Improving Power System Reliability Through AI-Based Image Recognition Application Design

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Abstract: The smooth operation of today's highly developed civilization depends on a steady flow of power. Since the early to mid-1980s, much work in power systems analysis has shifted away from the rigorous and less laborious approaches of artificial intelligence (AI), which are rooted in the domains of operations research, control theory, and numerical analysis. Power grids continuously expanding as a result of new methods for producing, transmitting, and distributing power, as well as the development of new regions. Power system issues in the areas of control, planning, scheduling, forecasting, etc. have all benefited from the widespread adoption of AI approaches. Applications in today's huge power systems, which have had to add additional interconnections to keep up with rising load demand, present challenging problems that can be overcome with the help of these methods. Many subfields of power system engineering have found success with the use of these methods. With the expanding social economy, safeguarding electrical infrastructure has become an increasingly pressing concern. However, knowing how to secure the electrical system is crucial since it serves so many diverse locations. AI image recognition is used to locate and organize power equipment components such as signal lights, digital instrument panels, switch locations, etc. AI image recognition has been shown to work in simulations and help in the management of power grids.

Keywords: Artificial intelligence, Machine learning, broadband oscillations

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1. Introduction

From induction generator effects the sub-synchronous resonance/oscillation (SSR/SSO) results in torsional trembling of the shaft system, and transient torque magnification; adverse restraining fluctuations result from substantial load lines, contemporary quick innervation, and high-ceiling issue innervation structures. All the difficulties connected with oscillation may be traced back to these factors [1, 2]. Inertia-, stability-, immunity-, and predictability-poor renewable energy units cause oscillation problems in the current "double-high" power system. These problems have been caused by the oscillations caused by oscillations in the power system [3]. This kind of oscillation is brought on by the converter; the process by which it begins is convoluted, and the frequency spectrum is rather broad [4]. Low-frequency oscillations and converter-induced oscillations are both present in today's power grids [5]. This is because both types of oscillations are caused by coexisting. Mathematical models are used as the foundation for most today's techniques for evaluating broadband oscillations. Eigen value investigation, impedance, and open-loop resonance are three of the most used techniques. Both the state space model and the impedance model may be assessed by using these techniques, and they can illustrate the inner workings of oscillation [6, 7]. The linearization assumption is necessary for these methods to perform well.

Obtaining precise parameters for broadband oscillation in the power system is difficult owing to interactions between equipment and control timescales, and building an electromagnetic transient equivalent model is difficult due to its high degree of randomness and significant nonlinearity. Both issues may be traced back to the sophisticated wideband oscillation problem within the power supply. Broadband oscillations in actual systems are notoriously difficult to investigate using the tools we have at our disposal now [8, 9]. AI is a helpful tool in this situation because it is not overly reliant on system models, it has excellent learning skills for nonlinear and sophisticated data exchanges, and it can swiftly adapt to unexpected, changing environments. By doing so, power systems may tackle the problem of "broadband oscillation" in novel ways.

Throughout the history of artificial intelligence's development, it has constantly improved its own methods and has slowly become a system that can solve problems with broadband oscillation. AI has been a significant portion of data science for a long time. In doing so, it circumvents the challenge of effectively modelling high-dimensional power systems [10, 11]. It can process and sift through vast volumes of data in order to locate relevant information and disclose the governing principles of complex systems. Combining AI image recognition with the image identification of equipment alarms is the focus of this article, which makes use of remote digital video monitoring as well as a digital image recognition system. This allows for a more precise determination of the reason of accident alarms at the site, provides new means to locate accidents, and provides trustworthy analysis of incidents.

2. AI in Broadband Oscillation

2.1 Characteristics of AI Applications and their Foundational Principles

Research on broadband oscillations frequently makes use of various AI technologies. Intelligent optimization algorithms copy the ideas and structures of nature and biology; ML makes computers smarter; and DL imitates how the human brain works [12, 13].

ML, which is at the core of artificial intelligence, enables computers to mimic human behavior by picking up new skills and growing better at what they do over time [11, 13]. Learning algorithms that are unsupervised do not require labelled data, which is a time- and cost-saving advantage. Figure 1 demonstrates that reinforcement learning possesses tremendous online capabilities for self-learning.

