Implementing XR Technology in the Tutoring on Substation O&M

ICT Research Lab: Liu, Yu-Heng; Hsu, Pei-Jen; Hung, Jui-Cheng

1. Purpose

With the inclusion of Extended Reality (XR) technologies in the 3GPP Release 17 communication standards and the impact of the COVID-19 pandemic, the adoption of ICT technologies to support prevention and diagnostics has gained significant attention. Furthermore, facing numerous challenges in transferring technical knowledge among personnel, the digitalization of substation operations and maintenance has become an urgent priority for our company.

Traditionally, technical knowledge has been conveyed primarily through printed documents or diagrams, which often leads to difficulties in communication and comprehension. In response, this study collects and analyzes training methods for 23kV GIS switchgear and main transformers at secondary substations. It introduces Standard Operating Procedure (SOP) training through Augmented Reality (AR), Virtual Reality (VR), and Mixed Reality (MR) technologies. By leveraging 3D visual aids and interactive interfaces, the training experience becomes more intuitive and accessible, significantly enhancing user comprehension. Moreover, the XR platform enables the recording and tracking of user interactions, thereby improving the overall effectiveness of the training.

In addition, with the evolution of wireless technologies for XR devices, this research integrates platform construction, cross-device application, and remote collaboration technologies to develop the "XR Remote Collaboration Smart Substation Platform System." This platform consolidates all digital functions required for remote collaboration into a single system, eliminating the need to switch between multiple applications and thereby enhancing operational convenience and efficiency.

2. Research Results

This study applies AR, VR, and MR technologies to assist maintenance personnel in becoming familiar with the operation of 23kV GIS switchgear at secondary substations. By using AR, a total of 38 complex components of the GIS switchgear are presented through 3D animations, supplemented by voice and text explanations to serve as a three-dimensional manual. VR is employed to simulate operations such as switchgear handling, equipment inspection, fault indicator troubleshooting, and related training and assessments, helping to pass on internal inspection techniques. Additionally, an MR-based IED relay operation support system has been developed, which utilizes voice recognition and image projection to guide users through IED operation procedures, as shown in Figure 1.

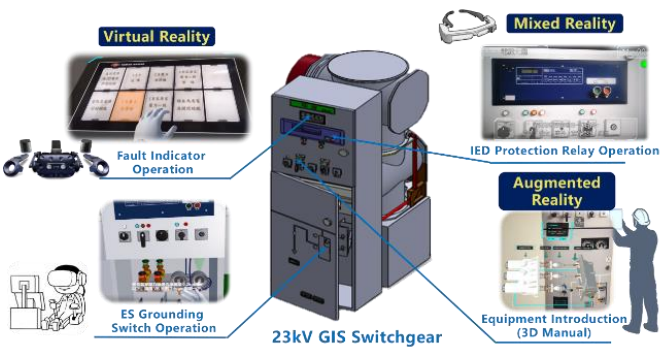

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Figure 1. Development of Educational Training for 23kV GIS Switchgear in Power Distribution

In addition, this study expands the VR system by integrating the existing four training modules and establishing a new one, “23kV GIS Switchgear Internal Inspection Training.” The detailed internal inspection procedures were recorded, with all corresponding tools and parts of various sizes cataloged. The disassembly and assembly process of the most critical component within the switchgear, the GCB (Gas Circuit Breaker), was divided into 12 distinct steps, each accompanied by detailed procedural guidance. The resulting VR training modules have been implemented at the Kaohsiung Training Center of the Taiwan Power Company, as shown in Figure 2.

This study also utilizes the MR device HoloLens 2 to develop a Mixed Reality (MR) guidance system for troubleshooting main transformers at secondary substations. By using MR spatial awareness and scanning technology, HoloLens 2 detects the user's current location and integrates virtual information with physical objects in the environment. Seventeen common troubleshooting procedures for main transformers have been standardized and converted into MR experiences. This system assists new substation personnel in following step-by-step instructions through the MR headset, enabling hands-free operation via voice commands and head movements. This system enables intelligent and efficient substation operation and maintenance processes, as illustrated in Figure 3.

Furthermore, the connectivity of XR terminal devices has evolved from earlier wired setups, such as the Epson BT-2 and HTC Vive, which relied on specialized positioning systems, to wireless communication via Wi-Fi, using devices like the Meta Quest and Microsoft HoloLens. These modern devices incorporate built-in spatial positioning systems, reducing the risks associated with tripping over cables during training sessions. They also support cross-device integration, allowing experts to provide instructional guidance through smartphones, tablets, or laptops, while users can perform rapid troubleshooting using MR glasses or mobile phones. This setup enables multi-user remote collaboration, as illustrated in Figure 4.

