World Journal of Engineering Research
Print ISSN: 2959-9865
Online ISSN: 2959-9873
DOI: https://doi.org/10.61784/wjer3126

RESEARCH AND IMPLEMENTATION OF ACTIVE PUSH TECHNOLOGY FOR TRANSMISSION LINE RISKS BASED ON METEOROLOGICAL INFORMATION

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Abstract: Frequent extreme meteorological disasters trigger numerous faults of transmission lines such as ice coating, wind deflection, lightning damage and wildfires. Existing power grid meteorological early warning systems suffer from drawbacks including single-dimensional data, insufficient accuracy of risk research and judgment, and generalized early warning push, which fail to support refined disaster prevention, operation and maintenance for single towers and local line sections. To address these issues, this paper conducts research on the technical system and application platform for active push of transmission line risks based on multi-source meteorological information. First, three types of power-specific multi-source meteorological data supporting line risk assessment are sorted out, namely real-time monitoring data, short-term forecast data and historical statistical data. Six categories of meteorological disasters threatening lines, including strong wind, ice coating, lightning, rainstorm and flood, wildfire and pollution flashover, are classified, and existing deficiencies in early warning for each disaster type are analyzed . Second, the overall architecture of the early warning push system based on the i-State Grid is designed. Centering on four core modules: information collection, standardized assembly, intelligent sorting and multi-channel push, screening and integration processes for early warning information for multiple scenarios such as meteorological forecasts and severe convection are constructed respectively. Multi-batch comparison and space-time matching algorithms are adopted to reduce false early warning alarms. Finally, a hierarchical and classified accurate push mechanism is established, realizing precise matching between risk points and operation & maintenance personnel combined with post responsibilities. Early warning information is issued through coordinated channels including i-State Grid and short messages. Engineering applications verify that the proposed technology breaks the data barrier between meteorological data and power grid equipment data, enabling intelligent research and judgment of tower-level refined meteorological risks and hierarchical active push. It transforms the traditional extensive and lagging passive prevention and control mode, significantly improving the pre-disaster prevention and control capacity of the power grid against meteorological disasters, reducing meteorology-induced line faults and emergency disposal costs, and providing technical support for the construction of meteorological disaster prevention systems for smart power grids.
Keywords: i-State Grid; Disaster early warning; Severe convection early warning; Rainstorm monitoring and early warning; Precise push

1 INTRODUCTION

In recent years, affected by climate and environmental changes, extreme meteorological disasters have become more frequent, intense and recurrent. Large-scale meteorological disasters have occurred for five consecutive years, turning meteorological hazards from rare incidents into normalized risks. Such disasters frequently cause transmission line failures including ice coating, galloping, wind deflection, lightning strikes, wildfires, severe convection, tower foundation erosion by floods, tripping, and even tower collapse and wire breakage, resulting in severe damage to power grid equipment. At present, most provincial power companies under State Grid have built meteorological disaster monitoring and early warning systems, which still have prominent shortcomings: single data dimension, low precision of risk assessment, and poor pertinence of early warning push. The common problem of "large-scale early warning with small actual affected areas" restricts refined disaster prevention and control targeting single towers and local line segments [1-4]. To tackle these pain points, the power industry is advancing in-depth integration of meteorology and power grid operation & maintenance, and continuous research on meteorological disaster early warning technologies [5]. Research on active push technology for transmission line risks based on multi-source meteorological information can integrate high-precision meteorological monitoring & forecast early warning data with power grid equipment ledgers and geographic information, so as to realize intelligent screening, accurate matching and hierarchical push of meteorological risks, enabling power grid operation and maintenance to achieve "advance awareness and active prevention & control". This paper systematically studies the technical system and supporting application system, elaborates core technical points of each link, and verifies its practical value through engineering application cases, offering support for the construction of meteorological disaster prevention systems for smart power grids [6].

