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A Review Article of Power System Fact Controller Implementation Using Deep Learning Techniques

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Abstract- The recent advances in computing technologies and the increasing availability of large amounts of data in smart grids and smart cities are generating new research opportunities in the application of Machine Learning (ML) for improving the observability and efficiency of modern power grids. However, as the number and diversity of ML techniques increase, questions arise about their performance and applicability, and on the most suitable ML method depending on the specific application. Trying to answer these questions, this manuscript presents a systematic review of the state-of-the-art studies implementing ML techniques in the context of power systems, with a specific focus on the analysis of power flows, power quality, photovoltaic systems, intelligent transportation, and load forecasting. The survey investigates, for each of the selected topics, the most recent and promising ML techniques proposed by the literature, by highlighting their main characteristics and relevant results. The review revealed that, when compared to traditional approaches, ML algorithms can handle massive quantities of data with high dimensionality, by allowing the identification of hidden characteristics of (even) complex systems. In particular, even though very different techniques can be used for each application, hybrid models generally show better performances when compared to single ML-based models.

Keywords- Text Here Your Keywords.

I. INTRODUCTION

RELIABLE and resilient electricity is vital to the economy and national security of all countries. Preventive control measures have been widely employed to ensure adequate security margins against some conceived (e.g. N-1) contingencies. However, several large blackouts still occurred in the US, Europe, India and Brazil in the last two decades [1]–[3].

It has been well recognized that emergency control is imperative in real-time operation to minimize the occurrence and impact of power outages or wide-spread blackouts. Conventional emergency control actions include generation redispatch or tripping, load shedding, controlled system separation (or islanding), and dynamic braking [4].Some of these actions are automatically triggered by control or protection systems, while others are armed by system operators. Ideally, these emergency control actions should be adaptive to real-time system operation conditions.

However, existing control and protection systems for emergency controls are usually based on fixed settings that are mostly determined off-line based on some typical scenarios, and they are operated in a "set-and-forget" mode.
Emergency controls used by system operators in control rooms today are predefined through off-line studies based on a few forecasted system conditions and conceived contingency scenarios.

In addition, it heavily relies on system operators to choose suitable control actions by matching the current system situation with the nearest system conditions defined in emergency control look-up tables, as well as determining when and how to apply them. These processes are time consuming and often overwhelming for system operators. For example, during the 11-minute time span of the 2011 Southwest blackout event in US, system operators lacked sufficient time to understand the causes and take effective corrective actions [5].

II. RESEARCH MOTIVATION

The review paper is intended for power system security and stability researchers with the intention of building analytics and/or artificial intelligence security solutions for power system infrastructure, using the current and emerging machine learning approaches.

Different from the previous studies, this paper gathers together different approaches, strategies, procedures, limitations and research gaps on MLT application to power system security and stability studies.
Specifically, the major contributions of this paper are stated briefly as follows:

- A comprehensive review of the most recent state-ofthe-art ML approaches and the applicability in power system security and stability domain.
- The major power system security and stability domains (TSA, VSA, PQD and SCADA network vulnerability and threats) are extensively discussed.
- An elaborate review of several MLTs applied to power system security and stability problems as regards to the classifier(s) design, dataset generation, preprocessing techniques, optimization techniques and test systems deployed; and
- The challenges, limitations and research gaps of the current machine learning techniques' applications in power system security and stability studies and the directions for the successful deployment of MLTs in future power system security and stability applications [6-10].

III. LITERATURE REVIEW

Oyeniyi Akeem Alimi, A Review of Machine Learning Approaches to Power System Security and Stability: Increasing use of renewable energy sources, liberalized energy markets and most importantly, the integrations of various monitoring, measuring and communication infrastructures into modern power system network offer the opportunity to build a resilient and efficient grid. However, it also brings about various threats of instabilities and security concerns in form of cyberattack, voltage instability, power quality (PQ) disturbance among others to the complex network.

The need for efficient methodologies for quicker identification and detection of these problems has always been a priority to energy stakeholders over the years. In recent times, machine learning techniques (MLTs) have proven to be effective in numerous applications including power system studies. In the literature, various MLTs such as artificial neural networks (ANN), Decision Tree (DT), support vector machines (SVM) have been proposed, resulting in effective decision making and control actions in the secured and stable operations of the power system.

Given this growing trend, this paper presents a comprehensive review on the most recent studies whereby MLTs were developed for power system security and stability especially in cyberattack detections, PQ disturbance studies and dynamic security assessment studies. The aim is to highlight the methodologies, achievements and more importantly the limitations in the classifier(s) design, dataset and test systems employed in the reviewed publications.

