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Immersive Technologies in the Power Industry

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ABSTRACT

Immersive technology blurs the line between the digital and physical worlds. It allows for a user to access the complete 360-degree space around them. Immersive technologies have the ability to be a growth driver in the digital transformation journey for the power and utilities sector. The power industry is beginning to see the benefits of their implementation because they bring new value to the industry. Due to the emergence of immersive technologies, the industry is facing a massive wave of powerful disruptions. The industry needs to rethink their traditional business methods. This paper explores the potential of immersive technologies, including virtual reality (VR), augmented reality (AR), and mixed reality (MR), within the electric power industry.

KEYWORDS: *virtual reality, VR, augmented reality, AR, mixed reality, MR, extended reality, XR, immersive technologies, power industry, electric utility*

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INTRODUCTION

The world is continuously changing and moving forward. Businesses that do not keep on track will be left behind and will not be in demand in the future. Today, as never before, it is very important to digitally optimize company business. With the emergence of new technologies and the need to make processes more sustainable, cities and utilities tend to become increasingly "smarter." It is no different for electric power systems. Therefore, the digitalization of the electrical utilities contributes to a better supply of energy with more reliability, as well as the reduction of operational and maintenance cost. For example, virtual and augmented realities is used to sharpening cognitive and on-field operational aspects. These technologies have applicability that involves learning process, training improvement, faster problem solution, facilitation of operations, etc. [1].

The digital and physical worlds are merging, and immersive technology is at the heart of this revolution. Initially perceived as tools for entertainment and engagement, the enterprise applications of immersive technologies have expanded significantly, particularly in the utilities sector. They have moved from science fiction into reality, becoming powerful tools that bridge the digital and physical worlds. These technologies now enhance maintenance operations, worker safety, employee training, and remote assistance. With advances in virtual reality and augmented reality, a new product can be viewed in the early stages of the design process. Companies can focus on correcting errors at this stage before moving on to production.

WHAT ARE IMMERSIVE TECHNOLOGIES?

The first step in understanding how to use immersive technologies is to learn the differences between its various forms. In their simplest form, immersive technologies consist in adding virtual objects to the real world. There are four types of digital realities leading to different types of immersive technologies [2,3]:

- *Augmented reality* (AR)- designed to add digital elements over real-world views with limited interaction.

- *Virtual reality* (VR)- immersive experiences helping to isolate users from the real world, usually via a headset device and headphones designed for such activities.
- *Mixed reality* (MR)- combining AR and VR elements so that digital objects can interact with the real world means businesses can design elements anchored within a real environment.
- *Extended reality* (XR)- covering all types of technologies that enhance our senses, including the three types previously mentioned.

These devices also enable new user interactions including spatially tracked 3D controllers, voice inputs, gaze tracking, and hand gesture controls.

Extended reality (XR) is the overarching term used to describe employing technology to blend real life and the digital world. It includes all the machine-human interfaces beyond the physical realm (reality) such as augmented reality (AR), mixed reality (MR), assisted reality (aR), and virtual reality (VR), as illustrated in Figure 1 [4]. Figure 2 shows the XR spectrum [5]. Immersive technologies reside along a continuous scale ranging between the completely real and the completely virtual world. At one end, the real environment refers to the actual physical space, objects, and people that exist in the tangible world around us. At the other end, the virtual environment represents a completely computer-generated and immersive digital space, distinct from the physical reality. The space in the middle is called mixed reality, which is a blend of the real and virtual environments, where digital and physical elements coexist and interact in real time. A range of devices makes up XR, and these are used by consumers and in many industries for entertainment, safety, training, or productivity purposes.

