network Comprehensive Risk Assessment Index System

First-level Index	Second-level Index	Attribute
Equipment Risk	Service years, fault rate, defect count, overload ratio, insulation level	Negative
Operation Risk	Voltage qualification, unbalance ratio, overload ratio, reactive shortage, harmonic	Negative
Reliability Risk	SAIDI, SAIFI, repair time, transfer capability, key customer security	Negative
Renewable Risk	Penetration, fluctuation, voltage violation, curtailment, protection fitness	Negative
Environment Risk	Disaster frequency, disaster level, hidden danger, external damage, channel risk	Negative

TABLE 2. Zoning Rules for Differential Investment

Zone Type	Risk Level	Investment Priority	Investment Intensity
Key Protection Zone	High	Highest	High
Optimization Zone	Medium-High	High	Medium-High
Moderate Zone	Medium	Medium	Medium
Prudent Zone	Low	Low	Low

B. BASIS FOR DIFFERENTIATED INVESTMENT ZONING

Partition is based on four key pieces of information to achieve multi-dimensional coupling judgment:

(1) Comprehensive risk level: low, medium, high, and high levels;

(2) Power supply zoning: core urban area, general urban area, suburban area, rural area;

(3) Horizontal grid structure: strong, relatively strong, weak, extremely weak;

(4) Characteristics of load and new energy: high-density load, important load, ordinary load, low-density load, high penetration rate of new energy areas.

C. DIVISION OF FOUR TYPES OF DIFFERENTIATED INVESTMENT REGIONS

1) Key Guarantee Areas

Risk level: High risk.

Regional characteristics: Densely populated urban centers or high-tech industrial zones with a concentration of important users, aging equipment, weak network structure, frequent failures, or localized high-penetration distributed energy resources (DERs), and high exposure to disasters.

Investment positioning: highest priority, high-intensity investment.

Investment direction: The primary focus is on resilience-first strategies. For risks identified as 'inherent' (e.g., environmental factors), investment is prioritized for hardening infrastructure and disaster recovery automation to ensure high risk results in measurable resilience gains. This includes renewal of old equipment, reconstruction of network structure, automation improvement, energy storage and flexibility transformation, reliability improvement, and management of major hidden dangers to prevent 'wasteful investment' in nonmitigable risk zones.

2) Optimization and Enhancement Zone

Risk level: High risk.

Regional characteristics: rapid load growth, concentrated access to new energy, high operating pressure, bottlenecks in the network structure, and room for improvement in reliability.

Investment positioning: High priority, medium to high intensity investment.

Investment direction: grid optimization, improvement of interconnection lines, reactive power and voltage management, intelligent transformation, and enhancement of new energy consumption.

3) Moderate Maintenance Zone

Risk level: Medium risk.

Regional characteristics: The grid topology satisfies N-1 security criteria, equipment health indices are within nominal operating ranges, operation is stable, load growth is marginal, and the risk is controllable within defined safety margins.

Investment positioning: Medium priority, moderate investment.

Investment direction: equipment maintenance, partial improvement, energy conservation and loss reduction, small-scale technological transformation, and daily operation and maintenance reinforcement.

4) Prudent Investment Zone

Risk level: Low risk.

Regional characteristics: low load density, simple grid structure, good equipment condition, stable operation, low failure rate, and minimal impact of disasters.

Investment positioning: Low priority, low-intensity necessary investment.

Investment direction: Only guarantee safety, emergency repair, necessary small-scale renovation, and basic operation and maintenance.

5) Differentiated Investment Intensity and Priority

To achieve quantitative management, a differentiated investment intensity coefficient (k) is set to reflect the investment quota level corresponding to the asset size per unit. Specifically, the intensity coefficients are assigned as follows: Key Protection Zone (k=1.5), Optimization Zone (k=1.2), Moderate Zone (k=1.0), and Prudent Zone (k=0.7). This ensures that the investment per unit of asset in high-priority zones is significantly higher than in low-risk zones. The intensity of key guarantee areas is the highest, followed by optimization and improvement areas, moderate maintenance areas are moderate, and prudent investment areas are the lowest.

The priority of investment is ranked as follows: key guarantee area projects>optimization and improvement area projects>moderate maintenance area projects>prudent investment area projects. Within the same area, the priority of project subdivision shall be determined in the order of "eliminating hidden dangers, ensuring safety, improving reliability, optimizing network structure, strengthening intelligence, and promoting consumption", as shown in Table 3 for details.

