The Role of Artificial Intelligence and Electronic Intrusion Detection Systems in Protecting Solar Power Plants

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The aim of the study is to show how the integration of artificial intelligence (AI) and electronic intrusion detection systems can contribute to increasing the security of solar power plants. The study analyses the use of smart camera systems, motion sensors, infrasound sensors and drone technology. The operation, benefits and integration potential of each technology are evaluated. The results show that AI-based systems significantly reduce false alarms, enable faster response and increase the effectiveness of security systems. Automated intrusion detection and drone-based surveillance facilitate proactive protection. The effectiveness of these systems can be affected by external environmental factors such as weather conditions, sensor maintenance requirements and the deployment of technological infrastructure. In addition, the use of AI may raise privacy and legal issues that need to be taken into account in its practical implementation. The results will contribute to safety engineering improvements and provide practical guidance for solar plant operators. AI-based systems create the potential for adaptive, self-improving security mechanisms that reduce human resource requirements and increase the reliability of security systems. The novelty of the research lies in the combined use of AI and electronic security, which allows for more effective operation of object protection systems.

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1 Introduction

Artificial intelligence is playing an increasingly important role in various industries, including critical steps for efficient operation of companies, or the defence systems of solar power plants (Pap et al., 2024). Due to their technology, solar power plants are located in areas that require increased security attention. The majority of these areas are located in so-called brown zones on the edge of residential areas. The surroundings of solar panels located on the edge of residential areas are typically very busy, with little pedestrian or vehicular traffic. And solar arrays on the outskirts are located in outlying areas where the barren environment poses a safety risk. There is no movement of people, goods or people during the operation of the solar power plants, except for maintenance, and therefore they are not subject to vigorous protection. In this situation, intrusion detection and monitoring systems supported by artificial intelligence play a key role. AI-based surveillance systems can autonomously detect suspicious movements, analyse their behavioural patterns and reduce false alarms. AI-powered systems support decision making by processing data in real time, allowing the centre to respond to alerts faster and more efficiently (Fogarasi & Kovács, 2020).

2 Operation and main elements of solar power plants

2.1 Operating principle

Solar PV systems with an electrical capacity of over 500 kVA are classified as solar PV power plants. The solar panels produce direct current (DC) from sunlight, which is first converted into alternating current (AC) by inverters in the strings. The string collection stations and the transformers at the node then "step up" and "feed in" the current, which is already 120 kV AC, to the national grid voltage level. The biggest difference compared to other solar systems - which is also important for protection - is the size. Such power plants can cover several hectares of land and have fences that can be hundreds of metres long.

2.2 Spatial distribution of a solar power plant

The solar power plant is divided into four areas based on their functions (Table 1).

Table 1: Spatial layout of the solar power plant

environment	boundary	buildings	assets
– **industrial and dirt roads**	– fencing	– inverter (1000 V DV - 400 V AC) + sub-transformer (0,4/6 kV AC) buildings	– power converters – solar panels – support structure
– **hiking and tourist paths**	– gates	– main/nodal distribution buildings	– IT
– **pathways**		– main transformer 6/120 kV AC enclosure	– cables

Many solar power plants are surrounded by footpaths and hiking trails. Therefore, solar power plants must not only be protected from intentional intrusion, but also prevented from accidental access or entry. It should be noted that such power plants not only pose a hazard due to their operating principle (~1000 V DC or high voltage >1000 V AC), but also pose an increased risk of lightning strikes in stormy weather. It is important to note that lightning strikes are not only a direct hazard, but can also cause severe shocks to pedestrians and tourists walking along the road, due to the step voltage, which can spread through the ground, even much further away from the power plant. It is therefore of the utmost importance that the area around the power plant is also monitored, within the limits of the law (Abubakar et al., 2021; Ali et al., 2024). Artificial intelligence-based monitoring systems can play a key role in this process. AI-based cameras and sensors can analyse movements in the environment in real time, identify people and animals, and distinguish suspicious activities from everyday movements (Singh et al., 2024). The system can thus detect not only intrusion attempts, but also if a tourist or passerby accidentally wanders into the danger zone. The AI-powered systems are able to send automatic alerts to operators or to the live alarm service, which can warn nearby people of the danger if necessary. The most basic protection is still provided by mechanical units: gates, fences, walls and other barriers that mark the boundaries of the object and prevent or slow down intrusion (Koller, 2016). However, their efficiency can be significantly increased by a monitoring system with artificial intelligence, which provides continuous and intelligent monitoring. Solar power plants are both "brick buildings" and container units. The reason for using a container is that the equipment consists of pre-typed components and is preassembled. The masonry of the buildings and containers is strong and resistant to extreme weather conditions, so that the windows are the weak link. Artificial intelligence can also be used here, for example in the form of access control systems with smart sensors and biometric identification to prevent unauthorised access. Artificial intelligence can therefore play a significant role not only in intrusion protection but also in keeping the plant environment safe, helping operators to make more efficient and faster decisions to deal with emergencies.