1. *VIRTUAL REALITY:* Virtual reality (VR) is XR at its most extreme. It completely immerses the user in a digital world, often using a computer-generated environment with scenes and objects that appear to be real. The term "virtual reality" essentially means "near-reality." Virtual reality is the key technology for experiencing sensations of sight, hearing, and touch of the past, present, and future. VR is a fully immersive technology where users wear a head-mounted display and experience a simulated world of imagery and sounds. VR enables active learning. The terms, "virtual reality" and "cyberspace" are often used interchangeably. A cyberspace may be regarded as a networked virtual reality. A person using virtual reality can look around an artificial world, move around it, and interact with virtual features or items. This effect is commonly created by virtual reality headsets. Head-mounted displays immerse the user in a virtual environment. Virtual reality is a simulated experience that can be similar to or different from the real world. It is a computer-generated, 3D environment that completely immerses the senses of sight, sound, and touch. The complete immersion of the senses overwhelms users engrossing them in the action. Virtual reality technology includes multiple components divided into two main groups: hardware and software components [6].

- *Hardware Components:* The hardware components include a computer workstation, sensory displays, a tracking system, wearable devices, and input devices. Sensory displays are used to display the simulated virtual worlds to the user. The most common type is the head-mounted displays (HMDs), which is used in combination with tracking systems. Head-mounted displays are shown in Figure 3 [7]. Users interact with the simulated environment through some wearable devices. VR depends on special responses such as raising hands, turning the head, or swinging the body. A wearable device is important in making these effects realistic. Special input devices are required to interact with the virtual world. These include the 3D mouse, the wired glove, motion controllers, and optical tracking sensors. These devices are used to stimulate our senses together to create the illusion of reality.
- *Software Components:* Besides the hardware, the underlying software plays an important role. It is responsible for the managing of I/O devices and time-critical applications. The software components are 3D modeling software, 2D graphics software, digital sound editing software, and VR simulation software. VR technology has been designed to ensure visual comfort and ergonomic usage.

2. *AUGMENTED REALITY:* Augmented reality (AR) is a technology that combines real-world environments with computer-generated generated information such as images, text, videos, animations, and sound. It can record and analyze the environment in real-time. In augmented reality, the user typically experiences the real world through a device such as a smartphone, tablet, smart glasses, or head-mounted display. For example, AR allows consumers to visualize a product in more detail before they purchase it. This feature enhances consumer interaction and helps them never to repurchase the wrong item. The key objective of AR is to bring computer-

generated objects into the real world and allows the user only to see them. In other words, we use AR to track the position and orientation of the user's head to enhance/augment their perception of the world. Augmented reality falls into two categories: 2D information overlays and 3D presentations, like those used with games. AR blends the virtual and real worlds by overlaying digital objects and information onto the users' view of the physical world.

To obtain a sufficiently accurate representation of reality, AR needs the following five components [8]:

- *Sensors:* AR needs suitable sensors in the environment and possibly on a user, including fine-grained geolocation and image recognition. These are activating elements that trigger the display of virtual information.
- *Image augmentation:* This requires techniques such as image processing and face recognition.
- *Head-mounted Display*: HMDs are used to view the augmented world where the virtual computer-generated information is properly aligned with the real world. Display technologies are of two types: video display and optical see-through display.
- *User Interface:* This includes technologies for input modalities that include gaze tracking, touch, and gesture. AR is a user interface technology in which a camera-recorded view of the real world is augmented with computer-generated content such as graphics, animations, and 2D or 3D models.
- *Information infrastructure:* AR requires significant computing and communications infrastructure undergirding all these technologies. The infrastructure determines what real-world components to augment, with what, and when.