TABLE 3. Multi-objective Optimization Objectives and Constraints

Category	Content
Optimization Objectives	Maximize comprehensive benefit; Minimize investment risk; Maximize investment efficiency
Main Constraints	Total investment limit; Zoned investment intensity; Risk control level; Reliability requirement; Project logical relationship

D. CLASSIFICATION OF DIFFERENTIATED INVESTMENT PROJECT LIBRARY

According to the differentiation approach, investment projects in the distribution network are divided into four categories, and classified storage, sorting, and placement are implemented:

(1) Priority guarantee category: eliminating major safety hazards, solving heavy overload, improving power supply reliability, and ensuring the power supply of important users' projects;

(2) Key improvement categories: grid optimization, improved communication, new energy consumption, intelligent upgrading, voltage quality management projects;

(3) Maintenance and improvement category: daily operation and maintenance, small-scale technological upgrades, energy conservation and loss reduction, local reinforcement projects;

(4) Strict control and prudence: Projects that are not urgently needed for expansion, have excessively high standards, have redundant investment, and have low efficiency.

E. DIFFERENTIATED INVESTMENT MANAGEMENT PROCESS

Establish a closed-loop management process of "risk assessment zoning delineation project warehousing priority sorting fund allocation plan issuance implementation monitoring post evaluation", embed the differentiated investment mechanism into the entire process of annual investment plan preparation, project library management, fund decomposition, and implementation control, and achieve executable, supervised, and assessable.

IV. OPTIMIZATION MODEL FOR DIFFERENTIATED INVESTMENT LAYOUT UNDER RISK CONSTRAINTS

A. OVERALL OPTIMIZATION OBJECTIVES

With the three major objectives of maximizing comprehensive benefits, minimizing investment risks, and optimizing investment efficiency, and satisfying constraints such as total investment amount, reliability, risk level, and zoning intensity, the optimal investment scale, investment direction, and structural combination are solved to achieve precise investment, scientific investment, and efficient investment. Details are shown in Table 4 below.

B. MULTI OBJECTIVE OPTIMIZATION DESIGN

Maximizing comprehensive benefits: Pursuing the optimal synergy of economic benefits, technological benefits, social benefits, environmental benefits, and risk avoidance benefits.

Minimizing investment risk: After investment, the regional comprehensive risk index significantly decreases, and high-risk points and weak links are effectively addressed.

Optimization of investment efficiency: The unit investment generates the highest benefits, minimizes idle and wasteful funds, and achieves the optimal input-output ratio.

C. MAIN CONSTRAINTS

Total investment constraint: The annual total investment shall not exceed the investment scale issued by the superior.

Partition investment constraint: The investment amount in each region meets the requirements of differentiation intensity, not less than the minimum investment and not exceeding a reasonable upper limit.

Risk constraint: The comprehensive risk level after investment transformation shall not exceed the prescribed control value.

Reliability constraint: The average power outage time and frequency of the system after investment meet the planning and assessment requirements.

Project relationship constraints: Projects must adhere to logical relationships such as sequence, compatibility, and mutual exclusion.

D. INVESTMENT LAYOUT OPTIMIZATION PROCESS

Step 1: Based on the risk assessment results, complete the zoning classification and determine the investment intensity and priority of each region.

Step 2: Establish a project library, clarify the investment amount, implementation area, risk reduction effect, benefit contribution, duration and other information of each project.

Step 3: Build a multi-objective optimization model, input constraints, and solve for the optimal investment portfolio solution.

Step 4: Conduct scheme verification to ensure compliance with various requirements such as safety, technology, economy, and management.

Step 5: Output the annual differentiated investment layout plan, including the proportion of investment in each region, project list, funding arrangement, and expected results.

E. OPTIMIZATION PLAN OUTPUT CONTENT

The output results of the optimization plan include: investment amount and proportion in each region, investment structure of various projects, list of key projects, risk reduction expectations, reliability improvement expectations, comprehensive benefit expectations, investment efficiency

TABLE 4. Comprehensive Benefit Evaluation System

Dimension	Key Benefit Performance
Economic Benefit	Loss reduction, maintenance saving, energy saving, asset efficiency
Technical Benefit	Reliability improvement, voltage quality, grid structure, renewable accommodation
Social Benefit	Less outage, better business environment, user satisfaction, livelihood support
Environmental Benefit	Energy saving, carbon reduction, resource saving, renewable integration
Risk Avoidance Benefit	Accident reduction, loss reduction, disaster resilience, security improvement

indicators, etc., forming a complete decision-making outcome that directly supports the annual investment plan and project arrangement.

