Health Perception System Design Based on Sensor Internet of Things for Transmission Tower’s Structure Status

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Abstract. By using Internet of Things smart terminal equipment based on low-power wireless sensing technology, integrated hybrid measurement technology and edge computing technology, this article designs a sensory perceptual system for structural health monitoring of transmission tower. This system have advantages over online monitoring, data fusion and unified transmission of status information related to tower inclination, structural stress, on-site images, status of lines and environmental meteorology, providing a practical and advanced solution for the informatization and intelligence of safe operation of the transmission tower, which can substantially improve the effectiveness and timeliness of patrol and protection, key positioning and early warning of hidden dangers of the transmission tower.

Keywords: Transmission tower, Structural health monitoring, Internet of Things, Sensing technology, Edge computing

1. Introduction
Transmission lines are important physical carriers for power grid energy transmission. Transmission tower is regarded as the direct support structure of transmission lines, and its structural health status is of vital importance to the entire line’s safety. However, during the long-term working of transmission towers, phenomena such as ageing material, loose bolts and steel corrosion will inevitably occur, resulting in continuous weakening of structural health status. Especially the frequent occurrence of disasters such as typhoons, tornadoes and icing, which often result in local structural damage, instability of rods or even collapse of the whole tower. At the beginning of 2008, a certain number of 500kV backbone transmission grids in southern China suffered tower collapse and breakage accidents due to large-scale, severe and continuous disastrous weathers such as low temperature, rain, snow and freezing in these areas, causing direct national property losses of tens of billions of Yuan [1].

In order to effectively prevent and control destructions of transmission tower, especially to cope with the huge damage caused by tower collapse and breakage accidents, the electricity industry spends much time and a great deal of efforts in theoretical analysis and engineering applications. The theoretical research focuses on occurrences mechanism of material yielding or structural instability resulting from static effects, dynamic effects or static-dynamic combined effects. Meanwhile, the engineering applications focus on the reinforcement and transformation measures of transmission towers, and the use of ice coating monitoring, weather monitoring and other methods to improve the timeliness of responds to disasters. However, due to the complexity of catastrophe mechanism of transmission tower, and the lack of effective means for monitoring the intrinsic safety of transmission
tower, as well as the lack of systematic, comprehensive, accurate and efficient technical means for perceiving the working behaviors of tower, it is difficult to scientifically and effectively acquire the health status of the transmission tower.

With the rapid development of measurement sensing technology, wireless communication technology and network information technology, technologies such as the Internet of Things, cloud computing and artificial intelligence have improved from concepts to practical applications [2, 3]. From a demand perspective, the inspection, operation and maintenance of transmission line have higher requirements and standards for advancement, practicability and informatization of solutions related to health monitoring technology and its application platform system. From a technical perspective, although the application of traditional health monitoring equipment is relatively mature, some are of backward level, which can’t meet the needs of information and intelligence in the monitoring and management during the operation of transmission towers. Therefore, it is an inevitable trend to design an online health monitoring system for transmission lines based on the currently mature IoT sensing technology and cloud computing technology. According to the online monitoring application characteristics of power transmission towers, this article uses Internet of Things smart terminal equipment based on low-power wireless sensing technology, integrated hybrid measurement technology and edge computing technology to construct a health status sensory perceptual system for tower, providing a practical and advanced solution to realize the informatization and intelligence of safe operation of grid engineering, which can substantially improve the effectiveness and timeliness of patrol and protection, key positioning and early warning of hidden dangers of the transmission tower.

2. Technical Principle

Previously, the operation inspection of transmission towers mainly depends on periodic inspections by operator and maintenance staff. Although certain hazards can be found in this way, due to the inevitable limitations of staff and inspection methods, such as a lack of real-time monitoring of special environment and climate, and shortage in timely grasping changes of corridor external force of grid during vacuum period of inspection cycle, it is very easy to cause a safety accident due to the lack of monitoring for hidden dangers before the starting of next inspection. With the rapid development of dynamic sensing monitoring technology, Internet of Things technology and wireless communication technology in recent years, the design ideas of intelligent perception system for monitoring health status of transmission towers also have more advanced technical supports.

