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Artificial Intelligence and its applications in Renewable Integrated Power Systems

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ABSTRACT

Electric power system is undergoing major changes, due to large-scale integration of renewable energy, complicated network structure and increased energy demand. Developing autonomous systems, intelligent and digital communication technologies are becoming more and more urgent to modernize, strengthen and stabilize the power grid. Among several innovative efforts, artificial intelligence (AI) is becoming more popular due to its human like thinking logic, advanced wisdom, reasoning, learning capability and knowledge representation. AI approaches have demonstrated precise, faster and scalable outcomes, thus can be ideal to handle complex non-linear power systems. The recent technological developments in AI and hybrid techniques, makes it possible for solving large-scale complex power systems problems like control, planning, scheduling, prediction etc. This article has briefly discussed seven major areas, where AI has been used easily to handle constraints such as power system stability assessments, power system forecasting studies, power quality problems, optimization of generation scheduling, 5G network data communications, SCADA intrusion detection and transformer fault identification.

Keywords: artificial intelligence, power system stability, power quality disturbance, renewable energy, SCADA.

1. INTRODUCTION

The transformation of conventional power grid to smart grid, incorporating renewable energy systems and other energy conservation technologies are subjected to various challenges on network's security and stability [1]. Therefore, it is very important to rely on technologies, which can monitor, and control various elements required for stable and secure power system operations [2]-[7]. The power system based control and monitoring techniques must deal with difficult tasks with more interconnections, connected with renewables and other distributed energy resources [1]. The renewable energy penetration can cause increase in uncertainty, huge economic loss and technical failures in power systems. Hence, there is a pressing need to use intelligent computational methods to identify the uncertainties and mitigate their potential risk both at the planning and operation stage [2]-[7].

Since the mid of 1980, most of the power systems analysis has turned away from conventional mathematical modeling into more sophisticated computer tools and digital technologies to solve the complex problems of power systems [1]. Among various computer tools, the research in artificial intelligence (AI) has made greater progress and has been extensively applied in various areas of power system including power system planning and design, coordinated control, simulation, prediction and estimation, diagnosis, and identification [3]-[7] etc. AI based techniques can self-adapt and self-learn, thus plays a vital role in handling the dynamic, non-linear and complex renewable integrated power system operations. AI techniques combined with other hybrid approaches can be a powerful computation tool for efficient analysis in power system applications, which are on the direction of future development [8]-[10].

This article has discussed seven important and relevant real-world power systems applications, where AI techniques shows greater potential in handling intellectual assignments successfully. The applications discussed are AI in stability assessments, forecasting studies, power quality problems, optimization of generation and scheduling, 5G network data communication, supervisory control data acquisition

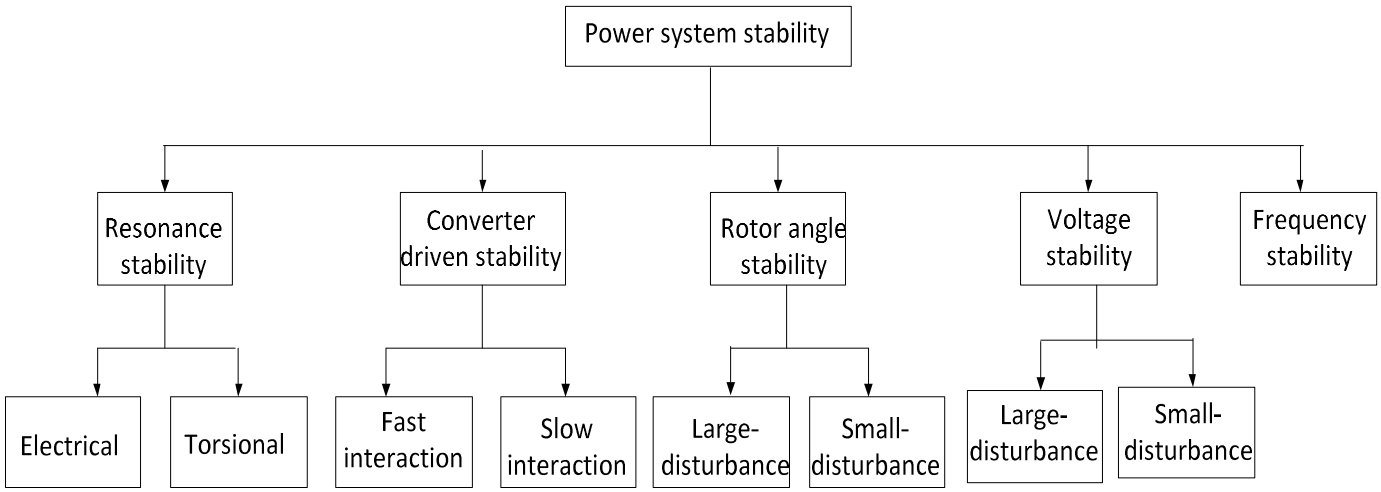

Fig. 1 Classification of power system stability [13]

(SCADA) intrusion detection and power transformer fault identification.