2 OVERVIEW OF METEOROLOGICAL DISASTER EARLY WARNING

2.1 Introduction to Meteorological Information

Meteorological information supporting transmission line risk assessment forms a multi-source, multi-dimensional and high-precision data system, serving as the foundation for accurate risk early warning. It is mainly divided into three categories: real-time monitoring data, short-term forecast data and historical statistical data. Combined with refined power-exclusive meteorological products, a dedicated power meteorological data base is established [7]. Real-time monitoring data includes wind speed, wind direction, temperature, humidity, precipitation, ice coating thickness and other real-time parameters collected from ground meteorological stations, micro-meteorological monitoring terminals, radars, satellites and UAV nests, which can accurately reflect the local real-time meteorological conditions along transmission corridors. Short-term forecast data covers hourly, 6-hourly and daily refined grid meteorological forecast data with kilometer-level or even tower-level resolution, capable of predicting short-term meteorological variation trends in the near future. Historical statistical data contains regional annual frequency, intensity, duration of meteorological disasters as well as corresponding line fault ledgers, providing data support for risk model training and threshold setting of risk levels [8].

Compared with general public meteorological information, power-special meteorological information is more targeted, focusing on key disaster-causing factors of transmission lines and eliminating invalid redundant data. It can precisely match various fault scenarios such as line galloping, ice coating, wind deflection, wildfire and lightning strike, supplying high-quality data for risk screening, assessment and push [9].

Currently, mainstream meteorological information access channels of State Grid include numerical weather prediction centers and enterprise-level meteorological data service centers under the unified promoted "Seven Centers" of State Grid, meteorological forecast and real-time information accessed from meteorological departments, micro-meteorological monitoring data self-built by power utilities, and partial meteorological forecast data provided by third-party manufacturers.

2.2 Types of Meteorological Disasters and Characteristics of Early Warnings

Combined with the fault mechanism of transmission lines and disaster-inducing characteristics of meteorology, six major types of meteorological disasters threatening safe operation of transmission lines are classified. The disaster-causing principles and fault characteristics of each type are clear, forming the core basis for classified risk assessment [10].

1. Strong Wind Disasters Instantaneous gusts and persistent strong winds easily trigger wind deflection discharge of transmission lines, collision of swinging conductors, tower inclination and collapse. Floating foreign matter carried by strong winds may wrap around lines and cause short-circuit tripping, making strong winds the primary disaster factor for transmission lines in plain and open areas [11]. At present, the forecast accuracy of strong wind early warning is generally lower than 70%. Especially under windy conditions, the predicted maximum local wind speed is often smaller than actual measured values, leading to delayed early warning when wind-induced line faults occur.
2. Ice Coating Disasters Low-temperature rain, snow and freezing weather cause ice coating on conductors and insulators, resulting in excessive line load, conductor galloping and insulator flashover. Severe ice coating may further lead to wire breakage, tower collapse and hardware damage, frequently occurring in high-cold mountainous and high-altitude transmission corridors in winter [12]. The current ice coating early warning precision can reach the millimeter level, yet obvious deviations exist in location and ice coating thickness for short-term forecasts due to terrain and ice melting effects [13].
3. Lightning Disasters Direct lightning and induced lightning during thunderstorms easily break down line insulators, burn equipment and trigger line tripping. Featuring strong suddenness and instantaneity, lightning strikes are the most frequent meteorological disaster for the transmission lines [14]. Current lightning prediction mainly focuses on regional scale, with sharply increased false alarm rates when conducting tower-level lightning forecasting [15].
4. Rainstorm and Flood Disasters Continuous heavy rainfall induces mountain landslides, mudslides and scouring collapse of tower foundations, accompanied by line waterlogging and equipment dampness faults, posing severe threats to transmission lines in mountainous areas and river channels. The accuracy of rainstorm early warning is relatively high, yet risk assessment of rainstorm-induced disasters requires comprehensive judgment integrating terrain, geological structure and water distribution [16].
5. Wildfire Disasters Prolonged high temperatures and drought lead to mountain fires around transmission corridors. High temperatures and smoke generated by wildfires reduce air insulation performance and induce line flashover tripping. Spreading wildfires may directly damage power transmission equipment, making wildfires a key disaster requiring prevention in spring and autumn [17]. The prominent characteristic of current wildfire risk early warning is excessive early warning coverage, affecting a large number of lines with poor pertinence.
6. Line Pollution Flashover Disasters Sandstorms, haze and fog accumulate pollutants on insulator surfaces and degrade insulation performance, easily triggering pollution flashover tripping, which frequently occurs on transmission lines in arid and dusty northern regions.