2.1. Online Monitoring Technology for Tower

Generally, physical elements that have a major impact on health of transmission tower structure include steel structure stress, inclination deformation, vibration, line load and micro-meteorology. For stress, deformation, load and so on, sensors such as inclinometers, strain gauges and vibration accelerometers can be installed on the tower structure, and the above-mentioned physical elements can be monitored online through automated collection and transmission devices. In order to acquire information of meteorological environment of transmission towers in special locations, a multi-element micro-meteorological online monitoring device is used to monitor meteorological parameters such as environmental temperature, humidity, wind speed, wind direction and atmospheric pressure. The derivation calculation of icing coverage of conductor situation can be achieved via collected various meteorological parameters, values of conductor tension and insulator deformation. When an abnormal situation occurs, the system will send out pre-alarm information in a variety of ways, reminding management staff to pay attention to the alarm point or take necessary preventive measures.

2.2. Integrated Wireless Sensor Communication Technology

For on-site environment of transmission tower, the integrated wireless sensor communication technology can be used to construct a state intelligent perception system. The system is mainly composed of monitoring points, convergence stations and equipment including field power supplies and lightning protection devices. Specific equipment includes integrated sensors, edge collection
terminals and edge IoT agents based on wireless LAN communication technology, supporting applications on Zigbee, LoRa, GPRS/CDMA, 4G/5G etc. Zigbee and LoRa communication have the characteristics of low power consumption, easy maintenance and low cost, which are suitable for data transmission scenarios under the outdoor conditions with features of short distance, low transmission rate and no electricity. GPRS/CDMA, 4G/5G communication have the advantages of long distance, good stability and high transmission rate. It is mainly used for data transmission from edge IoT agents to monitoring platforms. In practical engineering applications, different communication networking methods can be selected according to site conditions to meet the needs of sensor signal acquisition and transmission according to different measurement principles, in order to achieve online monitoring of important physical parameters and related environmental parameters of transmission tower.

2.3. Edge Intelligent Processing Technology
For bottlenecks problems such as large blind zone in perception of transmission tower’s structure status and data transmission, based on edge intelligent processing technology [4], the real-time data acquired at the edge end is pre-processed and decomposed, and the parameters about structure health status characterization could be extracted and uploaded to the cloud platform in real time. Transient load of transmission line and structural states of tower are fully sensed at a high speed. The whole system is divided into perception layer, transmission layer, convergence layer and application layer. The edge computing is at the transmission layer. Through the edge intelligent gateway device, it downward supports the access of various on-site devices, and it upwards can connect with the cloud IoT management platform (figure 1). Edge intelligent gateways generally have advantages of computing, networking and storage resources. It can be remotely connected to IoT management platforms or other business systems through Ethernet or wide-area wireless networks. The main functions include data collection and storage, connection management, equipment monitoring and safe terminal access, unification of data model, edge computing, remote maintenance and upgrading, etc.

![Figure 1. Structure diagram of the health perception system of transmission tower.](image)

3. System Design

3.1. Monitoring of Status Parameters of Transmission Lines and Towers

3.1.1. Transient Load State of Transmission Line. a) Perception of conductor load. In order to monitor the working status of transmission conductor lines under ice-coated conditions, tension sensors and inclination sensors are installed on armour clamps and insulators of tower. Based on the real-time data of the conductor tension and the inclination angle of insulators, and combined with meteorological monitoring data such as wind speed and direction, loads such as equivalent ice thickness and wire tension can be calculated and analyzed.
b) Perception of environment factors of lines. Typical iron towers in corridors of transmission line are selected to install micro-meteorological online monitoring system to monitor temperature, humidity, wind speed, wind direction, air pressure and other meteorological parameters in a local environment in order to acquire the real-time meteorological changes in the monitored area.