A brief review of reinforcement learning (RL) and deep reinforcement learning (DRL) approaches to transient stability assessment is also presented. Finally, we highlighted some challenges and directions for future studies.

Huating Xu, Deep Reinforcement Learning-Based Tie-Line Power Adjustment Method for Power System Operation State Calculation: Operation state calculation (OSC) provides safe operating boundaries for power systems. The operators rely on the software-aid OSC results to dispatch the generators for grid control. Currently, the OSC workload has increased dramatically, as the power grid structure expands rapidly to mitigate renewable source integration.

However, the OSC is processed with a lot of manual interventions in most dispatching centers, which makes the OSC error-prone and personnel-experience oriented. Therefore, it is crucial to upgrade the current OSC in an automatic mode for efficiency and quality improvements. An essential process in the OSC is the tie-line power (TP) adjustment. In this paper, a new TP adjustment method is proposed using an adaptive mapping strategy and a Markov Decision Process (MDP) formulation.

Then, a model-free deep reinforcement learning (DRL) algorithm is proposed to solve the formulated MDP and learn an optimal adjustment strategy. The improvement techniques of "stepwise training" and "prioritized target replay" are included to decompose the large-scale complex problems and improve the training efficiency. Finally, five experiments are conducted on the IEEE 39-bus system and an actual 2725-bus power grid of China for the effectiveness demonstration.

Yujing Zhang, New Dimensionality Reduction Method of Wind Power Curve Based on Deep Learning: Wind power curve is a key tool to characterize wind power output feature, and is also the basis of wind power planning and operation research. The wind power curve is a high dimension matrix data with local property.

So it's a vital task to find an effective method to reduce dimension of the curve. In this paper, the latest techniques of artificial intelligence and deep learning are introduced to probe a new method for reducing the dimension of wind power curve. The convolutional autoencoder of typical deep learning framework is redesigned, and it learns feature representation from massive history data. The experiment result shows that the proposed autoencoder is better fit the wind power curve dimensionality reduction study.

Sayak Mukherjee, Learning Power System Dynamic Signatures using LSTM-Based Deep Neural Network: A Prototype Study on the New York State Grid: In this paper we present a prototype study of classifying dynamic events using a deep learning (DL) tool for the New York State (NYS) power grid. We use the utility-level full-scale transmission planning model of Eastern Interconnection

(EI) in the PSS/E platform for generating simulation data that are used for learning. We specifically use simulation data from those bus locations where Phasor Measurement Units (PMUs) are installed in the actual NYS grid for faster event detection and decision making. We first conduct the coherency study of the NYS grid using a unsupervised learning technique, namely Principal Component Analysis (PCA).

Then we consider three different dynamic classification scenarios. We classify the loss of generation scenarios according to the coherent clusters, loss of loads according to the New York Independent System Operator (NYISO) zonal separation and localize the loss of transmission lines along the Central-East (CE) interface.

For the transmission line outage scenario, we have generated dynamic event data by changing the grid stress level through the said interface and then tripping different major lines. The deep learning tool used for this study is known as the Long Short Term Memory (LSTM) neural networks. This work is intended toward developing a PMU-based data-driven fast contingency analysis and decision making architecture for the next generation power grid.

Jiongcheng Yan, Insecurity Early Warning for Large Scale Hybrid AC/DC Grids Based on Decision Tree and Semi-Supervised Deep Learning: Fast insecurity early warning is the key technique to resist the dynamic insecurity risk, which becomes intractable due to the strong nonlinearity of hybrid AC/DC grids and the high uncertainty of wind generation. Considering dynamic security constraints and wind power uncertainty, this paper presents an insecurity early warning method based on decision tree (DT) and semi-supervised deep learning.

First, semi-supervised deep learning is deployed to estimate the dynamic security limit of the critical interface of hybrid AC/DC grids. The system security is assessed by comparing the actual power transfer of the critical interface with the security limit. Then, operating conditions (OCs) are ranked into different insecure levels according to the type of preventive control actions that is needed to ensure the system security.

Finally, oblique DT is utilized to identify insecurity classification boundaries in the wind power injection space. Insecure OC sets are constructed based on these classification boundaries. Simulation results of the real-life Jiangsu-Shanghai interconnected grid in east China demonstrate that the proposed method can fast construct the insecure OC sets corresponding to different insecure levels.