2. ARTIFICIAL INTELLIGENCE IN POWER SYSTEM STABILITY ASSESSMENTS

Power system stability assessment is a critical aspect necessary for achieving minimum standards of electric supply for progressive and developing nations [11]-[12]. Power system stability implies its ability to return to stable operation, by providing continuous service to customers after having been subjected to some form of disturbance [11]-[12]. Five types of stability assessments such as angular stability, transient stability, small-signal stability, frequency stability and voltage stability shown in Figure 1, are considered as the main stability studies for the safe and secure operation of power system [11].

The Power grid is designed to operate under controlled limits, but if the power limits are out of stability range, it will have huge impact on both the utility providers and users [11]. For example, frequency instability can cause the system to oscillate and damage the equipment [6]. The response of the power system to a disturbance may affect the power system dynamics such as variations in power flows, network bus voltages, machine speeds and voltage variations etc. Most importantly, the power grid collapses and brings huge economic losses [6]. Today power system stability assessment has become a significant area of research due to the integration of renewables and other distributed energy resources into the electricity grid [6]. The rapid development in AI technology provides a new revolution in assessing the stability of power system by learning more useful features through a large amount of training data. In addition, deep learning (DL) models, extracts information through multi-level abstraction and are designed for processing images, text, and audio files [19]-[21].

High penetration of inverter-based generation, e.g., DFIG is reducing the system inertia, so that monitoring the system inertia is becoming one of the prerequisites for effective power system control [13]. Traditional approaches for inertia monitoring [14]-[17] can be replaced with those based on ANN based monitoring system [18]. An Extreme learning machine (ELM) based feed forward neural network is used in frequency dynamics prediction procedure presented in [19] to assess the online frequency stability. In this work, both frequency response and load shedding process has been estimated using an integration approach based on ELM. A combined approach based on multilayer perceptron and support vector machine for transient stability assessment is presented for a Brazilian power grid [20]. This article has described how the high dimensional data is handled by AI techniques, while addressing the stability issue of the network. A deep learning-based learning technique is proposed in [2] to control the voltage of an offshore wind farm. The optimal power flow of the system is trained by deep deterministic policy gradient to stabilize the voltage level of the wind farm. A deep convolutional neural network (CNN) based AI method with multiple input is proposed in [21] for rotor angle and voltage stability analysis. In this work, a class activation mapping has been used for visualized analysis.

3. ARTIFICIAL INTELLIGENCE IN POWER SYSTEM FORECASTING STUDIES

An accurate forecasting of load is important for the reliable and resilient operation and planning of power system [22]-[26]. Forecasting can be defined into short-term, medium-term, and long-term forecasting. Short-term means, forecasting for few minutes to few days and is important for load-flow studies, planning load switching, shedding economic dispatch, predicting maximum load [23]-[25],[26] etc. Medium-term involves, forecasting from 1-12 months and can help utilities with maintenance planning, load switching operation and negotiation of contracts [27]. Long-term prediction means predicting for several years, which is important to make decisions on grid construction projects, modeling pricing policies, generating/purchasing power, policy/ technological changes, maintenance [28] etc. Therefore, forecasting has become one of the primary focus of research, contributing to the operation and planning of renewable integrated power system operations. Unlike, traditional load and power prediction approaches, the technological developments in AI combined with other hybrid techniques has received a widespread attention due to its high prediction accuracy.

A Multi-step forecasting model is discussed in [23] using long short-term memory (LSTM) and recurrent neural network (RNN) for a wind and solar energy system to predict the uncertainty in micro grid system. A hybrid forecasting approach is developed based on particle swarm optimization (PSO)- support vector regression (SVR) and grey combination model [24] for a wind energy system. In this work, SVR is established to fit the scatter operation data and the parameters of the model are optimized by PSO. In [26], a long short-term memory based deep learning forecasting framework is proposed to address the volatility of individual residential load. In this work, deep learning approach is used to forecast short-term load based on resident behavior learning. An advanced technique for data analysis is proposed in [27], using a recurrence plot time encoding and 2D-CNN model for a medium-term load prediction on a real-time load consumption dataset. An optimized DL model convolutional based on stacked LSTM is proposed in [28] using genetic algorithm for long-term load prediction and the hyperparameters are optimized using many DL techniques.

