Application of 5G communication technology on intelligent inspection in 750kV substation

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Abstract. Ultra-high voltage AC substation has the characteristics of high voltage level, large area, complex equipment structure, heavy inspection task and high operation risk. The existing video surveillance system is mainly used for substation security, but the distribution of points is insufficient and the clarity is low, so it can’t achieve full coverage of inspection points. UHV AC substation needs to develop remote intelligent inspection system to assist operation and maintenance staffs to carry out daily inspection work, reduce the workload of operation and maintenance staffs, improve the speed of emergency response and ensure the safety of operation. In this paper, remote intelligent inspection system of substation based on 5G communication transmission technology is proposed in 750kV substation, so as to achieve the purpose of intelligent inspection of substation, and expand the idea for the application of 5G technology in substation.

1. Introduction

With the rapid development of power grid and the applications of high-voltage and large capacity substation, the contradiction between the shortage of production staffs and the increase of inspection workload is becoming increasingly prominent. Integration of operation and maintenance puts forward higher requirements for substation operation and maintenance while expanding business scope. In such a situation, the traditional patrol operation mode of "manual inspection and manual record" is difficult to adapt to the development requirements of power system. Therefore, the adoption of new technology and new means to realize the change of operation and maintenance mode, reduce the burden of operation and maintenance personnel, and effectively ensure the safe and reliable operation of equipment, is one of the main problems facing the power system in the future [1].

Compared with general substation, EHV AC substation has the characteristics of high voltage level, large area, complex equipment structure, heavy inspection task and high operation risk. The existing inspection system is mainly used for manual work, which is inefficient and can’t achieve full coverage of inspection points. EHV AC substation needs to carry out the construction of remote intelligent inspection system to assist operation and maintenance staffs to carry out daily inspection work, reduce the workload of operation and maintenance staffs, improve the speed of emergency response and ensure the safety of operation.

With the emergence of 5G technology, the advantages of 5G networks such as ultra-low latency, high bandwidth, high reliability, and wireless communication are the rigid needs of the current power...
system development [2-15]. At present, the application of 5G communication technology in the distribution network has been extensively studied, while the research on the transmission network, especially in the 750kV substation, is seldom. The Literature [2] proposes a distribution network differential protection that uses a 5G slice network based on mobile edge computing as a data channel, and has ultra-low latency and ultra-high reliability. The Document [3] puts forward the requirements of differential protection for communication channels. Through analysis, it is concluded that 5G has good adaptability to differential protection of distribution networks, and can replace optical fibers as the new data channels for differential protection of distribution networks. The Literature [4] proposed a dynamic adaptive distributed feeder automation method based on 5G communication in the distribution network to improve the reliability of the power supply of the distribution network. The high performance and commercialization of 5G provide ideals and opportunities for the intelligent inspection of 750kV substations.

It is very important for the inspection of power equipment in substations. Many inspection technologies have been introduced, such as high-definition video surveillance [5], radio frequency identification technology [6], drone inspection and inspection robots [7-9], but no matter what kind of intelligent inspection technology, the requirements for network technology are extremely high. With the blessing of 5G communication transmission technology, intelligent inspection robots, drones, etc. can carry out efficient equipment inspection work, and perform information extraction, analysis and integration of patrolled pictures, so as to be able to discover hidden in substation equipment in time. In turn, provide protection for the operation status of the power grid [11]. In 750kV substation, 5G technology may also be applied to cameras and unmanned aerial vehicles, equipment and the like so that the station for real-time monitoring and intelligent monitoring data can be quickly positioned for the failure. The aerial view of 750kV substation is shown in Figure 1. In addition, the use of 5G network slicing can meet the needs of power grid automation and achieve millisecond-level communication delays [12-15].

![Aerial view of 750kV substation.](image)

Figure 1. Aerial view of 750kV substation.