3 Electronic intrusion detection systems

The structure of electronic intrusion detection systems is usually compared to the structure of an onionskin, with layers of perimeter, surface, area and object protection (Figure 1). Personal protection is also included, but this is not relevant for a solar power plant. Intrusion detection systems also include alarm signalling and remote monitoring communication (Utassy, 2009).

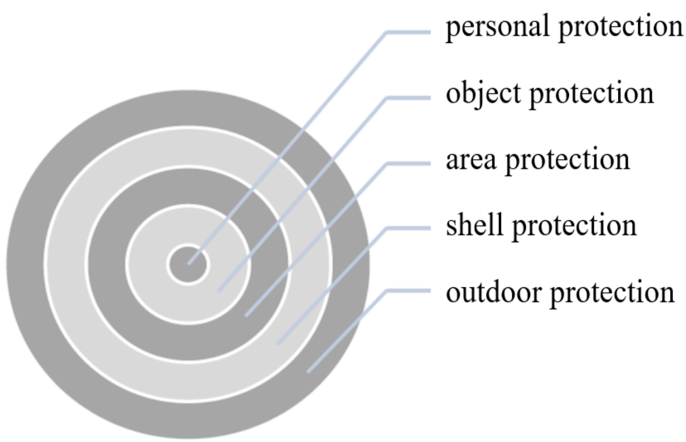

Figure 1: Onionskin protection structure

3.1 Elements of outdoor protection

An important aspect of outdoor protection devices is that they should be resistant to environmental impacts. These include UV radiation, wind, precipitation, dust and temperature fluctuations. Solar power plants are mostly installed in the countryside or on the edge of settlements, so false alarms, mainly caused by vegetation and animals, must be taken into account, but also pedestrians and tourists. Outdoor electronic protection is based on changes in movement, vibration, pressure or some other physical parameter. The use of artificial intelligence in this area is a major advantage, as AI-based systems can identify real threats and filter out false alarms, increasing the effectiveness of the system (Tóth & Tóth, 2014).

3.1.1 Motion detection (outdoor)

The operation of the motion sensor is based on the temperature radiation of the human body. It detects the wavelength in the infrared spectrum and its variation in intensity, and signals above a certain deviation value. The disadvantages of outdoor applications are short range and false alarms due to sudden temperature changes. Artificial intelligence can play a key role here too, as AI-based camera systems can continuously analyse sensor data, identify the source of movement and distinguish humans from animals or environmental influences. Such systems are becoming increasingly accurate through machine learning, and can therefore minimise false alarms. In addition, AI-based systems can automatically detect and signal when camera lenses become obscured or clogged, ensuring continuous and reliable operation (Oktel Kft., n.d.).

3.1.2 Security fencing

One of the basic elements of fence protection is the use of vibration sensors, which are fixed to the boundary element (fence, wall, railing, etc.) and detect its deformation and vibration. Weather conditions, especially strong winds and the presence of animals, can cause false alarms. AI-based systems can also help in noise filtering here, as they can analyse vibration patterns and distinguish genuine intrusion attempts from harmless environmental effects. For sensor-based sensors, artificial intelligence can be used to analyse detected vibrations and movements in real time. AI is able to integrate data from multiple sensors (such as piezoelectric, coaxial, linear magnetic or optical technologies) and generate more accurate alerts. Step sensors and infrared barriers also benefit from the use of AI, as it can detect the movement of people and animals and anticipate potential threats (Tóth & Tóth, 2014). For infrared barriers, AI not only detects signal loss, but also analyses the movement pattern between the transmitter and receiver, providing more accurate protection (Szandtber & Márkus, n.d.). AI plays a particularly important role in license plate recognition systems. AI-based number plate recognition systems are able to quickly and accurately identify vehicles and decide on access rights based on the information stored in the database. In addition, AI can help the system to learn and evolve, for example, by treating unknown number plates as warnings or managing periodic access authorisations (Bunyitai, 2011; Fogarasi, 2020).

3.2 Surface protection

Surface protection is designed to prevent intrusion through the structural elements of buildings. To this end, windows should be equipped with opening detectors, glass surfaces with glass break detectors and insufficiently solid wall structures with wall break detectors. The use of artificial intelligence in this area can take security to a new level, as AI-based systems can continuously monitor and analyse sensor signals and identify correlations, reducing false alarms and increasing the ability to react quickly (Tóth & Tóth, 2014).

3.2.1 Open sensors

Open sensors operate on a mechanical or magnetic principle. One of the best-known types of magnetic sensors is the reed-opening sensor, which consists of a pair of contacts and a permanent magnet in a glass tube filled with an air-cushioned or neutral protective gas. When the magnet comes close to the sensor, the contacts close and signal the system.