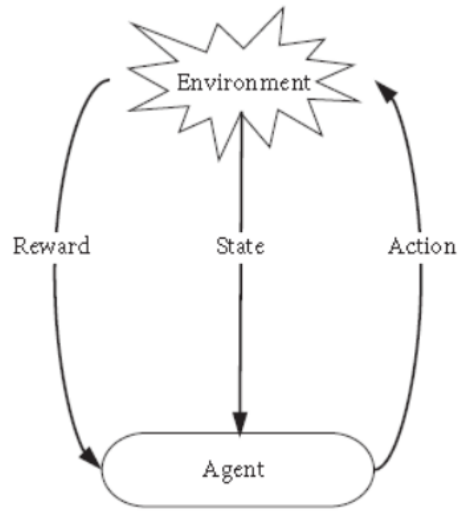


Fig. 1 Diagram to explain reinforcement learning

Traditional machine learning has a shallow structure that cannot generalize well enough to solve real complex problems. Therefore, deep learning, which has structures with several hidden layers, has become a popular area of research [14]. Deep learning is good at reducing the number of dimensions in data and analyzing it. It is also capable of using unsupervised learning to automatically extract features, which can assist in the resolution of huge, complicated, and nonlinear issues. One type of DL method is the convolutional neural network (CNN), while another is the deep belief network (DBNs). Research in artificial intelligence (AI) has mostly centered on algorithms which integrate deep, transfer, and reinforcement learning.

2.2. Broadband Oscillation Classification and Mechanism

Low-frequency SSR/SSOs are typical in conventional power systems. Power electronics and other grid components of today's contemporary "double-high" power system combine to generate a novel oscillation with broad frequency coverage, strong nonlinearities, and time-varying characteristics. For the most part, the new kind of oscillation may be understood as an electromagnetic fluctuation induced by PEC, as opposed to the previous power system's way of mechanically inducing oscillations. "Broadband oscillation" refers to its 10-103-Hz frequency range (Figure 2).

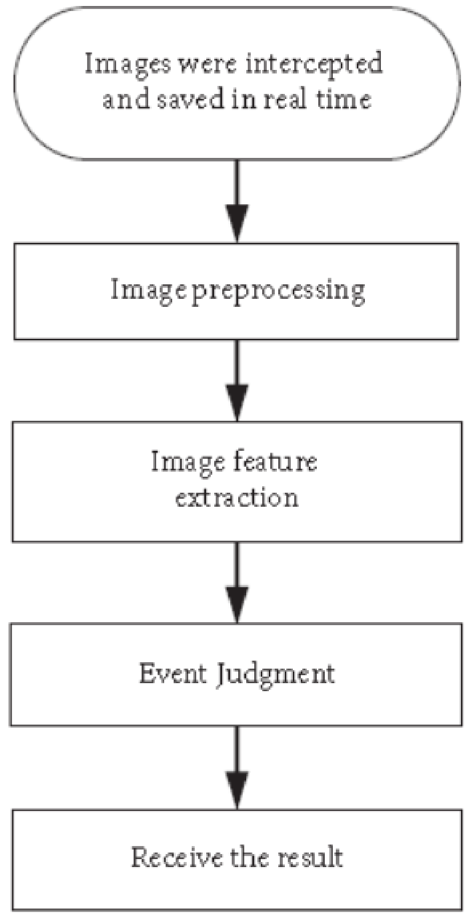


Fig. 2 A flowchart illustrating image processing for the power system

Based on the frequency difference between conventional oscillation and the new broadband oscillation, we may classify them as either low-frequency (0.1 - 2.5 Hz), sub- or super-synchronous, or medium- or high-frequency (100 – 1000 Hz).

Furthermore, the multipower electronic converter will be connected to the power grid at a higher frequency range in order to communicate with it. Oscillations at intermediate and high frequencies, particularly those between 100 Hz and above 1000 Hz, will be affected. The interaction between the voltage source converters and the grid may result in oscillations at both medium and high frequencies. Adding modular multilevel converters (MMC) to a weak grid has been shown to have negative damping characteristics, which might lead to the emergence of oscillations in the mid- and high-frequency ranges.

Parameter identification, positioning, and suppression techniques developed for low-frequency oscillations can be applied to "electromechanical" oscillations operating in a similar frequency range; this line of thinking also has significant reference for sub/super synchronous and mid to high frequency oscillations.