M. Santhosh, Ensemble deep learning model for wind speed prediction: Wind prediction is a significant prerequisite for look-ahead economic load dispatch. Wind speed data is normally exhibiting wide uncertainty nature. Evaluation of this wind data must be accurate to reduce the dangers of system operations. To address this problem, the hybrid approach is developed using long short-term memory (LSTM) network and ensemble empirical mode decomposition (EEMD).

This decomposition technique is utilized to divide training data into distinct subseries. The features of uncertainty involved in each sub-series are extracted and utilized to enhance forecasting accuracy by LSTM to learn the characteristics of the decomposed signals. This developed hybrid deep learning model is comprehensively validated with real-time data. The performance validation analysis using statistical error values shows that the developed approach gives superior performance to the existing benchmark approaches.

Wenjun Xu, Joint topology construction and power adjustment for UAV networks: A deep reinforcement learning based approach: In this paper, we investigate a backhaul framework jointly considering topology construction and power adjustment for self-organizing UAV networks. To enhance the backhaul rate with limited information exchange and avoid malicious power competition, we propose a deep reinforcement learning (DRL) based method to construct the backhaul framework where each UAV distributedly makes decisions.

First, we decompose the backhaul framework into three submodules, i.e., transmission target selection (TS), total power control (PC), and multi-channel power allocation (PA). Then, the three submodules are solved by heterogeneous DRL algorithms with tailored rewards to regulate UAVs' behaviors. In particular, TS is solved by deep-Q learning to construct topology with less relay and guarantee the backhaul rate. PC and PA are solved by deep deterministic policy gradient to match the traffic requirement with proper finegrained transmission power.

As a result, the malicious power competition is alleviated, and the backhaul rate is further enhanced. Simulation results show that the proposed framework effectively achieves system-level and all-around performance gain compared with DQL and max-min method, i.e., higher backhaul rate, lower transmission power, and fewer hop.

Pol Paradell, Increasing resilience of power systems using intentional islanding; a comparison of Binary genetic algorithm and deep learning based method: Several algorithms combining qualitative and quantitative components are currently used for splitting a large interconnected power grid into islands as a measure to provide the best reconfiguration option when a fault appears. The aim of this article is to compare the clustering results of a binary genetic algorithm and a deep learning based method in order to identify the differences and to find in which cases it is rather better applicable each of the techniques.

Van Nhan Nguyen, Intelligent Monitoring and Inspection of Power Line Components Powered by UAVs and Deep Learning: In this paper, we present a novel automatic autonomous vision-based power line inspection system that uses unmanned aerial vehicle inspection as the main inspection method, optical images as the primary data source, and deep learning as the backbone of the data analysis.

To facilitate the implementation of the system, we address three main challenges of deep learning in vision-based power line inspection: (i) the lack of training data; (ii) class imbalance; and (iii) the detection of small components and faults. First, we create four medium-sized datasets for training component detection and classification models. Furthermore, we apply a series of effective data augmentation techniques to balance out the imbalanced classes.

Finally, we propose the multi-stage component detection and classification based on the Single Shot Multibox detector and deep Residual Networks to detect small components and faults. The results show that the proposed system is fast and accurate in detecting common faults on power line components, including missing top caps, cracks in poles and cross arms, woodpecker damage on poles, and rot damage on cross arms. The field tests suggest that our system has a promising role in the intelligent monitoring and inspection of power line components and as a valuable addition to smart grids.

Mohamed Massaoudi, Convergence of Photovoltaic Power Forecasting and Deep Learning: State-of-Art Review: Deep learning (DL)-based PV Power Forecasting (PVPF) emerged nowadays as a promising research direction to intelligentize energy systems. With the massive smart meter integration, DL takes advantage of the large-scale and multi-source data representations to achieve a spectacular performance and high PV forecastability potential compared to classical models. This review article taxonomically dives into the nitty-gritty of the mainstream DL-based PVPF methods while showcasing their strengths and weaknesses.

Firstly, we draw connections between PVPF and DL approaches and show how this relation might cross-fertilize or extend both directions. Then, fruitful discussions are conducted based on three classes: discriminative learning, generative learning, and deep reinforcement learning. In addition, this review analyzes recent automatic architecture optimization algorithms for DL-based PVPF. Next, the notable DL technologies are thoroughly described. These technologies include federated learning, deep transfer learning, incremental learning, and big data DL.

After that, DL methods are taxonomized into deterministic and probabilistic PVPF. Finally, this review concludes with some research gaps and hints about future challenges and research directions in driving the further success of DL techniques to PVPF applications. By compiling this study, we expect to help aspiring stakeholders widen their knowledge of the staggering potential of DL for PVPF.