In this paper, the intelligent inspection technology based on video visual image recognition and perceptual data is proposed. Through cameras, sensors, background equipment and other devices, based on 5G communication technology, the research results can provide effective technical support for the intelligent inspection of 750kV substation.
2. Advantages of 5G communication transmission technology

The basic characteristics of 5G technology are as follows [10]:

1) The download speed is 10 times of the current 4G Internet speed, which will reach 10Gb/s.
2) Delays have also taken a qualitative leap. The theoretical delay is 1ms, which is one tenth of 4G delay, with strong real-time performance.
3) Support more devices to surf the Internet at the same time. The theoretical value of the number of Internet of things terminals that can be connected will reach one million, more than ten times that of 4G. In the case of multiple connections, there is no need to worry about the problem that data cannot be uploaded.
4) It can directly meet the transmission of a large amount of data, such as high-definition video or virtual reality.
5) The coverage is wide, which can give users a good internet speed experience.
6) It has the function of collaborative networking, which improves the intelligent level of the system.

3. Substation intelligent inspection system based on 5G communication transmission technology

3.1. Automatic mapping process of virtual circuit

The substation intelligent inspection system needs to carry out five types of automatic inspection, including routine inspection, light out inspection, limited inspection, special inspection and user-defined inspection, as shown in the Table 1.

| Classification of intelligent patrol system | Function |
|-------------------------------------------|----------|
| Routine inspection                         | Through routine inspection of the appearance and operation sound of the equipment, it is found that the shell of the equipment is damaged, the meter is damaged, the insulator is damaged, the oil leakage is leaking, the door is closed abnormally and so on. |
| Light out inspection                       | Timely find out whether there is flashover and discharge of each casing, and whether there is discharge and redness of leads and joints by means of lights-out inspection combined with visible light photos and infrared atlas. |
| Limited inspection                         | Limited inspection can deal with 10 types of severe weather, including strong wind, thunderstorm, fog and haze (including drizzle, fog, etc.), after rain, snow, sudden temperature change (including low temperature weather), high temperature, hail, ice, sand storm, etc., and timely find out whether there is debris falling on the equipment, whether there is equipment fracture, whether the temperature and heat dissipation is abnormal. |
| Special inspection                         | Through the special inspection can be timely equipment infrared temperature measurement, oil temperature table transcription, position status identification transcription and other work. |
| User-defined inspection                    | Combined with the operation and maintenance work arrangement, flexible development of inspection content and inspection program through custom inspection |

3.2. Function configuration of substation intelligent patrol system

The whole substation intelligent inspection system is composed of substation front-end system equipment, network transmission and monitoring center system equipment.

3.2.1. Front end system equipment of 750kV substation intelligent inspection system. The front-end system mainly refers to the image acquisition and processing of substation. The equipment mainly includes camera system (camera and its auxiliary equipment such as shield, pan tilt, decoder, etc.), infrared / smoke alarm, video coding server, inspection robot, UAV, etc.

In order to achieve valuable application effect, the 750kV substation remote intelligent inspection system selected in this paper adopts the following advanced technical means:
a) High definition network video monitoring technology

Network digitization and high definition are the basis of intelligent video monitoring. As the outdoor monitoring range of this site is large and the definition requirements are high, the outdoor cameras, especially the key surveillance cameras related to the intelligent patrol function, will be used no less than 1080P high-definition network cameras. Compared with outdoor, indoor monitoring range is relatively limited, so indoor camera adopts quasi high definition network camera with definition no less than 720p.

b) Panoramic video monitoring technology

The general panoramic monitoring of substation is the image monitoring in all directions of the real field area through 360 degree rotation of ball machine, while the new panoramic video monitoring technology is proposed for 750kV substation: that is, the video monitoring method of displaying the whole monitoring scene in real time through a video image with a large viewing angle (the horizontal viewing angle is usually about 180 degrees or 360 degrees).

The field of vision of a single camera is extremely limited. Even if a large number of cameras are set to cover the whole site, the monitoring staffs will not be able to see the whole scene of the site because of the incoherence between the monitoring images, a large number of overlaps, lack of integrity and other problems. Panoramic video surveillance image can take a panoramic view of the scene in a large range of monitoring area, and the monitored objects can be placed in the monitoring field of vision at any time, so that the monitoring staffs can overview the overall situation and grasp the overall situation of emergencies in time.

c) Video image quality analysis and management technology

Video surveillance cameras have the characteristics of large number and wide distribution. The image quality analysis and management function can automatically detect, diagnose and analyze various abnormal phenomena of video images, which can effectively improve the availability of the system and reduce the maintenance workload.