3. *MIXED REALITY:* Mixed reality (MR) is a term used to describe the merging of a real-world environment and a computer-generated one. Physical and virtual objects may co-exist in mixed reality environments and interact in real time. This is an extension of AR that allows real and virtual elements to interact in an environment. MR liberates us from screen-bound experiences by offering instinctual interactions with data in our living spaces and with our friends. Online explorers, in hundreds of millions around the world, have experienced mixed reality through their handheld devices. Mixed reality is a blend of physical and digital worlds, unlocking natural and intuitive 3D human, computer, and environmental interactions, as shown in Figure 4 [9]. This new reality is based on advancements in computer vision, graphical processing, display technologies, input systems, and cloud computing. Mixed reality has been used in applications across fields including design, education, entertainment, military training, healthcare, product content management, and human-in-the-loop operation of robots [10].
4. *ASSISTED REALITY:* Like mixed reality, assisted reality (aR) is an extension of augmented reality, with a few notable differences to both. One of these differences is that aR is primarily hands-free through the wearing of a headset, whereas AR usually requires the holding of a device such as a mobile phone. While MR is a digital-first, real-world second reality, aR is a real-world first system. It combines software and a head-mounted display. It is best experienced using smart glasses or other wearable technology. The aR market is growing rapidly and promises to be the next great leap to boost workers' productivity. A worker wearing an aR device is shown in Figure 5 [11].
5. *EXTENDED REALITY:* The term "extended reality" (XR) has recently gained favor as an umbrella term that encompasses all of AR, VR, and MR. The primary user inputs for XR devices are described as follows. Voice interfaces are now ubiquitous thanks to mobile devices and standalone smart speakers. Apple's Siri, Amazon's Alexa, Google's Assistant, and Microsoft's Cortana are all voice-driven software interfaces that are continuously gaining new capabilities. Many XR devices enable user control with handheld controllers, which have capabilities beyond button press inputs. Both voice-driven interfaces and human-computer interactions have been developed specifically for XR devices, including gaze and gesture controls [12]. Figure 6 compares conventional computing with extended reality [12].

IMMERSIVE TECHNOLOGIES IN POWER

Power industry is one of the most dynamic and complex sectors in the world. Both residential and commercial customers are looking for better and faster resolution times. Power and utility providers increasingly need to collect accurate data and information from equipment without on-site travel. Incorporating an immersive technology into service operations can make processes considerably more productive for both the provider and the customer. AR/VR for utility sector is shown in Figure 7 [13].

It is well known that the power and the utility sector is usually reluctant to adopt new technologies. There are several reasons why this is the case. First, the players in these segments prefer to use traditional methods in their work. Secondly, the transition to new

technologies requires professional employee training. Thirdly, the introduction of any technological innovations requires significant investments [13].

Across sectors like healthcare, logistics, and manufacturing, AR is bringing unprecedented precision, efficiency, and safety to operations. One of the most exciting applications is its emerging role in power systems, where small errors can lead to costly consequences. From cable installation to maintenance of vast energy grids, the electrification sector depends on flawless execution. A single error can disrupt power supply, lead to costly repairs, or pose serious safety risks. In such a high-stakes environment, AR can provide technicians with the tools they need to ensure precision and efficiency in real-time. AR is set to become an indispensable part of ensuring that our power grids remain efficient, reliable, and future-proof. The power industry is in the midst of a tremendous shift as it embraces the use of virtual reality software (VR) and augmented reality (AR) technology on a global scale. Using this technology has improved processes for engineers, resulting in better decisions, higher efficiency, and reduced costs. Figure 8 shows an example of how VR is used the power company [14].

APPLICATIONS OF IMMERSIVE TECHNOLOGIES IN POWER

As immersive technologies continue to gain traction across industries, their impact on electric power systems is becoming more evident. In a sector where reliability and precision are paramount, AR is providing the tools needed to meet these challenges head-on. The use of virtual (VR) and augmented reality (AR) in the utility sector reduces operating expenses, improves safety, and expands the list of services provided. Figure 9 shows some applications of AR in energy and utilities [15]. Here are common areas where immersive technologies are poised to make an impact [16,17]:

- *Asset Localization:* Electric and water assets including cables and pipes are often located underground or between buildings. This increases the chances of damage and risk during construction or maintenance work. To enable safe working conditions and to avoid the destruction of assets, utilities are leveraging immersive technology. They are working on augmented and virtual reality apps and software platforms to locate assets and manage utility infrastructures. Many emerging companies are working on AR and VR-based hardware and software applications that accurately map the location of assets in 3D. This makes visualization easy, limits the maintenance time, and enhances the safety of workers
- *Asset Management:* The number of assets which are maintained or monitored is on the rise, and power utilities are increasingly witnessing inclusion of renewable energy sources, electric vehicles (EVs) and distribution control equipment. Engineers can see digital overlay above their assets that is followed with instructions and a mapping of asset functionality. Workers in the utility sector are often under-equipped. This increases the chances of accidents such as electric shocks while working. Visualizing broken cables or leaking water pipes, that are often hidden from plain sight, is crucial to increase worker safety. This is why utilities are using augmented and virtual technology to visualize assets and manage asset infrastructure. For example, when an asset fails, the performance data of this asset can be fed into a VR model to help maintenance engineers understand what led to the asset failure, and improve future maintenance procedures.
- *Inventory Management*: Inventory management is another strong use case for mixed reality in the energy sector. AR and VR technologies are successfully applied for managing various material and technical assets. AR technologies can be used to superimpose digital information on the real world. For example, a photo or video can be overlayed on a real object via a smartphone or tablet. This information is beneficial in situations such as power outages or damage to equipment. The technicians can capture images of damaged equipment using augmented reality. AR can help the technician know what parts need to be repaired and request the right personnel for the issue. A typical inventory management is shown in Figure 10 [13].
- *Training and Education:* Virtual reality (VR) technology can help the power industry to deliver workforce training and education in an immersive environment. The technology helps power utilities and companies to improve employee training, which will lead to safer and more efficient maintenance processes. VR-based health and safety (H&S) training has the benefit of teaching the workforce without exposing them to potentially hazardous conditions. While AR use cases extend into operations, VR use cases are almost exclusively focused on training, planning and customer education. Working on renewable energy infrastructures such as solar panels and wind turbines is often challenging due to their

hard-to-reach, remote locations. People working on these sites undergo on-site training that further increases the cost and risk for utilities. This is why utility companies use immersive technologies to simulate the site environment to train workers remotely. Immersive technologies play a key role in educating stakeholders about renewable energy systems. AR/VR-powered simulations visualize solar and wind energy generation, enabling better system designs, interactive learning, and training for critical situations.

- *Work Order Management:* Work order management refers to a set of procedures that are designed to process a work order in a timely and efficient manner. They are an integral part of a field technician's daily routine. By merging immersive technology into the work order management system, the process can be streamlined. Immersive technologies, like augmented reality, can guide employees through their work orders in real-time. This process can guide technicians through a step-by-step checklist and even send the information out to managers
- *Electrical Engineering:* Electrical engineering is one of the oldest branches of engineering education. Electrical engineers work on designing, developing, and maintaining small and giant electrical equipment and systems. They work on the generation, transmission and distribution of electricity. They design and develop electrical power systems. Figure 11 shows a typical electrical engineer [18]. Virtual reality in electrical engineering education can be a powerful tool, offering immersive, innovative, and intense solutions. Virtual reality technology can be a boon to electrical engineering in various ways. VR-based electrical engineering education can be especially useful in teaching complex electrical concepts to students. VR simulations can replicate electrical systems and equipment, offering a cutting-edge approach to immersive engineering. It allows engineers to train and test equipment designs in a safe and controlled environment. It also allows students to understand power generation, transmission, and distribution.