3 ARCHITECTURE DESIGN OF METEOROLOGICAL DISASTER EARLY WARNING PUSH TECHNOLOGY

3.1 System Architecture

To guarantee information security, an active push platform for transmission line risks based on meteorological information is designed on the basis of i-State Grid, consisting of four modules: information collection, information assembly, information sorting and message push, as illustrated in Figure 1. The information collection module connects to various meteorological forecast and early warning systems to acquire meteorological forecast and disaster early warning information researched and judged by source systems. The information assembly module screens various forecast and early warning information, conducts induction and merging, and generates customized content structures for different recipients. The information sorting module distributes relevant forecast and early warning information to mobile terminals of corresponding staff according to their job responsibilities and management scope, reducing interference from irrelevant information. The message push module undertakes message transmission, sending status monitoring and historical record management, ensuring all messages are successfully delivered to target users.

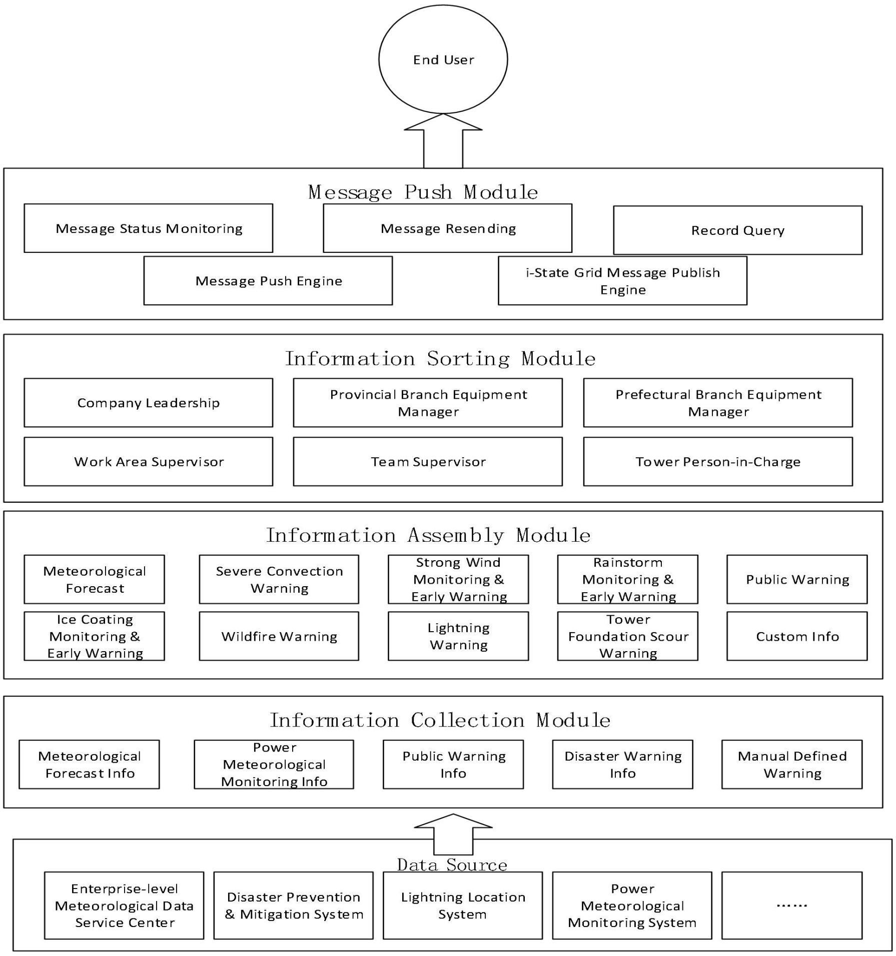

Figure 1 Architecture Diagram of Meteorological Disaster Early Warning Push Technology

3.2 Assembly of Meteorological Forecast and Early Warning Information

Multi-source meteorological and disaster data suffer from messy formats, high false alarm rates and space-time mismatch. Direct push to equipment management and operation & maintenance staff will result in information overload and low guiding value. Therefore, standardized information assembly and intelligent screening are required to unify the space-time coordinates and data formats of meteorological monitoring data, forecast data, power grid equipment data and geographic information data, constructing refined meteorological datasets at regional and tower levels to improve readability of meteorological forecast and early warning information [18].