3.1.2. Structural Health Status of Transmission Towers.

a) Perception of tower deformation. In order to monitor the inclination and deformation of the tower, according to the actual situation, it is considered to set up two-axis inclinometers on the cross arms at different heights of tower to monitor the inclination of each part of the tower, in order to find the abnormal deformation trend of the tower. At the same time, based on the conversion of the inclination angle, the deflection curve of tower can be drawn to judge the tower structure behaviors.

b) Perception of tower stress. According to structural design data, stress monitoring points can be selected at stress concentration locations and components of lower reliability and key points on the tower, and multiple sets of two-way strain gauges can be deployed to monitor the stress changes of the steel structure.

c) Perception of tower vibration. In order to monitor the vibration parameters of the transmission tower in extreme weather such as strong winds, an accelerometer is equipped on the top of the tower to monitor the dynamic response characteristics of the structure, so as to acquire the real-time changes in the vibration acceleration and dynamic displacement of the steel structure.

3.2. Monitoring Methods

3.2.1. Monitoring of Conductor Icing Coverage and of Environmental Elements on Transmission Lines. By real-time monitoring of various on-site information such as mechanical parameters (suspended load, wind deflection angle, inclination angle) of transmission line, meteorological conditions (ambient temperature, humidity, wind speed, wind direction), combined with line and tower information, the calculation model of equivalent ice coverage thickness of transmission line based on material mechanics and environment meteorology monitoring can automatically complete the quantitative calculation of unbalanced tension and equivalent icing thickness. In order to meet the requirements of conductor transient load perception under special working conditions, and comprehensively considering factors such as the long-term stability of the monitoring device, and considering service life and system power supply capacity, the mechanical parameters are triggered and monitored according to the meteorological conditions, and the micro-meteorological elements need to adopt a normalized monitoring method.

3.2.2. Monitoring of Transmission Tower’ Structural Status. The monitoring of the tower’s structure status includes three kinds of physical elements of structural inclination, stress and vibration. The monitoring of structural inclination deformation adopts a biaxial inclinometer with a range of ±15° and an accuracy of 0.2%FS. The monitoring of structural stress adopts a two-way steel plate strain gauge with a range of ±2300με and an accuracy of 1%FS. The structural stress is calculated by elasticity modulus of steel. The structural vibration is monitored by a three-axis acceleration sensor with a range of ±2g and an accuracy of 0.1mg. For monitoring methods of inclination and stress monitoring consider low-frequency (2 to 4 times a day) measurement under normal working conditions. It is necessary to trigger encrypted measurement under special working conditions. The accelerometer adopts the triggering measurement method, and each duration does not exceed 5 minutes, and the sampling rate is 20~30Hz at the same time.

3.3. Networking Framework

The system network framework designed is shown in figure 2, based on the structural characteristics and on-site environment of transmission towers and lines. The integrated edge collection terminal is a data acquisition device based on the Internet of Things technology, which connects the sensing layer.
and the transmission layer in the Internet of Things monitoring system, and can realize data acquisition and send data to the monitoring centre. The integrated collection terminal achieves the perceptions related to weather, load, angle, stress, vibration and so on, and realizes rapid sampling of important effect quantities, and supports automatic data collection, processing, encryption, remote wireless transmission and other functions, with features of automatic identification, remote configuration management, battery powered, easy installation and so on. After those collected various monitoring physical elements are converged, calculated and analyzed by the intelligent gateway of the perception layer of the Internet of Things, they are transmitted to the IoT management platform through the wide-area wireless network, thereby realizing communication networking, edge computing and regional autonomy of the perception layer.

Figure 2. Network framework of the intelligent perception system for the health status of the transmission tower.

4. Design of System functions

4.1. Remote Measurement and Control of Data
The performance in remote measurement and control of the monitoring system based on the Internet of Things is closely related to the brand and model of the on-site equipment. Based on obtaining the development interface of the on-site IoT terminal equipment, the secondary development should be carried out according to the equipment interface or standard model. The efficiency of development, versatility and accessibility of monitoring information management platform also should be taken into consideration at the same time. The on-site monitoring station network can be remotely controlled through the cloud-based IoT management platform and the monitoring business application platform. Various measurement methods and measurement parameters can be set to easily obtain various measurement data and perform diagnosis for module faults.