4. ARTIFICIAL INTELLIGENCE IN POWER QUALITY PROBLEMS

Power quality (PQ) problems and related phenomena are caused due to the increased usage of power electronic equipment, non-linear loads, computers, data processing equipment [29]-[30], etc. Figure 2 shows the blocks diagram of PQ monitoring process.

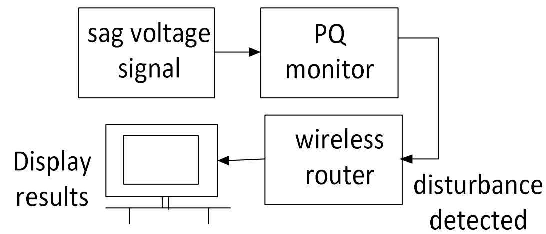

Fig. 2 PQ monitoring process

Power quality disturbances like transients, harmonic distortions, voltage sag, voltage fluctuations, voltage swell, voltage spikes, flickers, very short and very long interruptions, over voltages, under voltages etc, affects the quality of the power [29]-[33]. The power quality problems results in failures in equipment's, malware disruptions, faulty operations of transformers and relays etc, which eventually leads to significant decline in the revenue of the power system [31]-[33]. Hence, accurate analysis of power quality events is very important to extract features such as statistical information, spatio-temporal characteristics, stationary and non-stationary behavior of power quality signals [30] etc. Therefore, the study on power quality problems become indispensable, as it has direct impact on system's efficiency.

Recent developments in AI technology in the field of signals, image and information processing provides an effective way of dealing the power quality problems [32]. Several AI based classifiers including radial basis function neural network, artificial neural network (ANN), probabilistic neural network, multilayer perceptron NN, decision tree, K-nearest neighbors, extreme learning machine, SVM etc are used in literature to extract accurate features [31]-[33]. The performance of shunt hybrid filter is improved using artificial fuzzy neural network (AFNN) based control is proposed in [31], for achieving an effective smart grid operation under different scenarios of load and supply voltages. A new method is described to realize multiple power quality events based on variational mode decomposition (VMD) and ELM for multilabel learning [32]. In this work, ELM is extended to handle multi-label power quality events along with VMD and PSO, which is used to find the optimal solution. A deep CNN based structure is proposed in [33] for a micro-grid energy system to identify and classify the power quality disturbances. In this work, deep CNN is developed into a new n-dimensional structure. The modified deep CNN structure along with optimization techniques addresses the problems of low convergence speed and generalization ability and improves the identification and classification results.

5. ARTIFICIAL INTELLIGENCE IN OPTIMIZATION OF GENERATION SCHEDULING

The large-scale deployment of various renewable energy generation poses many challenges to the operation and governance of power system due to its intermittent nature [34]. To effectively smooth fluctuations and optimize the operations, generation scheduling optimizations are used to optimize and compensate the production from various renewable generation units [34]-[37]. The database of multiple generating units in a micro-grid are optimized to achieve unit commitment and economic dispatch. Economic dispatch reduces the need for additional unloaded reserve capacity in the power grid [35], [36]. Hence, optimization of generation scheduling is one of the most important optimization problems for the optimal planning and control, considering various operational constraints at a minimum operating cost. In recent times, AI based optimization techniques are succefully used in solving generation scheduling problems. An integrated energy management control is proposed in [35] for a domestic PV system. In this work, the controller is formulated on stochastic dynamic programming-based optimization technique using deep LSTM method, to reduce the purchase cost of electricity. In [36] and [37], an AI based solution is given for generation scheduling problem by modifying particle swam optimization technique for the convoluted nonlinear optimization problem in a micro grid system, aiming to minimize the cost paid by the customers.

6. ARTIFICIAL INTELLIGENCE IN 5G NETWORK DATA COMMUNICATION

With the ever-increasing demand of electricity, high-speed connectivity and automation can give high reliability, safety and better protection for electric power grid [38]-[39]. As a new infrastructure, 5G network is very clear and guarantee smart distribution network operation for another 5-10 years [40]-[41]. Figure 3 shows the communication between electricity providers and users. The arrival of 5G will bring major developments in the current power communication networks due to its high performance, improved efficiency, and a more uniform user experience [38]-[41]. Besides, the technological evolution of big data provides AI and 5G network an integrated intelligent future grid monitoring system [38]-[41]. In [42], a multi sensor data fusion technology is presented based on 5G network and AI. In this work, the authors have explained the importance of fusion of AI and machine learning as the main method for future power grid operation and monitoring system. An integrated intelligent operation and maintenance system is discussed in [43], based on 5G and AI technology. This article has explained the need for integrated intelligent operation, maintenance system, real time monitoring, auxiliary analysis, and emergency responses. The article in [44], has discussed a smart infrastructure build on an integrated structure based on 5G technologies and AI suitable for a complex power system. This type of smart architecture is very secure and reliable with intelligent digital technology and automated control.