Information assembly covers three core links: information classification, risk information screening and content integration. First, information is classified by types of meteorological forecast and early warning, and push contents are assembled targeting different categories such as meteorological forecast and severe convection early warning. Second, core meteorological factors strongly correlated with line faults are screened out combined with disaster-inducing mechanisms of transmission lines; irrelevant redundant data are eliminated, and risk levels corresponding to various meteorological parameters are identified to accurately lock high-risk meteorological information (e.g., wind below Grade 7 and low-risk wildfire early warnings are filtered out). Finally, forecast and early warning information is integrated by management unit, affected area, impacted equipment and corresponding countermeasure suggestions to form complete content for terminal users.

3.2.1 Assembly of meteorological forecast information

Meteorological forecasts predict gusts, precipitation, temperature and disastrous weather processes including severe convection, wildfire and ice coating, divided into medium-range forecast (3–15 days ahead), short-range forecast (3 days ahead) and very-short-range forecast (2h, 4h, 6h ahead). For content assembly: gusts above Grade 7, moderate rain and heavier precipitation, temperature below -20°C or above 35°C, and zero-degree line distribution regions are focused. The specific assembly process is shown in Figure 2.

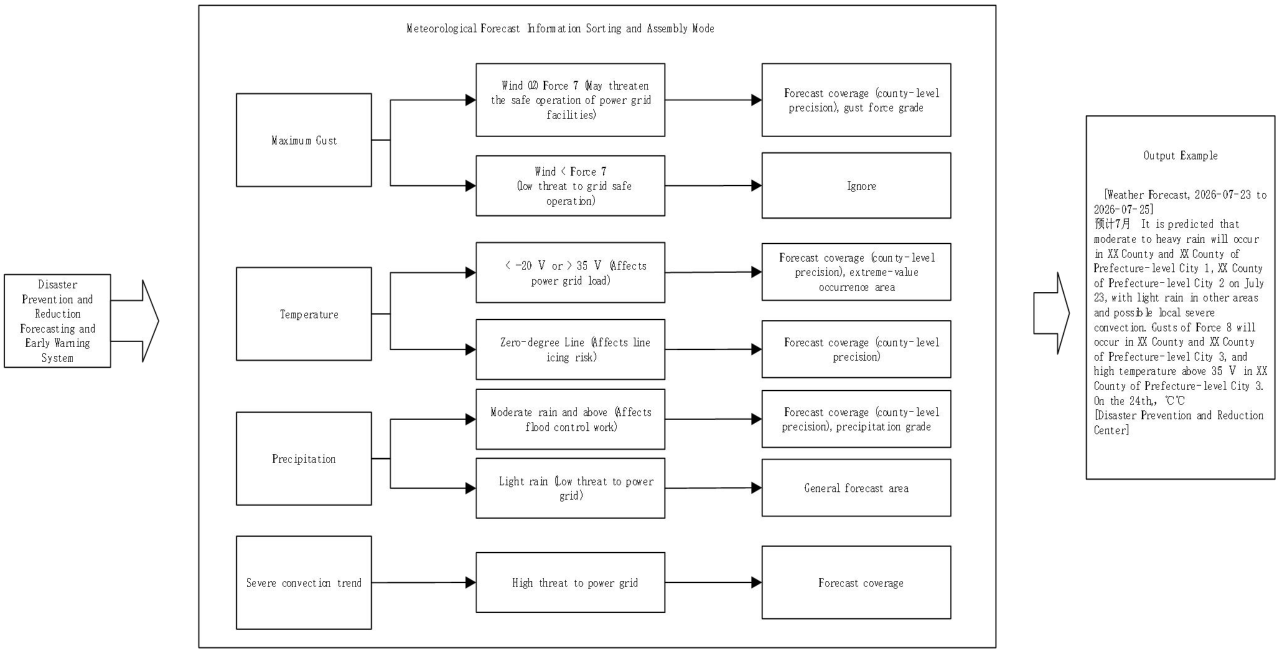

Figure 2 Flowchart of Meteorological Forecast Information Assembly

3.2.2 Assembly of severe convection early warning information

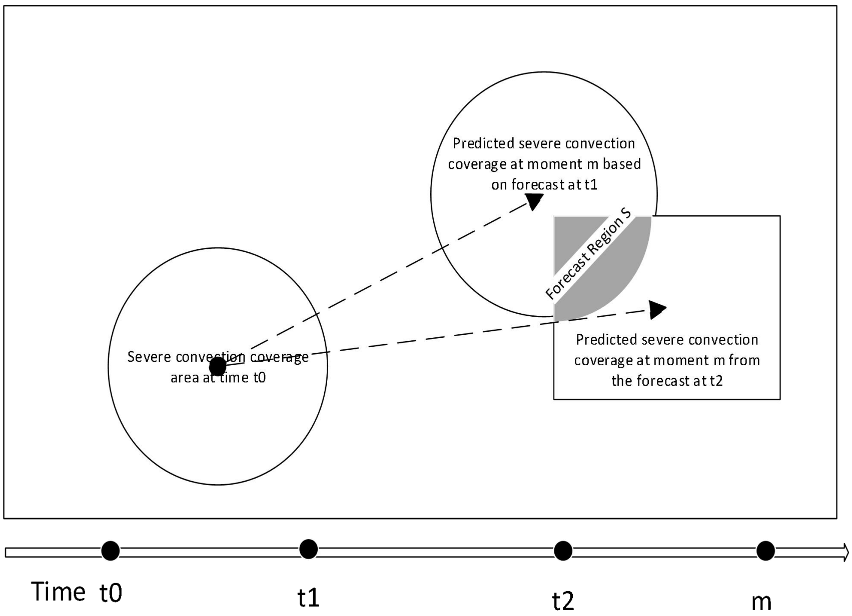

Figure 3 Schematic Diagram of Severe Convection Coverage Forecast