2.3. The Need for and Sense of Using AI in "Broadband Oscillation"

It's difficult to develop a mathematical electromagnetic transient model on the right scale that takes into account how different elements interact on different scales. It is also hard to get accurate model parameters. Broadband oscillation is made up of many different parts, and each part of the "double high" system has more than one way to control it. So, if electromagnetic transient modelling is done, the system model will have a very high order. Due to the manufacturer's secret technology and the unpredictability of the operating state, it's difficult to gather the genuine system's control strategy and equipment characteristics. Getting this info may be difficult.

AI is useful for tasks like data mining and analysis. It has the potential to extract useful information efficiently and cheaply from massive datasets, therefore obviating the challenges of accurate modelling using high-dimensional models of real-world power systems. Data sets may be made smaller with the use of feature engineering, extracting data, and selecting data. End-to-end learning may automatically acquire input attributes and map beginning data to desired output. End-to-end learning includes both capacities.

In terms of analysis approaches, it is difficult to examine broadband oscillations using the methods that are now available. This is since the techniques have their limits. Broadband oscillation problems with strong nonlinear characteristics are notoriously challenging to analyze with existing linear oscillation analysis techniques like eigenvalue and impedance analysis because of the sheer volume of calculations required and the restrictions imposed by system scale and equation order. More study into smart applications of broadband oscillation is required for a complete and correct analysis of the real system.

The oscillation modes have time-varying and temporal-spatial characteristics. Because of this, there are increased needs for the speed and adaptability of the technologies used for monitoring and suppression. Conventional strategies for detecting and dampening oscillations target a specific frequency range or number of units. Broadband oscillations have a time-space distribution that is difficult to coordinate among several electrical devices across a large region. It is also tough to watch the system's real-time working condition to cope with random time-varying systems' broad frequency oscillation issue. AI-based strategy may modify online by interacting with the environment in real time. Because of this, it has a remarkable ability to swiftly adapt to environments in which conditions change in unpredictable ways over time. For instance, artificial neural networks can adapt their architecture or weights in response to shifts in the data that is received from the outside world. Both the agent and the environment learn from each other in reinforcement learning. This type of learning allows the agent to continually progress its individual performance patterns in order to acclimate to changes in the outside world.

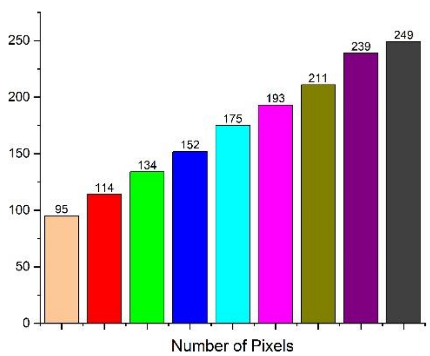
Broadband oscillation has many unanswered questions, and AI approaches depend less on system models, can learn how to tackle difficult nonlinear issues, and can adjust to surroundings that change randomly over time. Broadband oscillations might benefit from the use of AI, which could add to the knowledge base of current oscillation analysis methods and inspire new lines of inquiry.

2.4. Broadband Oscillation Identification and the Use of AI

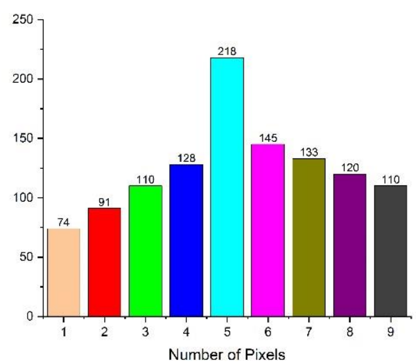
Broadband oscillation identification is mostly about finding the parameters and finding the oscillations. The current approach compares the derived parameters with the predefined threshold in order to ascertain whether the system is oscillating and, if so, what its frequency and amplitude are. This signal analysis may be performed in the time domain, the frequency domain, or both. Prony's method, quick.