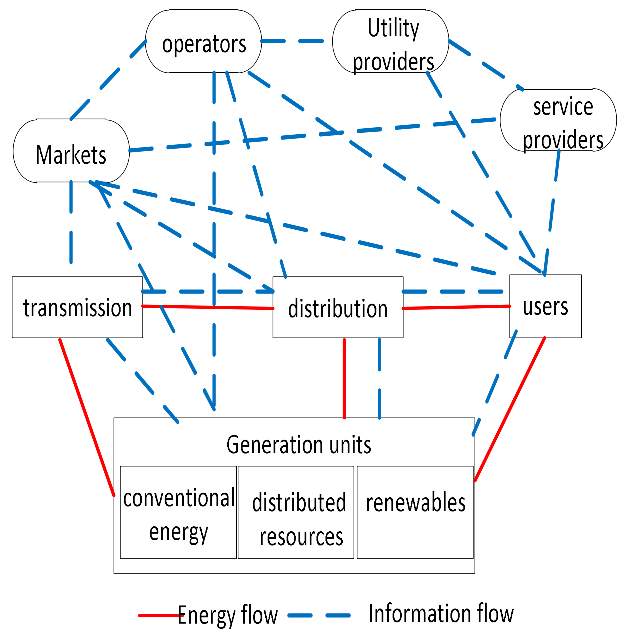

Fig. 3 Illustration of communication between generation units, service providers and users [44]

7. ARTIFICIAL INTELLIGENCE IN SCADA INTRUSION DETECTION

Advanced monitoring system based on SCADA is a critical infrastructure for renewable integrated power system operations [45] - [46]. SCADA is a well-established computer-based automate system used to gather real-time data from remote or local equipment such as programmable logic controller, remote terminal unit (RTU), intelligent electronic devices (IED) and human machine interface (HMI), etc. [45]-[48]. Figure 4 explains the block diagram of SCADA architecture connected from operation center, energy management and distribution systems (EMS and DMS) through control room to the substation. SCADA networks are secured in the past because they are disconnected from the internet and are made of specially designed software and hardware. However, with the integration of renewable energy resources, the traditional passive, radial network was subjected to a huge technological change in the power system network [45]-[46]. Therefore, an active network monitoring system has been implemented with emerging techniques to control and assist the power system operations.

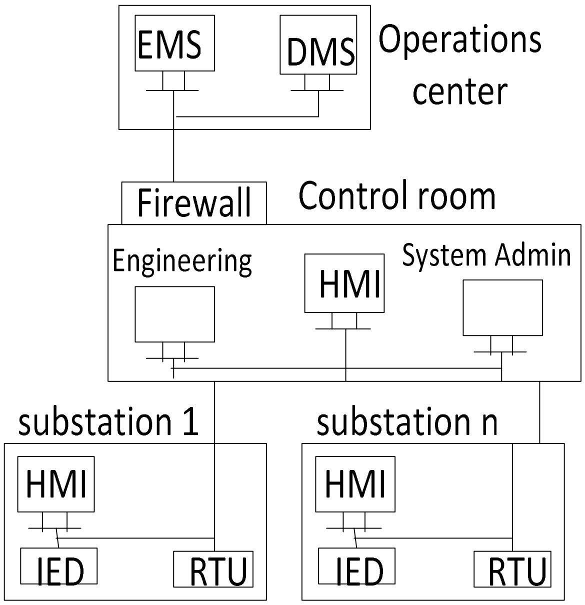

Fig. 4 Illustration of SCADA infrastructure

Over the last two decades, connecting SCADA networks to the internet has become essential due to performance and commercial needs. Hence, SCADA network's complexity and interconnectivity has increased [47]-[48]. SCADA networks are made to adopt with Transmission control protocol/internet protocol and are accessible via internet and corporate networks, they are vulnerable to cyberattacks. An attack on SCADA is a direct threat to the national security and economy of the country. Therefore, SCADA intrusion detection has become a prevalent area of study among the research community. The challenge in constructing SCADA intrusion system framework is to deal with unbalanced intrusion datasets. The recent studies in SCADA intrusion detection systems clearly shows, AI and DL techniques provides solution for both cyber-physical attacks and network-based attacks [45].