Artificial intelligence in this system increases efficiency by analysing sensor signals to detect suspicious patterns, such as the movement of a slowly, carefully opened door or window, which might not be an obvious alarm situation for a conventional system. AI-based algorithms are able to combine data from other sensors, such as motion sensors and cameras, to create a more accurate picture of what is actually happening. Micro-switches are mainly used in places where the sensor has to operate with little force, such as switch cabinets and fitting boxes. AI can also be useful here, as the system can monitor the status of cabinets and other equipment and automatically send an alarm if, for example, a switch cabinet is left open. In high-security areas, several signal catches and counter-bars rotated relative to each other are used to prevent tampering. Artificial intelligence can also optimise the operation of these systems by learning and recognising signals generated during normal operation, so that unusual or tampered events can be detected immediately (Szandtber & Márkus, n.d.; Tóth & Tóth, 2014).

3.2.2 Glass break detector

Glass break detectors are not normally used in solar power plants, but in facilities with education and visitor centres, their use is essential. There are two main types of glass break detectors: vibration-based and contact-based. Piezoelectric vibration detectors detect high-frequency vibrations generated by breaking or cutting glass by fixing them to the glass surface to be protected. By incorporating artificial intelligence (AI), these sensors can analyse vibration patterns and minimise false alarms, for example by distinguishing vibrations caused by objects falling on glass from real breaking events. Contact glass break detectors use a conductive metal layer on the glass surface, which breaks in the event of break, thus signalling to the security system. With the help of AI, such a system can be combined with other sensors, such as cameras or acoustic analysis algorithms, which can refine alarms based on sound patterns. Acoustic glass break detectors use a condenser microphone to detect the sound vibrations generated during break. With the help of AI, these devices can learn to distinguish between real glass break and other sounds of similar frequency (such as the rattling of a pot or loud banging), thus significantly reducing false alarms (Szandtber & Márkus, n.d).

3.3 Space protection

The purpose of space protection is to monitor movements within the area to be protected. The sensors are either focused on the specific area to be protected or installed at entrances and corridors. Since the interior of solar power plants usually consists of narrow service corridors, space protection is not typically used here, except in demonstration and training rooms. The most common space protection device is the passive infrared (PIR) motion detector, which detects infrared radiation emitted by living bodies. With the help of AI, these sensors can more effectively analyse detected movements and can distinguish human movement from signals generated by animals or environmental factors (e.g. air currents). Ultrasonic and microwave motion sensors are based on the Doppler effect: they emit a wave of a given frequency and then monitor the frequency variation of the reflected signal. The use of AI in these sensors can also help to detect false alarms by analysing movement patterns and taking into account environmental effects such as wind or shadow movement (Tóth & Tóth, 2014).

3.4 Object protection

A significant proportion of the inverters used in solar panels are mounted in mounting brackets. To facilitate maintenance, they can be lifted off by their handles like a briefcase and transported to the service centre. These inverters can sometimes be worth millions of forints, so they should be specially protected. One such protection device is a weight sensor.

4 Other intrusion detection support systems

4.1 Cameras

Cameras are not intrusion detection devices per se, but the signal they transmit can be used for alarms by image processing software. Such software processes the image information using a large database and "artificial intelligence". Their great advantage is that they can use filters and lenses to monitor the area and the surroundings of the object to be protected from a great distance, even at night - while complying with the law. By using smart cameras, you can reduce the workload on your staff and reduce the number of people needed to monitor the area (Berek, 2014).

4.2 Drones

Drones (actually UAVs) are now very common tools in the operation of solar power plants. Their main role is to support maintenance and increase operational safety. One important task in the maintenance of solar fields is to check the cleanliness of the solar panels. The easiest way to assess this is by aerial drone survey. And in maintenance, it is used to detect hotspots - abnormal solar panel, cell heating. Such flights provide an opportunity to assess damage to protection devices (e.g. fences). They can show traces of unusual movements or preparations for intrusion (e.g.: strike making) (Szalkai, 2021).

5 Summary

Various intrusion detection and protection systems are used to ensure the security of solar power plants. Surface protection uses opening and glass breakage detectors to monitor intrusion attempts, while area protection uses motion detectors to monitor protected areas. Valuable assets such as inverters are protected by weight sensors and other object protection technologies. Security systems are becoming more advanced and the integration of artificial intelligence (AI) is opening up new possibilities. AI-based cameras can automatically detect suspicious movements, filter false alarms and provide night-time surveillance. Smart drones can patrol autonomously, identify intrusion routes and transmit real-time images to the security centre. The use of AI increases the efficiency of intrusion detection systems, reduces false alarms and optimises the work of security personnel. In the future, intelligent security systems will increasingly be able to operate autonomously, predictively identifying potential threats and taking preventive action.

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