BENEFITS

Immersive technologies play a key role in educating stakeholders about renewable energy systems. Immersive AR/VR-enabled interfaces support data-driven decision-making, enhancing asset management and incident response. Other benefits include [19]:

- *Cost:* Businesses are always looking at finding ways to keep costs down and improve efficiency. Keeping operational costs down is one of the essential considerations currently required in the energy industry. AR and VR are part of the solution. They can help ensure that companies can extract more energy while keeping costs in check. For example, AR is being used for remote consulting. The company saves on travel expenses and can keep these highly-experienced experts on the payroll.
- *Sustainability:* From real-time monitoring of supply networks to immersive planning tools for infrastructure upgrades, immersive technologies enable sustainable water management and operational efficiency. Companies are increasingly conscious about their environmental impact, and implementing virtual reality software to reduce their carbon footprint.
- *Efficiency:* From remote diagnostics to real-time maintenance guides, mixed reality (MR) enhances technician efficiency and reduces costs while boosting customer satisfaction. Augmented reality assists with safety and efficiency in the utility industry. It can provide technicians with the tools they need to ensure precision and efficiency in real-time. Smart technologies allow companies to reduce costs, increase efficiency, and optimize maintenance.
- *Workforce:* For the power industry, the workforce is a constantly target to improvement. Organizing and presenting necessary information to electric power workforces just-in-time is a challenging issue. Today, power industry severely suffers from the lack of sufficient knowledge of young workforces at the field. VR can help utilities improve knowledge management, especially given the problems with an ageing workforce and the loss of knowledge as employees retire. Using AR tools, field workforces can observe required information just-in-time and in-location in front of their eyes. The Electric Power Research Institute (EPRI) is working with major utilities on how VR can fit into the industry's workforce.
- *Workplace:* There are numerous general benefits to the adoption of augmented reality technologies in the workplace. These include the ability to perform actions on mobile devices and instantly receive relevant information with enriched, real-world objects.
- *Error Prevention:* By overlaying digital data on physical environments, AR can prevent human errors in cable installation and maintenance. It ensures that each task is performed with exacting precision, avoiding costly mistakes and rework.

- *Remote Assistance:* AR could allow experts to guide field workers remotely, offering live feedback as they troubleshoot issues on-site. This could drastically reduce response times and the need for expert travel, particularly in rural or hard-to-reach locations.
- *Less Risk of Accidents:* Augmented reality in energy industry surroundings has tremendous benefits for health and safety. Adopting AR in energy and utilities allows them to identify errors, which lowers the chances of mistakes. AR can simulate the related hazards on the ground and in real-time to provide superior safety insights. It is a highly effective solution to navigate hazardous situations, enhancing the productivity and safety of industrial workers. Figure 12 shows an industrial worker [13].
- *Safety*: A lot of jobs across sectors carry inherent risk and the safety of the workers is of upmost importance. An employee working in a real-world environment with moving parts, high heat or dangerous chemicals etc. is at risk. Using AR technology, these risks can be minimized as the person needs not engage in hazardous environments and can instead use an AR simulation. This significantly reduces risks and injuries to workers.
- *Reduced Training Time:* AR training takes less time that the traditional training sessions. By integrating augmented reality in energy industry training solutions, the time it takes to provide the highest standards of learning is cut significantly. The fact that training can be provided in safe, secure environments means companies can save money and this gives them the edge over their competition. AR also opens the doors for education from industry experts that can be provided remotely and from anywhere in the world.

CHALLENGES

The power industry is facing some challenges. As the pressure on energy and utility companies grows in dealing with the retirement of a highly skilled workforce, aging infrastructure, grid digitization, and increasing regulation, new solutions must be found. The utility sector is severely understaffed. Lack of technical skills, specialized education, and needed experience are the main challenges facing hiring managers in the utility sector. Another major problematic issue is the slow adoption of advanced technologies by major players in the power sector. Other challenges include the following [20];