Linear analysis approaches assume a signal is a linear mixture of others. In other words, the method cannot effectively identify sub/super synchronous oscillations. Since the frequency range of wide-frequency oscillations is between 10-1 and 103 Hz, the application of previously developed methods for spectrum analysis is constrained. The "double-high" system's condition can change, and broadband oscillation can take several shapes. When it comes to the component that monitors for oscillations, the current alarm threshold must be manually adjusted by a human, since the capacity to adjust itself to a variety of different working situations is insufficient. Spectrum analysis contrasts with AI-based wideband oscillation identification.

It considers parameter identification and oscillation detection as classification problems, not regression problems. Reducing data dimensionality improves oscillation parameter resilience and accuracy. Spectrum analysis and artificial intelligence are the two main components of the technique that is outlined in Figure 3 as the basis for locating broadband oscillations.



(a)



(b)

Fig. 3 Histogram in red, illuminated in red both "on" and "off"

After modelling the issue as a regression problem, methods like Adaline, EDSNN, etc. are utilized to identify the oscillation parameter. The neural network model known as Adaline is frequently employed in the modal identification process. Some research suggests combining Adaline with Prony's, Fourier's methods, etc., in order to determine all oscillation parameters with greater precision. Artificial intelligence can forecast oscillation modes, but traditional approaches are unable to.

2.5. The Challenge of Using AI to Find Broadband Oscillations

(a) AI-based method for spotting wide-frequency oscillation is inflexible, making it challenging to employ in a variety of scenarios. Most study has focused on sub/super synchronous oscillations and model training. Because the "double-high" system is so complicated, oscillations come in different forms and show up in different ways. Their dynamics are distinct from one another as well. It is necessary to do more research in order to determine whether the monitoring approach that is based on AI still possesses a high level of accuracy and precision for the various oscillations.

(b) Identifying an oscillation requires a high level of accuracy, and methods based on artificial intelligence are very dependent on data. It is because of this that widespread difficulties with data quality have made it more difficult for AI-based identification algorithms to be accurate. When collecting or transmitting data, there will always be unknowns, such as the possibility of data loss, communication delays, and data inaccuracies. This is because the actual power system is so sophisticated. Therefore, research is needed to design an effective algorithm structure employing AI to boost oscillation identification accuracy when data quality is inadequate.

Now, there are several theoretical study results regarding how artificial intelligence might be used to reduce oscillations, and one of the ways it can do this is by learning from past mistakes. However, before it can be utilized to halt the broadband oscillation of a real system, there are still several challenges that need to be overcome. These problems include the following:

(a) AI-based oscillation prevention has trouble meeting power system safety and stability norms. Simulations have shown that neural networks and reinforcement learning can dampen time-varying wideband oscillations. When data-driven reinforcement learning (DRL) techniques that pick-up information from interactions with the environment are coupled with data-driven neural network techniques, an effective control strategy is achieved, it is challenging to establish system stability via theory. So, it is still hard to make sure that the control strategy is reliable, which is a big problem for using it in the real power system, which needs to be very stable.

(b) Global coordination of multiple devices makes it hard for algorithms that use artificial intelligence to stop oscillations from happening. The power system was experiencing wide-frequency oscillations, which extended across a huge region and affected a variety of locations, machinery, and electrical equipment components. This is a problem that involves complexity on a global scale. Controlling electrical equipment in a coordinated manner with many power sources, grids, and loads is becoming increasingly vital as the "double-high" power system continues to expand its capacity. Applying AI to build a regional multi-device cooperative controller to suppress wideband oscillation extends state space tremendously. Because the quantity of characteristics influences controller-device interaction. This shows that AI-based oscillation suppression may face dimensionality disaster and algorithms may not converge. Additionally, this suggests that the method may not be effective.

2.6. AI-based Image Recognition

Picture preprocessing is the most significant approach to obtain information when it comes to artificial intelligence-based image recognition technology. Because it has such a direct impact on the results of the recognition, it is an essential component of the overall process. Image preprocessing can increase the image recognition system's accuracy. This might provide the framework for future work, reduce the amount of time needed to recognize a picture, and make the process simpler. When it comes to preprocessing, the most essential step is to find ways to boost the effectiveness of the identification process in whatever manner possible.

Most of the time, noise reduction and defogging are the two techniques that are utilized. The work done during preprocessing may be utilized to bring back a picture's clarity and brightness, restoring the image. Inspection of overhead transmission lines in the power system is carried out with the use of clever image recognition technologies. With one key, the collected pictures are processed and the best solution for the picture data is found.