4.2. Query and Display for Basic Information
Basic information includes geographic information on transmission corridors, tower and line structure information, monitoring layout information, IoT terminal equipment information, on-site meteorology information, inspection information of lines and so on. Basic geographic information, tower location and important meteorological data can be displayed through GIS maps, and professional monitoring data, abnormal warning information and on-site image information can be updated in real time and displayed dynamically on the map (figure 3).
4.3. Data processing and Figure Display
Through the cloud monitoring business application platform, the result calculation of monitoring data can be conducted, in order to realize automatic drawing of process lines, correlation diagrams, distribution diagrams, layout diagrams, and realize display and output of data report, and realize input of manual inspection information and records of event logs, etc. The data processing function can continuously process data in real time, and the collected data will be calculated to generate business statistical data. Data solution can be calculated according to pre-set formulas and parameters. The data processing and result calculation can be finished via the background process monitoring and regularly call service of data processing program. The diagram customization provides functions of automatic monitoring data, query and input of manual inspection data and maintenance functions. In addition, the detailed data of tower structure will be displayed via various graphics and reports.

4.4. Analysis of Forecasting and Early Warning
The early warning analysis functions include early warning analysis and warning, meteorological disaster warning, early warning strategy and criterion management via monitoring data of transmission tower. Through the establishment of the forecasting, early warning analysis and evaluation mechanism for tower health status, data of ice and rain monitoring, typhoon monitoring, patrol inspection monitoring and other data are used as input parameters, combined with geographic and geological information, meteorological data, the accuracy and correctness of early warning can be ensured based on probability statistics of warning index judgments and historical risks, and an early warning conclusion of potential safety hazards of the tower structure is finally analyzed and generated. At the same time, it provides quantitative analysis and calculation methods of monitoring data, and can establish effect quantity forecasting models and early warning criteria for different types of safety hazards.

4.5. Release of Warning Information
Through the health status perception application platform of transmission tower, it provides functions such as query of monitoring information, online monitoring, links to public weather information and danger forecast services. Early warnings are released through messages, voice broadcasts, sound and light alarms and so on. The external early warnings could be released until those potential safety hazards in the tower and lines have been confirmed by professionals. This platform can support the release of forecasts and warnings to the public through the portal method of Web, and it can also request delivery services from the SMS sending device through the Web man-machine interface, and send messages via sending device on the server side, or send the broadcast command to the wireless broadcasting station for voice broadcast warning.

Figure 3. The functional interface of the intelligent perception system for the health status of the transmission tower.
5. Conclusion
The structure health perception system based on the sensor Internet of Things can adapt to the comprehensive business applications under transmission engineering scenes of multiple distributed monitoring areas and multiple data source information management. Monitoring information such as tower inclination, structural stress, on-site images, status of lines, environmental meteorology can be integrated. By using low-power wireless communication technology, edge collection terminal and edge IOT agent equipment of IoT technology development, the intelligent analysis of edge monitoring information, multi-source data convergence and unified transmission can be realized, providing hardware support of on-site systems for building the sensor IoT to realize the interconnection of intelligence devices.

For monitoring data of transmission line, geographic information, risk warning, status monitoring and other services, this system can also be used to have a further development to achieve functions of data mining and analysis, providing professional graphics visualization, analysis of data trend, analysis of equipment status, image recognition and other application services. By in-depth analysis of the monitoring information of the key parts of the transmission tower, combined with the environmental conditions, the mechanical characteristics and diachronic change laws in deformation, stress and vibration of the transmission tower can be studied during the monitoring period. At the same time, the future trends of transmission tower can be predicted and evaluated. The structure health status of transmission line can be perceived comprehensively, thereby the accuracy and intelligence level of health status perception of transmission towers can be effectively improved.

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