- *Emissions:* The US power sector produced close to a third of overall energy emissions in 2020, according to Energy Information Administration estimates. While the sector is well on the road to zero emissions, process efficiencies such as a reduced need for physical travel and the ability to closely assess internal energy usage and other sustainability calculations will remain essential.
- *Regulation:* The power sector is prone to changes, from both national and international levels. An enterprise must track and follow every guideline, rule, regulation, and compliances they come across this sector. A water utility company grappled with slow response times, the increasing pressures of regulatory commitments, and hefty fines for violations discovered during audits. AR-powered digital platform can drive improvements in regulatory compliance and avoid fines.
- *Labor Shortage:* Finding skilled and experienced labor to run your daily operations is a task in itself. As the workers retire, attracting and retaining talent amidst a tight labor market is becoming challenging. By adopting innovative technologies, the sector can mitigate the risk of skill gaps. Due to these rapid changes, enterprises are always in the need to hire skilled and experienced workers to manage new processes in a sophisticated way.
- *Manage Ageing Workforce*: The ageing workforce creates an issue for many enterprises as it becomes difficult to train newly hired frontline workers. AR training can be provided with 3D AR annotations to your workforce and make them experience how to work on complex machines in real-time.
- *Technical Glitches:* Machine downtimes and delayed operations in power and renewable energy sector is not only costly but also life threatening. One wrong move or diagnosis can interrupt the operations of the whole enterprise and damage it heavily. Thus, enterprises need to avoid these situations and lead their enterprise towards uninterrupted operations.

CONCLUSION

Immersive technologies like augmented reality (AR) and virtual reality (VR) have come a long way since their inception. In all likelihood, immersive technology will remain a niche technology. It is no longer a futuristic concept. It is here to stay, making industries more efficient, safer, and smarter.

The adoption of immersive technologies has seen exponential growth over the last several years. From improving the assembly of aircraft to enhancing medical procedures, AR is transforming the way we work across the board. AR for energy and utilities is

creating the basis for a successful future. With the development of hardware and applications related to immersive technologies, their adoption is likely to further increase. More information on the integration of immersive technology into the power industry is available from the books in [21,22] and the following related journals:

- Technologies
- Energies
- Automation in Construction

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Figure 1 Extended reality (XR) includes AR,MR, and VR [4].

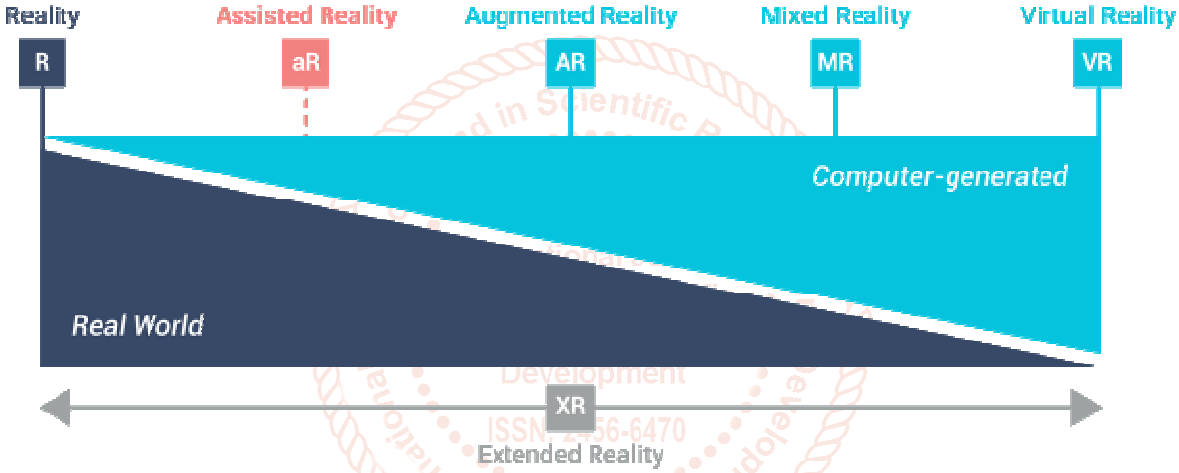

Figure 2 The XR spectrum [5].

Figure 3 Head-mounted displays [7].