Extraction and selection are usually required to extract picture features. Even though there may be a large number of feature points in the target picture, their feature subsets tend to be rather similar. The selection of feature points involves scientific understanding to ensure rapid and accurate identification. The most typical components of contemporary pictures are color characteristics, texture characteristics, form characteristics, spatial connection characteristics, and so on.

When a local feature is caught, the color feature points are captured first, but when a local feature is captured, the image texture feature points are captured first. Image recognition technology that is built on artificial intelligence could extract features and choose those characteristics based on how those features will be utilized and what sort of recognition is required. Because pictures include a lot of information, it is essential to be able to differentiate between the many components of an image while working with technological means. This is because pictures contain a lot of information. When checking and repairing overhead electricity transmission lines, for instance, the texture of the wires should be taken into consideration so that faults may be detected early on. This will allow for the most efficient use of time and resources.

Create a probability distribution function and an energy function using it. Categorizing photo matches is the final stage in AI-based image recognition. If each method is followed to the letter, the identical database picture may be obtained. This makes it possible to conclude the investigation of the qualities. In the power system, image matching categorization should be done based on the images' circumstances, and the necessary information should be acquired from the database. AI-based picture recognition is used to examine and maintain transmission cables.

2.7. Online Monitoring System Application Analysis

Because of the manner that the power system operates, there will be a great number of mishaps, such as burglaries and fires, that will severely compromise the power system's level of safety. To avoid the harmful effects of unforeseen events, you must gather knowledge quickly. This prepares you for anything. Online monitoring of the power system's aberrant alert data can help personnel identify the problem promptly. This can help technicians resolve the issue more rapidly. The surveillance system can accurately identify people by using image recognition technology and can keep an accurate record of who is entering and exiting the building in real time. The internet monitoring system may utilize infrared cameras to capture visitors' infrared outlines. This enables the infrared contours to be utilized for the purpose of data preprocessing. Additionally, the infrared camera could detect temperatures, which means that even if it is thermal power production, you can tell by the condition of the flame and figure out the temperature of the flame to ensure that the power system is fully protected from any potential dangers.

2.8. Using Audiovisual Compression and Unusual Alarm: A Practical Analysis

With so much information to keep track of, it is helpful to have the option of using scientific video compression. Data and images can be saved in sync so that technicians always have access to the most up-to-date version of the data for analytical purposes, and data retrieval demands with varying limitations can be satisfied. Video categorization depends on time series and data synchronization, so it's important to review picture and data storage, delete duplicates, and simplify the database so it can fulfil users' customized queries. Second, an anomalous alert and display will occur if the system identifies out-of-range data. This occurs simultaneously if the system finds data that is outside of its usual range. The system is supervised by an intelligent secondary screen cabinet, and its data are used to build an intelligent inspection system for substation secondary equipment using AI image recognition technology; finally, the data are summarized and submitted to the data warehouse, where monitoring efficiency is greatly improved through the combination of big data and power model, resulting in a reduction in the amperage needed to run the system.

Figure 2 depicts the many steps taken by the AI image recognition system, beginning with capturing an image from the live video feed so that it may be used later in image recognition processes including preprocessing, feature extraction, and event identification.

2.9. Analysis of a Recreation Experimentation

Video image recognition may now be used to inspect and identify indicators, 7-segment numbers, switch positions, and transformer oil levels.

2.9.1. Getting to Know the Signal Lamps

Red, green, and yellow lights are mostly what the equipment's signal lights look like. Finding out what these three-color signal lights represent when they are on and off is the task of signal-light identification. Calculating the mean, variance, difference square, mean difference, and other statistics pertaining to the hue of the signal light may be done with the use of the histogram approach. The red histogram of a particular red light is seen in Figure 3. This light can either be on or off.

When red is active, most pixel values are between 225 and 255, and most are 135. This is seen in the figure. Most of the pixel values fall anywhere between 72 and 184 when the red light is turned off. The maximum number of pixels that may be utilized is about 19. For this function, the square root of the absolute difference between each pixel's value and the total number of pixel points is used to determine if the signal light is on.