Dongxia Zhang, Review on the research and practice of deep learning and reinforcement learning in smart grids: Smart grids are the developmental trend of power systems and they have attracted much attention all over the world. Due to their complexities, and the uncertainty of the smart grid and high volume of information being collected, artificial intelligence techniques represent some of the enabling technologies for its future development and success. Owing to the decreasing cost of computing power, the profusion of data, and better algorithms, AI has entered into its new developmental stage and AI 2.0 is developing rapidly.

Deep learning (DL), reinforcement learning (RL) and their combination-deep reinforcement learning (DRL) are representative methods and relatively mature methods in the family of AI 2.0. This article introduces the concept and status quo of the above three methods, summarizes their potential for application in smart grids, and provides an overview of the research work on their application in smart grids.

Shahrzad Hadayeghparast, A Hybrid Deep Learning-Based Power System State Forecasting: Smart power grids are one of the most complex cyberphysical systems, delivering electricity from power generation stations to consumers. It is critically important to know exactly the current state of the system as well as its state variation tendency; consequently, state estimation and state forecasting are widely used in smart power grids. Given that state forecasting predicts the system state ahead of time, it can enhance state estimation because state estimation is highly sensitive to measurement corruption due to the bad data or communication failures.

In this paper, a hybrid deep learning-based method is proposed for power system state forecasting. The proposed method leverages Convolutional Neural Network (CNN) for predicting voltage magnitudes and a deep Recurrent Neural Network (RNN) for predicting phase angels. The proposed CNN-RNN model is evaluated on the IEEE 118-bus benchmark. The results demonstrate that the proposed CNN-RNN model achieves better results than the existing techniques in the literature by reducing the normalized Root Mean Squared Error (RMSE) of predicted voltages by 10%. The results also show a 65% and 35% decrease in the average and maximum absolute error of voltage magnitude forecasting.

Zidong Zhang, Deep reinforcement learning for power system applications: Due to increasing complexity, uncertainty and data dimensions in power systems, conventional methods often meet bottlenecks when attempting to solve decision and control problems. Therefore, data-driven methods toward solving such problems are being extensively studied.

Deep reinforcement learning (DRL) is one of these data-driven methods and is regarded as real artificial intelligence (AI). DRL is a combination of deep learning (DL) and reinforcement learning (RL). This field of research has been applied to solve a wide range of complex sequential decision-making problems, including those in power systems.

This paper firstly reviews the basic ideas, models, algorithms and techniques of DRL. Applications in power systems such as energy management, demand response, electricity market, operational control, and others are then considered. In addition, recent advances in DRL including the combination of RL with other classical methods, and the prospect and challenges of applications in power systems are also discussed.

Kursat Rasim Mestav, Bayesian State Estimation for Unobservable Distribution Systems via Deep Learning: The problem of state estimation for unobservable distribution systems is considered. A deep learning approach to Bayesian state estimation is proposed for real-time applications. The proposed technique consists of distribution learning of stochastic power injection, a Monte Carlo technique for the training of a deep neural network for state estimation, and a Bayesian bad-data detection and filtering algorithm.

Structural characteristics of the deep neural networks are investigated. Simulations illustrate the accuracy of Bayesian state estimation for unobservable systems and demonstrate the benefit of employing a deep neural network. Numerical results show the robustness of Bayesian state estimation against modeling and estimation errors and the presence of bad and missing data. Comparing with pseudo-measurement techniques, direct Bayesian state estimation via deep learning neural network outperforms existing benchmarks.

Jian Xie, A Review of Machine Learning Applications in Power System Resilience: The integration of power electronics enabled devices and the high penetration of renewable energy drastically increase the complexity of power system operation and control. Power systems are still vulnerable to large-scale blackouts caused by extreme natural events or man-made attacks. With the recent development in artificial intelligence technique, machine learning has shown a processing ability in computational, perceptual and cognitive intelligence. It is an urgent challenge to integrate the advanced machine learning technology and large amount of real-time data from wide area measurement systems and intelligent electronic devices, in order to effectively enhance power system resilience and ensure the reliable and secure operation of power systems. Therefore, this paper aims to systematically review the existing application of machine learning methods on power system resilience enhancement, to expand the interest of researchers and scholars in this topic, and to jointly promote the application of artificial intelligence in the field of power systems.

IV. CONCLUSION

This paper presents a bibliographical survey of the published work on the application of different heuristic optimization techniques to solve the problem of optimal placement and sizing of FACTS devices in power systems.

Various heuristic optimization techniques that have been used to address the problem are summarized and classified. The paper also provides a general literature survey and a list of published references as essential guidelines for the research on optimal placement and sizing of FACTS device

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