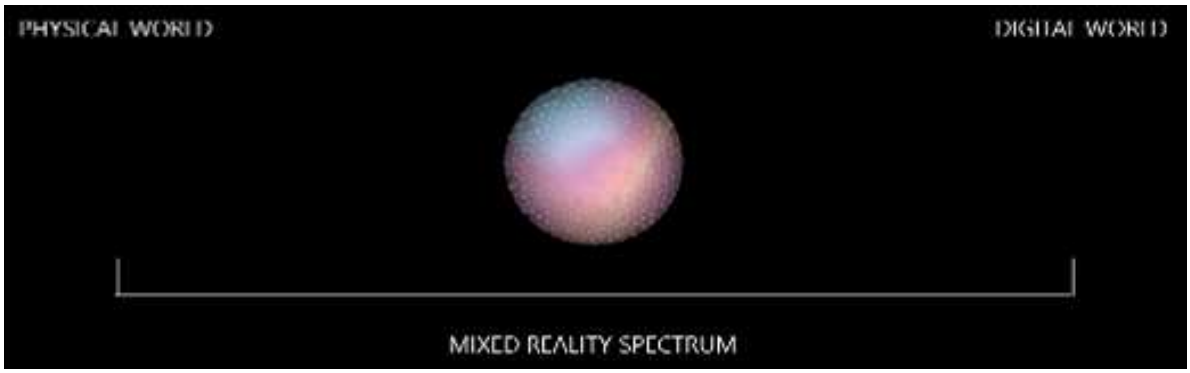

Figure 4 Mixed reality is a blend of physical and digital worlds [9].

Figure 5 A worker wearing an assisted reality device [11].

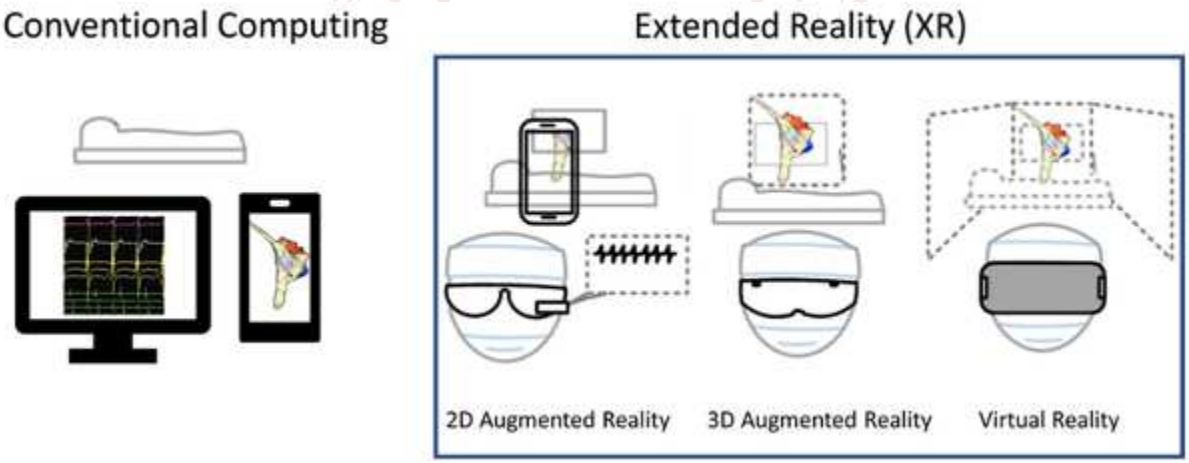

Figure 6 Comparing conventional computing with extended reality [12].

