Application and Prospect of Human-Machine Interaction in Power System

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Abstract. Poser system provide many scenarios the innovation of human-machine interaction technology. Four advanced human-machine interaction technologies in power system are introduced and the necessity of human-machine interaction in power system are summarized from four aspects. Development Course of Human-Machine Interaction in Power System are divided into five generations based on technical characteristics. Four technological trends which should be focused on are given.

1. Introduction
With the development and application of digital technology such as computer technology, mobile communication, Internet and artificial intelligence technology, human-machine interaction technology has made rapid development in the 21st century [1]. Electric power industry as the generator of industrial revolution has become the most complex industrial system in the world with more than a century of development [2,3]. The application of human-machine interaction technology in power system has a long history and it is in a new period of great development [4].

Human-machine interaction as a technology to realize the friendly interaction between users and various systems is used to complete the exchange information tasks between, human and various systems, such as computer, mechanical systems [5]. Electric power system is an electric power production, transmission and consumption system consisting of four links: power plant, power transmission and transformation equipment, power supply and distribution equipment and utilization equipment [6,7]. To realize economic and safe production of electric energy, the four links of electric power system need a lot of human-machine interaction to realize the production and transmission of electric energy and the control, maintenance and overhaul of the power system equipment.

Firstly, this paper analyses the technical concept of human-machine interaction and introduce typical application scenarios of advanced human-machine interaction in power system. Secondly, the necessity and importance of human-machine interaction in power system are analyzed and the development course of human-machine interaction in power system are given based on application characteristics of technology. The innovative development of human-machine interaction technology in power system will bring new management and technology drive to the innovative development of power system.

2. Application of Human-Machine Interaction in Power System

2.1. The Concept of Human-Machine Interaction
Human-machine interaction is the procedure that users observe the state of the system and control the system through the human-machine interactive interface [8]. Users use the panel, knob and switch to observe the state of the system and control the system in the initial stage of the human-machine interaction [9]. With the development of computer technology and the sensor technology, the human-machine interaction technology based on computer technology gives users a new experience [10].

In order to realize a better understanding and operation of the system for users, users and researchers pay more attention to man-machine interactive interface representation model and design method[11], availability analysis and evaluation of human-machine interaction system[12], multichannel interaction technology supporting voice, gesture, eyes, expression, mobile terminal interaction mode[13] and cognitive and intelligent user interface [14].

2.2. Application Cases of Advanced Human-Machine Interaction System

2.2.1. Multi-terminal system. On the server side, man-machine service receives browsing requests from human-machine terminal and calls file service, data refresh service, real-time library service, history library service and application operation service from backend to process these requests, then pushes the final display content of the screen, such as data, graphics and so on, to client sides.

On the client side, human-machine client obtains the information needed for screen display through human-machine service, and the client side no longer directly interacts with various specific services in the backend. A large amount of displayed content has been processed on the server side. The content received by the client side is the final display state. The human-machine terminal and the backend service are loosely coupled. The human-machine terminals in different places can browse the displayed content like the local man-machine terminal under the restriction of authority and the support of communication [15]. Multi-terminal electric power maintenance system [16], multi-terminal asset management system [17], multi-terminal power grid dispatching system [18], and multi-terminal business reporting of power system service system are typical representatives.

2.2.2. Training System based on Mixed Reality. Using hybrid reality, artificial intelligence and other emerging technologies to build the power grid simulation training system which can realize many training functions, such as power grid simulation teaching training [19], equipment virtual maintenance test [20], construction safety training [21] and emergency rescue training [22]. The training system can solve the objective problems encountered in the power system training, such as relative shortage of personnel, high-risk construction operation, expensive physical testing equipment, and difficulty in reproducing emergency scenes [23, 24]. It can be applied to power generation, transportation and inspection, power engineering construction, emergency disposal training and other departments.
The training system can show the structure, principle and basic theory of equipment, and integrated power grid construction process, power simulation process, equipment internal structure and disassembly and installation process [25]. The shortage of high-tech personnel and insufficient training resources can be solved.