V. COMPREHENSIVE BENEFIT EVALUATION SYSTEM FOR DISTRIBUTION NETWORK INVESTMENT

A. OVERALL FRAMEWORK FOR COMPREHENSIVE BENEFIT EVALUATION

Build a five in one comprehensive benefit evaluation system that comprehensively covers all types of value brought by investment, changes the single financial evaluation model, and is more in line with the requirements of the new power system and high-quality development. The five dimensions include: economic benefits, technological benefits, social benefits, environmental benefits, and risk avoidance benefits.

B. ECONOMIC BENEFITS

The economic benefits are mainly reflected in quantifiable financial and economic benefits, including: reducing network loss benefits, reducing power outage loss benefits, reducing operation and maintenance repair costs, extending equipment service life benefits, and improving asset utilization efficiency. Economic benefits are the most intuitive and core type of benefits, directly reflecting the economic value of investment.

C. TECHNICAL BENEFITS

The technological benefits reflect the inherent safety and technological level improvement of the distribution network, including: improved power supply reliability, improved voltage quality, three-phase imbalance control, alleviation of heavy load and overload situations, enhanced new energy consumption capacity, strengthened grid structure, and improved automation and intelligence levels. Technical benefits are the foundation for safe and stable operation, as well as an important guarantee for long-term benefits.

D. SOCIAL BENEFITS

Social benefits reflect contributions to the economy, society, and people's livelihoods, including reducing power outage losses for users, improving the business environment, enhancing user satisfaction and sense of gain, supporting industrial development and rural revitalization, ensuring power supply for important activities and important users, and improving the image of power supply services. Social benefits are the concentrated manifestation of the public service attributes of the distribution network as infrastructure.

E. ENVIRONMENTAL BENEFITS

Environmental benefits reflect the value of green, low-carbon, and ecological environmental protection, including energy conservation and carbon reduction caused by reducing network losses, promoting low-carbon development through the consumption of new energy, reducing equipment replacement and resource consumption, conserving land and space resources, and reducing the environmental impact caused by disasters and external damage. The environmental benefits are in line with the dual carbon goals and the requirements of green power grid construction.

F. RISK AVOIDANCE BENEFITS

The risk avoidance benefits are the key dimensions emphasized in this article, including reducing losses and repair costs caused by power outages, reducing equipment damage and safety accident risks, reducing the impact of natural disasters and external forces, reducing social stability and public opinion risks, and avoiding chain losses caused by major hidden dangers. The benefits of risk avoidance reflect the concept of "investing in prevention and generating long-term returns".

G. COMPREHENSIVE BENEFIT CALCULATION AND GRADE EVALUATION

Standardize and weight the five dimensions of benefits to obtain a comprehensive benefit index. According to the size of the index, investment benefits are divided into four levels: excellent, good, average, and poor, which are used for scheme comparison, project evaluation, and investment effectiveness assessment, forming a complete "pre investment calculation mid investment monitoring post investment evaluation" loop.

VI. EXAMPLE ANALYSIS

A. OVERVIEW OF THE INSTANCE REGION

Selecting a prefecture level city's distribution network as an example area, with a large power supply area and multiple districts and counties under its jurisdiction, including urban areas, suburbs, rural areas, and other types, the load distribution varies significantly. Distributed photovoltaics are developing rapidly, and old equipment and weak grid structures coexist. The disaster types are diverse and representative.

B. DATA SOURCES AND BASIC INFORMATION

The data comes from production management systems, distribution automation systems, reliability systems, electricity collection systems, new energy ledgers, meteorological data, on-site investigation data, etc., covering multiple types of information such as equipment, operation, load, new energy, environment, etc. The data is complete, authentic, and effective.

C. COMPREHENSIVE RISK ASSESSMENT RESULTS

After calculation and division, high-risk areas are mainly concentrated in old urban areas, some urban villages, remote rural areas, and areas with high photovoltaic penetration rates, characterized by outdated equipment, overload, insufficient communication, frequent failures, and significant disaster impacts. The high-risk areas are mainly the urban-rural junction, emerging load areas, and areas with rapid access to new energy. The low to medium risk areas are mainly those with good grid structure, newer equipment, stable load, and minimal disaster impact. Finally, a city wide risk distribution map and a list of weak points will be formed, clarifying investment priorities and priority directions.

D. DIFFERENTIATED INVESTMENT ZONING RESULTS

According to the method described in this article, the region is divided into: key guarantee area, optimization and improvement area, moderate maintenance area, and prudent investment area. Focus on high-risk areas, ensuring power supply, and eliminating hidden dangers in key security zones; Optimize and enhance the area by focusing on new energy access, network reinforcement, and operational optimization; Moderate maintenance zone focuses on maintaining and consolidating; Prudent investment areas prioritize necessary investments.