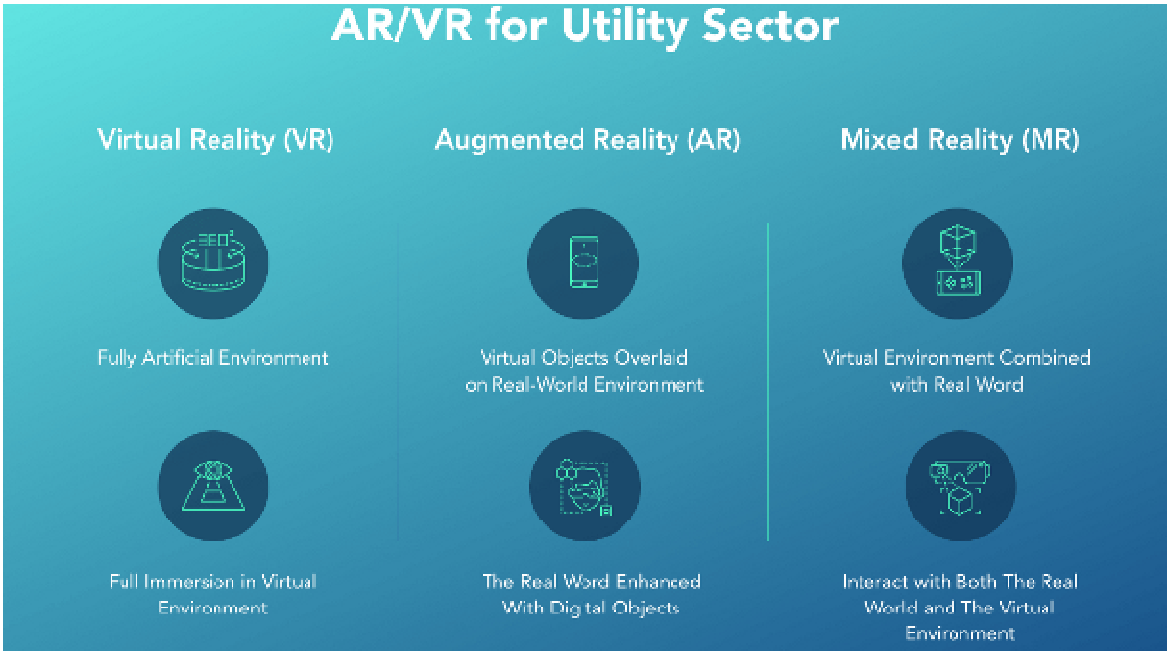

Figure 7 AR/VR for utility sector [13].

Figure 8 An example of how VR is used the power company [14].

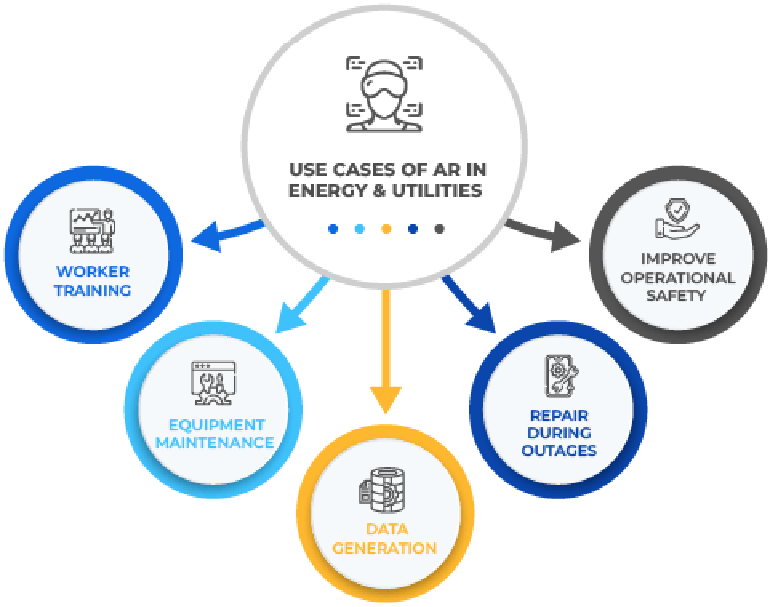

Figure 9 Some applications of AR in energy and utilities [15].

Figure 10 A typical inventory management [13].

Figure 11 An electrical engineer [18].

Figure 12 An industrial worker [13].