d) Intelligent audio and video monitoring technology

The general way of video monitoring belongs to passive monitoring, that is to set up special monitoring personnel to monitor the image through the display screen and record the video. Because there are many monitoring points, and most of the time the video monitoring image is not valuable, it is very easy for the monitoring staffs to cause visual fatigue and miss useful information. Therefore, in most cases, video surveillance only plays the role of recording video images and forensics. Intelligent video surveillance technology originated in computer vision, 5g transmission technology and artificial intelligence research, using computer vision technology, video image processing technology and artificial intelligence technology to monitor the content of the video description, understanding and analysis, automatic monitoring of interest to the target or events, such as text, images or video way to output the results of the analysis, so as to make the video monitoring system has a higher level of intelligent level.

The remote intelligent inspection system of 750kV substation plans to adopt intelligent video monitoring technology such as image recognition to realize intelligent video monitoring and inspection functions such as image monitoring of equipment defects, intelligent alarm of wearing safety helmet recognition, and cross boundary monitoring of construction operation area in switch station. Based on the harmonic characteristics and vectorization of sound recognition algorithm, remote intelligent inspection system process and analysis the sound signal. By extracting harmonic features and establishing a large database, the voiceprint of main transformer is identified.

e) Infrared temperature measurement technology

Scientific research shows that all objects whose temperature is higher than absolute zero are constantly emitting infrared radiation energy to the surrounding space. The distribution of infrared radiation energy according to wavelength is closely related to its surface temperature. Therefore, its surface temperature can be accurately measured by measuring the infrared energy emitted by the object itself.
Infrared imaging temperature measurement technology is a high-tech detection technology, which integrates photoelectric imaging technology, computer technology and image processing technology. By receiving the infrared radiation from the object, the thermal image is displayed on the fluorescent screen, so as to accurately detect the surface temperature distribution, and then accurately, timely and quickly judge the heating condition of the equipment.

The remote intelligent inspection system of 750kV substation adopts infrared temperature measurement technology to convert the surface temperature and thermal field distribution of the tested equipment into video signal and display it in the form of thermal image, so as to provide intuitive basis for operators to master the evolution degree of equipment operation state, so as to improve the ability of operators to find and judge equipment defects, which is conducive to ensure the long-term safe and stable operation of the tested equipment in this station.

F) Intelligent inspection robot

With the continuous expansion of the development scale of smart grid, the problem of "ensuring the security of power grid" is highlighted. The traditional human inspection can't meet the development needs of the industry. In this case, the intelligent inspection robot inspection has become the most ideal inspection method. As an efficient, stable and important inspection method in power system, intelligent robot inspection has been paid more and more attention by power inspection department [14-15]:

(1) Stop for no reason. The navigation mode adopted by the intelligent inspection robot is magnetic navigation. Therefore, the magnetic track should be laid along the walking route of the machine. When the track is set close to the roadside, the holly and other flowers and trees on the roadside grow luxuriantly and block the probe of the robot, the "fault stop" will be reported.

(2) There is no video image, and the background host image of the robot is not displayed due to the crash and network interruption.

(3) Due to the influence of daytime sunlight and nighttime light, the infrared temperature measurement spectrum gives false alarm of high temperature.

(4) The visible light inspection lacks many pictures. The images are not clear, and the data is not accurate.

Optical fiber is the most reliable way of communication, but mobile robots can't use optical fiber communication. At present, inspection robots generally use wireless local area network (WiFi) to complete common inspection tasks, but WiFi can't meet the requirements of complex inspection tasks. From the current statistics, 5G communication transmission technology of low delay, high bandwidth, high reliability and other network capabilities will greatly improve the current situation. For most of the substation tests show that the high-speed transmission characteristics will also reduce the processing speed to millisecond level, while minimizing the risk.

g) Combination of 5G and UAV

Unmanned aerial vehicle (UAV) is controlled by setting cruise program or using radio remote control device. With the intelligent and high-speed development of UAV technology, its application in power grid construction, emergency response, planning and design, supervision and other aspects is gradually increasing, which can not only effectively reduce the cost budget of power enterprises, improve work efficiency, but also greatly reduce the failure rate. The application of UAV in the power industry plays a vital role, but now the information transmission is based on 4G technology whose delay and limitations are the disadvantages of UAV. There are many line patrol accidents caused by signal transmission instability and delay. The low delay and high transmission speed of 5G technology will make UAV technology more mature and stable, which greatly reduces the risk.