Severe convection weather refers to destructive weather processes triggered by intense convective activities, the major cause of power grid disasters such as wind-induced tower collapse, lightning tripping, floods and substation waterlogging, including thunderstorm gales, downbursts, tornadoes and short-duration heavy rainfall. It features strong suddenness, small local scale and instantaneous drastic wind speed changes. Severe convection early warning integrates multi-source observation data from weather radars, ground meteorological stations and radiosondes, calculating the forecast falling areas of thunderstorm gales and short-duration heavy rainfall in the next 2 hours with updates every 6 minutes. Such early warnings cover wide areas, change rapidly, impact numerous equipment and have high false alarm rates, bringing difficulties in response for grassroots units. To reduce false alarms and improve early warning pertinence, path correlation and multi-batch comparison methods are adopted to ignore short-term, occasional severe convection early warnings. For example, thunderstorm gale early warnings are only released when forecast paths of multiple consecutive batches overlap within a reasonable range, and affected areas and equipment are determined accordingly. As shown in Figure 3, the circular area on the left represents severe convection falling areas observed by radar at time t0; the circle and rectangle on the right denote predicted falling areas at moment m from forecasts at t1 and t2 respectively. If both predictions at t1 and t2 fall within a reasonable range judged by severe convection movement direction and speed, the early warning for moment m will be issued at t2, with the early warning coverage defined as region S.

3.2.3 Assembly of rainstorm monitoring and early warning information

Rainstorm monitoring and early warning comprehensively analyze multi-source data including meteorological station monitoring data, micro-meteorological online monitoring data, numerical forecast data, river & lake information and hidden danger data of power equipment against floods. It assesses cumulative historical precipitation in the region, predicted precipitation in subsequent periods, and potential secondary disasters such as floods, mudslides, landslides and substation waterlogging. The schematic diagram of rainstorm monitoring, forecast and early warning is displayed in Figure 4.