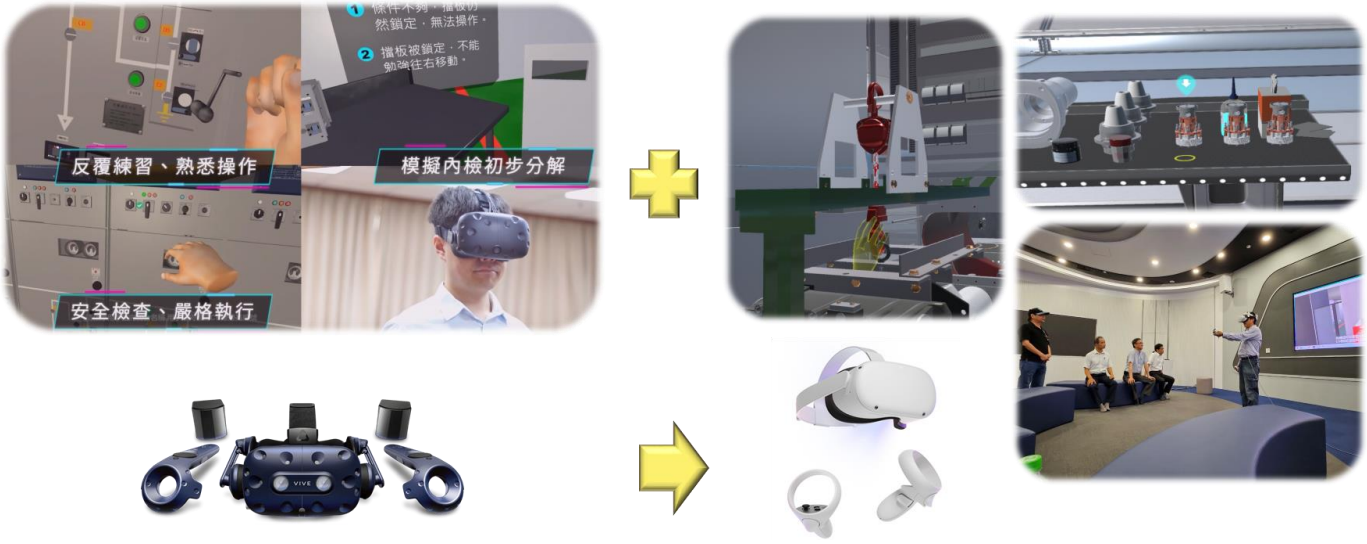

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Figure 2. 23kV GIS Switchgear VR Training

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Figure 3. MR Main Transformer Fault Diagnosis System

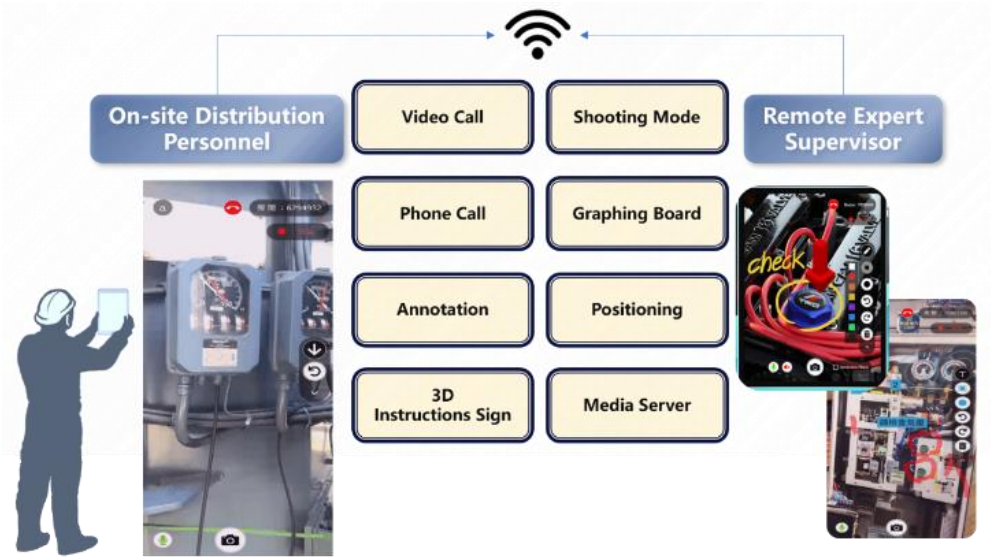

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Figure 4. Remote Collaboration and Communication System for Substations

Through the development of the aforementioned system, the sustainable and easily updatable digital transformation of traditional knowledge content can be achieved. This not only enables on-site personnel to complete tasks remotely in real time, ensuring work safety and enhancing operational efficiency, but also reduces travel costs, contributing to net-zero carbon emissions and supporting environmentally sustainable practices, thereby putting high-efficiency ESG principles into action.