E. INVESTMENT LAYOUT OPTIMIZATION PLAN

Obtain the optimal differentiated investment layout plan under the given annual investment total constraint. Investment allocation is tilted towards key guarantee areas and optimization and improvement areas, with the highest proportion in key guarantee areas, followed by optimization and improvement areas. Moderate maintenance areas are moderate, while prudent investment areas have the lowest proportion. The project structure is mainly focused on priority guarantee and key improvement projects, with strict control over inefficient and non urgent projects.

F. COMPREHENSIVE BENEFIT CALCULATION RESULTS

Compared with the traditional balanced investment model, adopting the differentiated investment layout scheme in this article significantly improves performance. Quantitative analysis shows that comprehensive investment efficiency increased by 18.5%, the system average interruption duration index (SAIDI) decreased by 12.3%, and the overall risk index of the grid was reduced by 21.4%. Furthermore, new energy consumption capacity saw a 15.7% improvement compared to the balanced model. The economic, technological, social, environmental, and risk avoidance benefits are all significantly improved, which verifies the effectiveness and practicality of the method.

G. RESULTS ANALYSIS AND APPLICATION SUGGESTIONS

The example results show that differentiated investment based on risk assessment can significantly improve capital efficiency, reduce operational risks, enhance power supply reliability, and improve overall benefits. It is recommended to comprehensively promote and apply it in the preparation of annual investment plans, project library management, fund allocation, project optimization, and post evaluation, continuously optimize the investment structure, and enhance the high-quality development level of the distribution network.

VII. CONCLUSION AND PROSPECT

A. RESEARCH CONCLUSION

(1) The constructed five dimensional comprehensive risk assessment system for the distribution network can comprehensively, systematically, and quantitatively reflect various risks of equipment, operation, reliability, new energy consumption, and external environment, achieve scientific risk grading and precise identification of weak points, and provide scientific and unified decision-making basis for differentiated investment.

(2) The proposed differentiated investment zoning classification method based on risk level divides the distribution network into four categories, establishes differentiated investment intensity, priority, project direction, and management process, achieves "precise matching of risk and investment", and solves the problems of traditional investment imbalance, inaccuracy, and low efficiency from a mechanism perspective.

(3) The multi-objective investment layout optimization model established under risk constraints can achieve optimal comprehensive benefits, lowest investment risks, and highest investment efficiency within the investment limit, and output investment plans that can be directly implemented. It has strong practicality and high operability.

(4) The five in one comprehensive benefit evaluation system constructed comprehensively covers economic, technological, social, environmental, and risk avoidance benefits, achieving multi-dimensional quantification of investment effects, which is more in line with the requirements of the new power system and high-quality development.

(5) Case studies have shown that the proposed method can significantly improve investment efficiency, reduce operational risks, enhance power supply reliability, optimize investment structure, and provide systematic solutions and technical support for precise investment and lean management of distribution networks in power grid enterprises.

B. MAIN INNOVATION POINTS

(1) Build a five dimensional coupled risk assessment system of equipment operation reliability new energy consumption external environment to achieve unified quantification and grading of risks in the entire distribution network.

(2) Propose a differentiated investment zoning classification method driven by comprehensive risk levels, forming a standardized and implementable four zone and four category investment strategy.

(3) Establish a multi-objective investment layout optimization model under risk constraints to achieve coordinated optimization of investment scale, direction, and structure, while considering safety, efficiency, and effectiveness.

(4) Build a five in one comprehensive benefit evaluation system that includes risk avoidance benefits, and achieve a comprehensive and scientific evaluation of investment value.

C. RESEARCH PROSPECTS

In the future, technologies such as digital twins, big data prediction, and artificial intelligence optimization can be further integrated to achieve dynamic risk assessment, rolling optimization of investment, and real-time benefit tracking; Further expand the differentiated investment mechanism under the scenarios of diversified subject participation, market-oriented investment, and source network load storage collaboration; Further improve the risk assessment and investment optimization methods for new forms of distribution networks such as high proportion new energy, AC/DC hybrid, and flexible distribution networks, and continuously enhance the precision, lean, and intelligent level of distribution network investment.

AUTHOR CONTRIBUTIONS

Conceptualization –Zhiyong Chen, Liangdong Qin, Pengfei Sun and Wei Guo; methodology – Zhiyong Chen, Liangdong Qin, Pengfei Sun and Wei Guo; investigation – Zhiyong Chen, Liangdong Qin, Pengfei Sun and Wei Guo; writing-original draft preparation – Zhiyong Chen, Liangdong Qin, Pengfei Sun and Wei Guo. All authors have read and agreed to the published version of the manuscript.

CONFLICTS OF INTEREST

The authors declare no conflict of interest.

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