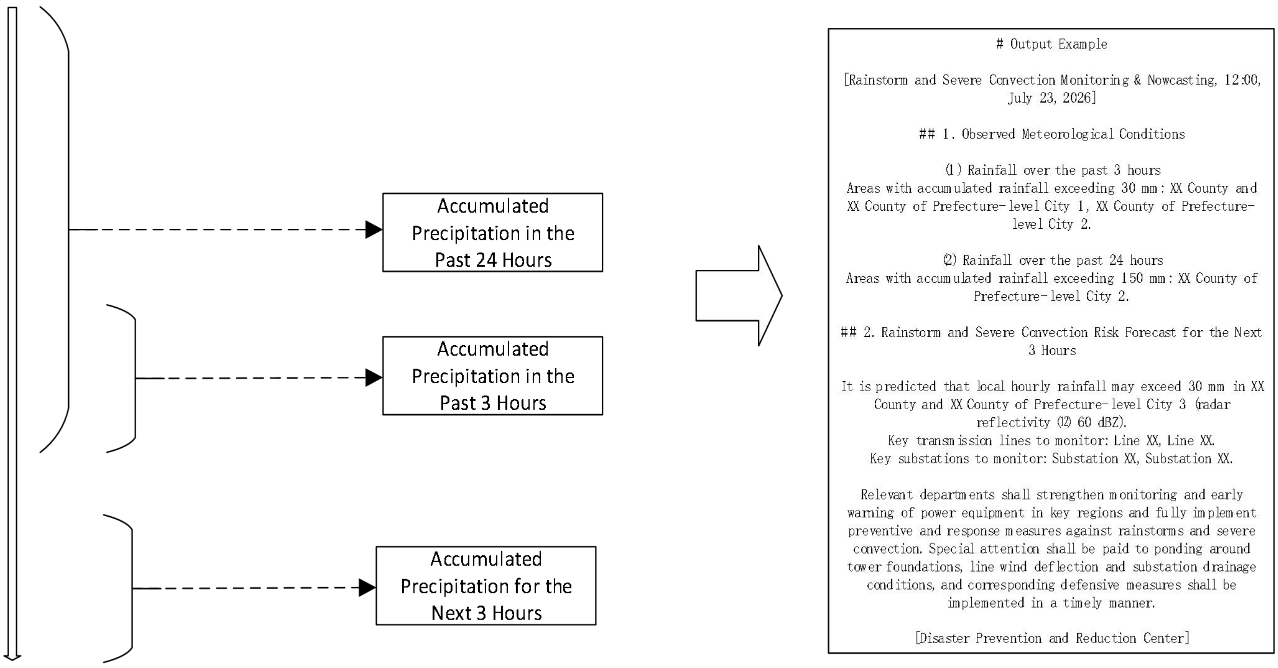

Figure 4 Schematic Diagram of Rainstorm Monitoring, Forecasting and Early Warning

3.3 Accurate Push of Early Warning Information

Centering on the core principles of "accurate matching, hierarchical classification and on-demand push", the accurate push mechanism of early warning information is built based on risk assessment results and staff responsibility systems, solving the traditional pain points of blanket push, poor pertinence and information overload. First, an equipment management responsibility system is constructed, covering company leaders, equipment managers, work area supervisors, team leaders and tower operation & maintenance personnel:

Company leaders receive only severe weather process forecasts and major risk early warnings of key equipment for decision-making;

Tower operation & maintenance personnel only obtain early warning information of equipment within their own maintenance scope.

Second, accurate matching of early warning recipients is realized, abandoning the traditional full-domain push mode. Specific towers, line segments, operation & maintenance teams and responsible personnel affected by meteorological disasters are precisely located, achieving "risk targeting equipment points and early warning reaching individual staff".

Finally, a multi-channel coordinated push system integrating i-State Grid messages, short message platforms and disaster prevention & reduction systems is established: i-State Grid serves as the primary sending channel, short messages act as supplementary retransmission channels when i-State Grid message delivery fails, and the disaster prevention & reduction system monitors, records and queries short message sending status to ensure timely and accurate message delivery to designated personnel. The hierarchical and classified push model for disaster early warnings is presented in Figure 5.