2.2.3. **Intelligent Patrol Robot.** Intelligent Patrol Robot is applied in outdoor substation patrol personnel. The robot system can carry infrared thermal imager, visible light and other related power plant equipment detection devices independently and remotely, instead of outdoor high-voltage equipment patrol personnel, timely detection of thermal defects of power equipment [26]. It can acquire real-time position and attitude information with high precision fiber optic gyroscope in order to achieve high precision positioning requirements. At the same time, it can realize autonomous obstacle avoidance by combining ultrasonic sensor and mechanical collision avoidance [27,28].

2.2.4. **AI Power Supply Service Robot.** AI Power Supply Service Robot integrates the basic abilities of speech recognition, dialogue management, real-time communication, image recognition, process automation and professional knowledge aggregation. Through AI training team and large data training including business model, business hall photos, customer repair audio, knowledge base data, distribution transformer name and address information, the AI Robot can understand customer demands, understand grid indicators, control power system business processes, issue command orders, transfer service information, remind abnormal behaviour [29,30].

She not only can distribute emergency repair work orders optimally, but also can present the whole process of emergency repair and command in real time, plan the best route for emergency repair personnel to obtain spare materials, improve the efficiency of emergency repair and reduce the power outage time of users.
3. Development and Necessity Course of Human-Machine Interaction

3.1. Necessity of Human-Machine Interaction in Power System

3.1.1. Normative design for power system. The Equipment types in power system are complex, such as primary equipment for power production transmission transformation and control equipment for power system control and protection [31]. The design work of each link in power system is heavy, the technical accuracy is high, and the design is universal. Computer system is needed to provide basic design model, standardized design, three-dimensional display and other support to reduce design repeatability and improve design accuracy.

3.1.2. Obtain system state. The operating conditions of power system equipment are complex. Thermal power generation equipment consists of fuel system, combustion system, steam-water system, electrical system and control system. Operators need to know the operation status of each system under different conditions, such as start-up, normal operation and shutdown [32].

   Transmission and distribution system include power conversion and distribution equipment, such as transformers, buses, switches. Operators need to know states of the system, such as the load of transformers, conditions of bus, to and grasp clearly the power conversion and distribution situation. Human-machine interaction system is needed in every link of power system to help operators realize operation states of power system.

3.1.3. Control power system. Electric energy can’t be stored on a large scale and need to be produced on demand and consumed in time [33]. In order to realize the safe production and transmission of electric power, operators need to make dispatching plan and maintenance plan of power generation equipment based on the states of power system, such as the demand of electricity consumption, operation conditions of power transmission and transformation equipment.

3.1.4 Measurement of electric energy. As a secondary energy which is easy to transfer, transform and use, electric energy doesn’t have actual physical state [34]. Production measurement and consumption measurement of electric energy need to be realized by the electric energy metering device consisting of an electric energy meter, a measuring transformer and a secondary connection device. Production operators and power users can view the measurement results through human-machine interaction interfaces such as interactive instruments and remote display devices.

3.1.5 Efficient maintenance. Operations and maintenance managers conduct management and maintenance work, such as implement physical assets management of power system, implement video on-line monitoring of important power equipment, formulate maintenance and repair plans, investigate and verify equipment fault information, and distribute maintenance work orders [35]. All these work need the support of operation and maintenance management system and know well the fault state of electric power equipment.

3.2. Development Course of Human-Machine Interaction in Power System

The first generation of power system human-machine interaction system, represented by mechanical switches such as knobs, knives and gates, and using analog signals as the main means of interaction, has high complexity of interactive information, low efficiency, and can only achieve relatively simple tasks, but also has the strongest reliability. In this stage, the human-machine interaction system mainly includes all kinds of switches in the power system, generally without operating system [36].

The second generation of human-machine interaction of power system, represented by fixed terminals and using complex graphics as the main means of interaction, has low complexity of interactive information, improved efficiency and reduced learning costs. In this stage, production and management system based on computer and sensor technology, such as power grid dispatching system,
power system material management system are the principal representatives of human-machines interaction system [37]. Windows and Linux are representative operating systems [38].

Figure 5. Development Course of Human-Machine Interaction in Power System

The third generation of human-machine interaction in power system, represented by the combination of mobile terminal fixed terminal, is simpler in interactive graphics, less complex in interactive information, easier to use. In this stage, the human-machine interaction system in power system is mainly to upgrade mobile terminal based on the second generation of human-machine interaction system to achieve multi-terminal interaction, such as multi-terminal power grid dispatching system, in which the mobile terminal operation system is represented by IOS and Android system [39].