In [45], an intrusion detection system for smart grid is proposed utilizing IC61850. This system is developed with AI technology, which can monitor all transmitted and received messaged and prevents abnormal conditions in power system networks. A DL based intrusion detection system is proposed for a SCADA network to protect from both conventional and network-based attacks [47]. In this work, CNN serves as an intelligent real-time traffic monitoring system without intervening SCADA operations. The intrusion detection system proposed in [48] uses unsupervised learning in DL approaches to analyze the big data obtained from SCADA systems. In this work, several DL architectures such as CNN, LSTM, deep belief networks (DBN) and autoencoders (AE) are used to learn the features of SCADA system and prevents the malware attacks.

8. ARTIFICIAL INTELLIGENCE IN POWER TRANNSFORMER FAULT IDENTIFICATION

The reliability and stability of electrical power generation and distribution system depends on the proper functioning of power transformers. Any malfunctions in power transformer will lead to unexpected device damages, explosions, disconnection of the system and great economic losses [49]-[53]. The early-stage detection of transformer fault is very important to detect the transformer fault at an early stage. With the developments in AI technology, various approaches including ANN and DL are proposed in literature to accurately detect the faults in power transformer [18], [44]-[45]. Figure 5 explains the process of fault identification scheme of a power transformer from dissolved gas analysis dataset.

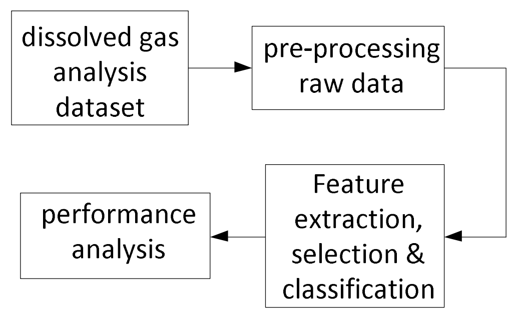

Fig. 5 Transformer fault identification scheme

Several AI based approaches are found in literature such as k-nearest neighbor's classifier, extreme gradient boosting ensemble classifier, frequency response analysis signatures based on decision tree classifiers, multilayer ANN with SVM classifier, LSTM based recurrent neural RNN classifier etc to increase the diagnostic accuracy of SCADA [49]-[53].

In [50], k-nearest neighbors (k-NN) based AI algorithm is used to detect the transformer faults. In this work, 501 data samples are used as an input vector and a training model is created based on k-NN and decision tree principle to obtain accurate results. The study reported in [51], has proposed an adaptive whale optimization algorithm to improve the transformer diagnostic accuracy. In this work, several data samples are created in binary form to obtain a trained model. The binary data is evaluated using optimization algorithms to obtain feature selection and classification. This method is proved to be efficient in handling data uncertainty and transformer faults. An empirical mode data decomposition method along with AI technique is used in [52], to calculate the transformer faults. In this work, a large set of parameters are decomposed, and the optimal parameter are classified to find the transformer fault. To increase the reliability and reduce the maintenance cost, a combined method based on support vector machine and decision tree is proposed in [53]. The total accuracies of the classifiers are evaluated to be very high and proven to be very effective in dealing with transformer faults. Table 1 summarizes different areas of AI applications and its corresponding references.

Table 1: Summary of AI applications in power systems

Sl.no	Application areas	References
1.	AI in power system stability assessments	[6],[11]-[21]
2.	AI in power system forecasting studies	[22]-[28]
3.	AI in power quality problems	[29]-[33]
4.	AI in optimization of generation scheduling	[34]-[37]
5.	AI in 5G data communication	[38]-[44]
6.	AI in SCADA intrusion detection	[45]-[48]
7.	AI in transformer fault identification	[49]-[53]

9. CONCLUSIONS

Modern power system is a critical infrastructure due to massive electricity consumption and renewable energy penetration. The security and reliability of modern power system has become a challenging issue due to its complex and nonlinear behavior. In recent times, Artificial intelligence (AI) technology has gained more interest due to its precise output, deeper data analysis and decision-making skills. AI has the potential to facilitate, accelerate, monitor, and manage the power grid operations. The application of AI provides a powerful technical support for monitoring and controlling the operation of renewable integrated power systems. This article has covered a wide range of area, where AI approaches are easily applied to handle power system stability, power system forecasting studies, power quality problems, optimization of generation scheduling, 5G network data communications, SCADA intrusion detection and transformer fault identification. Several other AI based applications are found in literature. A lot of research is yet to be done to explore the full advantage of the AI technology in power systems to improve the overall efficiency of electricity market, particularly for a renewable integrated power system. In future, AI technology will be deployed as a core component in all areas including cyber operations to meet new demands and facilitate safe and resilient power system operations.

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