2.9.2. Recognize Numbers with 7 Segments

Numerical light indicate voltage, current, and temperature on power system automation equipment. Figure 4 shows seven-segment numerals. After the image has been preprocessed, the number composed of seven segments is quite easy to spot. Checking for dark pixels after character segmentation determines the seven-segment number's value.

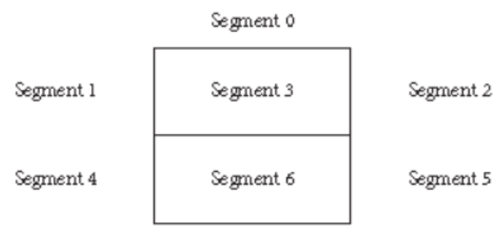


Fig. 4 7-segment digital structure

2.9.3. Recognizing the Location of a Pointing Device

Voltmeters, ammeters, barometers, and thermometers are just a few of the meters used in the power system that have pointers. Figure 5 depicts the methods used to manage pointer gauges and pointer photos.

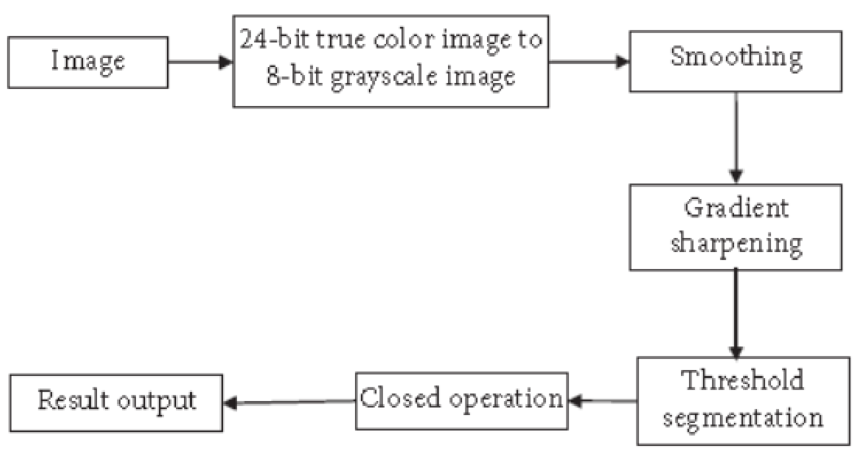


Fig. 5 7-Segment digital structure

2.9.4. Identifying the Position of a Switch

AI image identification of power supply equipment to identify the switch requires manual troubleshooting and repair of frequent issues initially. The on and off indicators will be placed up to indicate the change location.

2.9.5. Transformer Oil Level Detection

As the temperature inside the transformer goes up, the amount of oil in the transformer goes up as well. The oil level of the transformer cannot be quickly determined from the temperature data transmitted from a thermometer positioned within the transformer and sent to the substation automation system. AI image recognition can identify the transformer's oil level. Figure 6 shows the preliminary transformer oil study and original design.

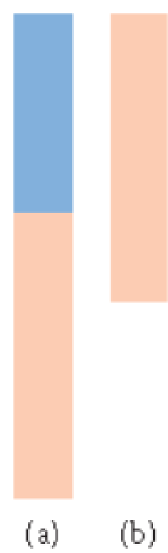


Fig. 6 Transformer pretreatment oil level. (a) Transformer oil pipe schematic (b) Pretreatment oil levels

Only horizontal projection can identify the transformer's oil level. Targets must be observed in order during image recognition. At first, this is accomplished by the application of AI technology that recognizes images. When the preset level is reached, an audible alarm sounds, the event and time are put into the database, and the image is saved. Thus, the image's properties and related information may be accessed and analyzed afterwards.

Conclusion

The AI image recognition system not only lets you look at things from a distance, but it also lets you keep an eye on signals and recognize them. Because it monitors the equipment's state, it can undertake maintenance and troubleshooting as needed. In this article, artificial intelligence is utilized to integrate picture identification with recognition of power systems. It is determined where the switch for the circuit breaker is located as well as the amount of oil that is in the transformer. The first one informs the dispatcher about the precise location of the switch, which improves the reliability and timeliness of the dispatching command and provides more direct techniques for event analysis and problem detection after the fact. The second one lets maintenance workers immediately check the transformer for hidden problems and fix them, making sure the transformer works safely and reliably.

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