The fourth generation of power system human-machine interaction, voice is the main means of interaction. The radius of human-machine interaction becomes farther, the hands of operators are released, and the human-machine interaction becomes simpler. At the same time, the coupling between human-machine interaction and content services is stronger. The interaction has the attributes of knowledge learning and transmission, but the reliability is relatively low. The fourth generation is still in its infancy and the representative human-machine interaction system in this stage includes intelligent operation and maintenance assistant system [40].

The fifth generation of human-machine interaction in power system refers to the application of human-machine interaction technology driven by multi-sensor fusion technology and intelligent technology in power system, represented by intelligent robots. The fifth generation technology uses multi-sensor fusion technology as the main interactive means to improve the system's ability to understand interactive information and enhance the intelligence and initiative of human-machine interaction. Robots can initiate active interaction with power system staff. At present, the fifth generation in power system is still in its infancy and the application scenarios include AI patrol operation and maintenance robot [41], AI customer service robot [42].

4. Technology Trend Prospect

4.1. Zero Trust Security

In the process of human-machine interaction in power system, it involves a large number of sensitive information, such as power production information, power equipment fault information, power network weak link information and electricity information of power users.

How to improve the efficiency and security of human-machine interaction in power system is an important problem. At present, security isolation devices are mostly used in information security of human-machine interaction system in power system [43]. Zero-trust security technology [44] provides a new flexible operation technology.

In the human-machine interaction system of power system, identity governance platform can be constructed to realize the overall identity of equipment, users, applications and other entities. Two key technologies, equipment authentication and user authentication, can be adopted to realize the credible access of users and equipment. Business security access system can be setted up. Then equipment and users, which can through the security access authentication and have authorization, can access business.
Dynamic access control system, multi-attribute trust and risk measurement can be set up to realize dynamic adaptive access control.

![Business security access system](image1)

**Figure 6. Zero Trust Security in human-machine interaction system of power system**

4.2. **Hybrid Communication Network**

In the process of human-machine interaction in power system, it is necessary to realize a large number of information interchange between machine and operators, and has critical real-time requirement [44]. At present, the optical fiber backbone network has been established in the transmission and distribution system [45], communication costs are high.

The development of 5G and IoT technology provides a more comprehensive and techno-economic communication technology for lots of human-machine interaction scenarios, such as power equipment maintenance and user-side power service. Wireless, 4G, 5G and optical fiber hybrid communication networks can be constructed based on business requirements to improve the technical economy of human-machine interaction communication.

![Wireless, 4G, 5G and optical fiber](image2)

**Figure 7. Zero Trust Security in human-machine interaction system of power system**

4.3. **Sensory Fusion**

Human-machine interaction in power systems uses a large number of electrical, thermal and optical sensors as a technical means of sensing system information [46]. With the diversified development of power system business, the rapid perception and analysis of various physical information has put forward higher requirements.

Multi-sensor information fusion technology provides a fast perception fusion method for human-machine interaction in power system. Information of various sensors can be fusion processed by multi-level and multi-space and can be optimal combined to realize the overall perception of state of power system and needs of operator.

4.4. **Intelligence and initiative**

The scale of power system is growing, business types are expanding, and the information that operators need to deal with is increasing [47]. The requirement of information validity and comprehensiveness in human-machine interaction is constantly increasing.

The level of intelligence and initiative of human-machine interaction system in power system should be improved, so that human-machine interaction system can provide operators with more suitable information for direct use; make human-machine interaction system more active to perceive information other than machine system state, make comprehensive judgment, and improve the operational efficiency of power operators.
5. Conclusion
As one of the most complex industrial systems, power system needs lots of human-machine interaction technology to complete the operation of the system. At the same time, many scenarios are provided for the innovation of human-machine interaction technology. Four advanced human-machine interaction technologies in power system, multi-terminal system, training System based on mixed reality, intelligent patrol robot and AI power supply service robot, are introduced. Summarize the necessity of human-machine interaction in power system from four aspects, normative design for power system, Obtain system state, Control power system, Measurement of electric energy and Efficient maintenance. Development Course of Human-Machine Interaction in Power System are divided into five generations based on technical characteristics. Four technological trends, zero trust security, hybrid communication network, sensory fusion, intelligence and initiative, should be focused on in the development of human-machine interaction in power system.

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