3.2.2. Network transmission of 750kV substation intelligent inspection system. The TCP/IP network transmission mode is adopted between the substation monitoring system and the monitoring center system. The built optical transmission network is used to form a TCP / IP monitoring special network with two-level monitoring form from the station to the monitoring center.
3.2.3. Monitoring center system of 750kV substation intelligent inspection system. As the maintenance and management center of the system, the monitoring center is the core of the whole system, which is mainly responsible for the processing of video and audio information, including remote monitoring, video recording, playback, etc.; system control, including the front-end pan tilt, lens control, etc.; system management, including system settings/configuration, user management, etc.

The equipment of monitoring center system mainly includes server, monitoring workstation, control software, storage equipment and media, image display TV wall, etc. The system structure is shown in Figure 2.

![System composition diagram of monitoring center](image)

Figure 2. System composition diagram of monitoring center.

4. 750 kV substation intelligent patrol system architecture

The remote intelligent inspection system of 750kV substation is configured in Safety Zone IV, which is composed of station level equipment and front-end equipment. Horizontally, the system is interconnected with the I/II area system through a set of physical isolation equipment, and vertically, the information is transmitted to the substation integrated information processing system of the maintenance company through a set of firewalls through the integrated data network. The system adopts a layered, distributed and open network architecture, and the overall architecture is shown in Figure 3.

The station level equipment is mainly composed of a set of video coding / processing equipment (with video signal acquisition, compression coding / forwarding processing, network transmission and other functions, which can be in the form of hard disk video recorder NVR, disk array integrated machine, etc.), a set of power inspection server, a set of image management and streaming media server (which can be merged with video coding / processing equipment or power inspection server, and this report scheme is temporarily considered to be merged), a set of intelligent analysis server, a set of image quality monitoring and management server (which can be merged with intelligence analysis server), a set of storage device (which can be merged with video coding / processing equipment), a set of man-machine workstation and other equipment which are connected to a set of convergence switch. Due to the large number of cameras and scattered installation locations, it is considered to install access switches in the equipment room or local distribution box to connect the cameras to the system network through the access switches.
The 5G core network has micro-service-level orchestration capabilities. Operators can perform network slicing parameter settings, resource division, and function deployment on the background interface according to the needs of power users. In order to ensure that 5G network slicing services meet security requirements, technical personnel will set up interface security management, including user and device access authentication, power slicing security isolation, and message transmission encryption. At the same time, a large number of sensing devices are used in the 750 substation, and by adopting 5G communication transmission technology, traditional cable wiring is saved, which effectively guarantees the stability, timeliness and reliability of data transmission, and improves the economy of substation inspection, and reduce the workload, provide reference value for the realization of intelligent inspection of 750kV substation.

5. Conclusions
Aiming at the problems of high voltage level, large area, complex equipment structure, heavy inspection task and high operation risk of UHVAC substation, this paper proposes an application scheme of remote intelligent inspection system based on 5G communication transmission technology in 750kV substation, which can help to improve the automation and informatization of UHVAC substation operation, reduce the workload of operators and improve the quality of work, so as to achieve the purpose of intelligent inspection of substation, and expand the idea for the application of 5G communication transmission technology in EHV AC Substation in the future.

In view of the current high voltage level of ultra-high voltage AC substations, large footprint, complex equipment structure, heavy inspection tasks, and high risk of personnel operations, this paper proposes a remote intelligent inspection system for substations based on 5G communication transmission technology in 750kV substations. Application scheme, the scheme adopts the remote
intelligent inspection system of substation including advanced camera system, infrared/smoke alarm, video encoding server, inspection robot and drone, and uses the ultra-low time of 5G network on this basis. The advantages of long delay, high bandwidth, high reliability, wireless communication, etc., effectively ensure the stability, timeliness and reliability of data transmission, improve the economy of 750kV substation intelligent inspection, convenient operation and maintenance, and reduce the workload of operators, improve work quality and work efficiency, so as to achieve the purpose of intelligent inspection of substations. This solution has a higher application prospect and broadens the thinking for the future application of 5G communication transmission technology in ultra-high voltage AC substations.

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