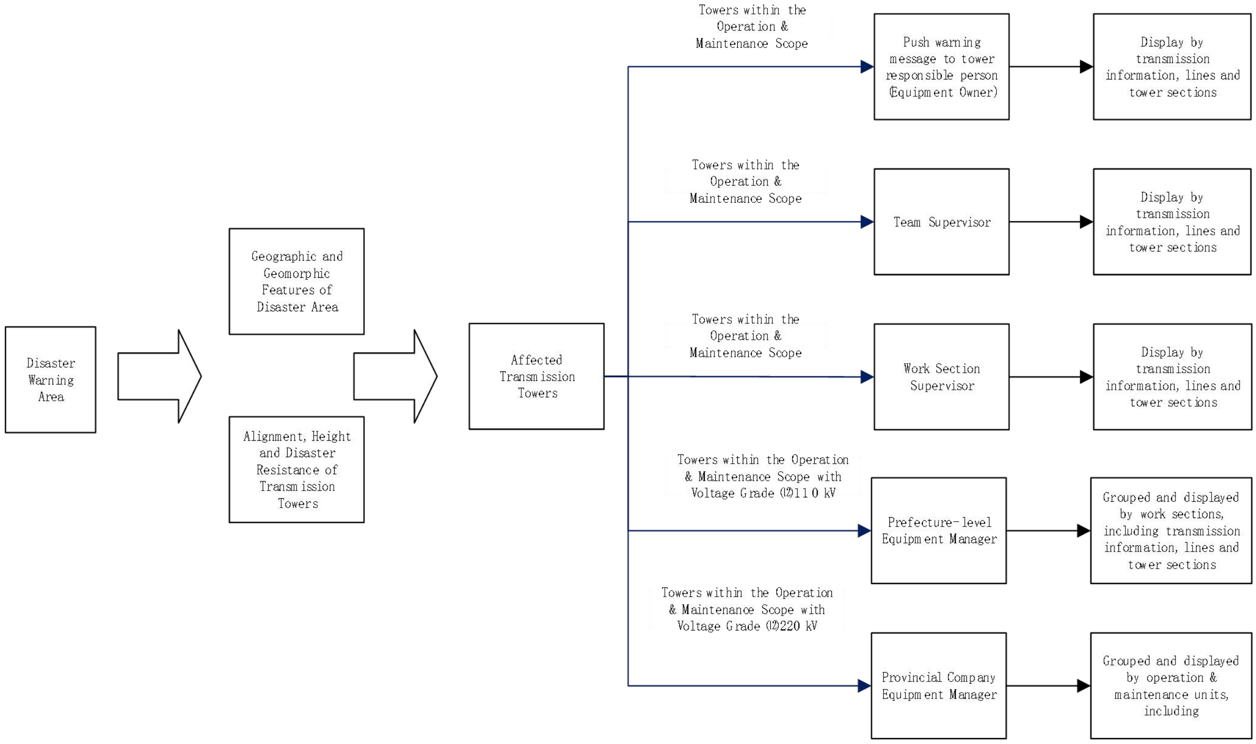

Figure 5 Hierarchical and Classified Push Model for Disaster Early Warning

4 CONCLUSIONS

Targeting the industry pain points of passive, extensive, lagging prevention and control and information overload in traditional meteorological risk management of transmission lines, this paper systematically studies the technology and application system for active push of transmission line risks based on meteorological information. Meteorological disaster categories for power applications are clarified, and full-process core technologies including multi-source meteorological information assembly & screening, intelligent risk assessment and hierarchical accurate active push are improved, forming an application system adapted to actual power grid operation & maintenance scenarios.

The developed system realizes refined, point-targeted and time-efficient assessment of meteorological risks for transmission lines, breaks the data barrier between meteorological data and power grid operation & maintenance data, and addresses the problems of low early warning accuracy, poor push pertinence and lagging prevention & control in traditional modes. It effectively enhances the capacity of power grids to conduct pre-disaster prevention and control against meteorological hazards, reduces the occurrence rate of meteorological-induced line faults, cuts emergency disposal costs, and improves the safe and stable operation level of power grids [19-20].

FUNDING

The project was supported by Research on Holographic Monitoring, Analysis, and Management Technology for Key Power Grid Equipment Driven by a Hybrid of Data and Knowledge (Project No.: 52467M250005).

COMPETING INTERESTS

The authors have no relevant financial or non-financial interests to disclose.

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