A NOVEL DESIGN FRAMEWORK FOR SMART OPERATING ROBOT IN POWER SYSTEM

Seminar Report

Submitted in partial fulfillment of the requirements for the award of degree of

BACHELOR OF TECHNOLOGY

In

COMPUTER SCIENCE AND ENGINEERING

of

APJ ABDUL KALAM TECHNOLOGICAL UNIVERSITY

Submitted By

ANJALI SIJI

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CERTIFICATE

This is to certify that the report entitled **A Novel Design Framework for Smart Operating Robot in Power System** *submitted by* **Miss. ANJALI SIJI, Reg. No. MAC15CS013** *towards partial fulfillment of the requirement for the award of Degree of Bachelor of Technology in Computer science and Engineering from APJ Abdul Kalam Technological University for December 2018 is a bonafide record of the seminar carried out by her under our supervision and guidance.*

....	....	....
Prof. Joby George Varghese	**Prof. Neethu Subash**	**Dr. Surekha Mariam**
Faculty Guide	***Faculty Guide***	***Head of the Department***

Date: Dept. Seal

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ABSTRACT

Power system control center is one of the most important facilities in power systems. The main work of the control center is to monitor and analyze the status of the power system and reacts with appropriate actions to ensure the stability of the power system. One problem in power systems is that the power system analysis system in the control center is not fast and powerful enough to help the operators in time to deal with the incidents in the power system. Another issue in current power system control center is that the operation tickets are compiled manually by the operators. So that it is less efficient and human errors cannot be avoided. A framework of the smart operating robot is proposed with an intelligent power system analysis system and a smart operation ticket compiling system. This framework is faster and more capable of dealing with the highly nonlinear and complex power system.

Contents

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List of abbreviation

SCADA	Supervisory Control And Data Acquisition
AI	Artificial Intelligence
DSA	Dynamic Security Assessment
HMI	Human Machine Interface
RTU	Remote Terminal Units
SSA	Steady-State Security Assessment
HITL	Human-In-The-Loop
OTS	Operator Training Simulator

Introduction

Power system control center is one of the most important facilities in power systems. The main work of the control center is to monitor and analyze the status of the power system and reacts with appropriate actions to ensure the stability of the power system. Also, according to the maintenance tickets submitted by the maintenance crew, the control center should manipulate the operation of the power system to provide a good condition for the maintenance work. Typically, these actions from the control center are written on the operation ticket, which is manually compiled by the operators.

However, modern power systems are very complex and huge amount of information are collected by the SCADA in control center. It becomes a challenge for the operators to make good decisions for the problems in the complex power system based on the massive information. Also, since the control center is critical for the stability of the power system, the control center should be operated in 24 hours. So, it brings risks for the power system if the operators are tired in the night. Therefore, the concept of the smart operating robot is proposed in this paper to help the operators to better operate the power system and thus improve the stability and safety of the power system.

The smart operating robot is a system which mainly includes two parts, one is intelligent power system analysis system and another is smart operation ticket compiling system. The intelligent power system analysis system is a technique based on neural network, which can analyze the states of power systems and provide operation suggestions for the operators. The smart operation ticket compiling system is a deep learning based system to automatically generate the operation tickets instead of manually compiling by operators. The existing publications about the automatic operation ticket generation system are very rare. In [1] an operation ticket generation system with misoperation checking is proposed. In order to realize the automatic operation ticket generation, the system generates the operation tickets for the switches in the power system based on the operating rule templates and deal with the primary equipment operations and the secondary equipment operation separately. Also, an intelligent operation ticket expert system for power substations is proposed. In this paper, based on the experts knowledge base, fuzzy rule is developed for decision making. On the other hand, paper [3] introduces an intelligent checking system for the operation tickets which includes the recognition of objects, the topological analysis and the organization of knowledge rules. According to the existing papers, the proposed systems are developed mainly based on the operating rules. However, in order to obtain an reasonable and optimized operation ticket, the operators not only rely on operating rules, but also the experience and abstract thinking. Therefore, to emulate the experience and abstract thinking of the operators during the operation ticket compiling, this paper develops the smart operation ticket compiling system based on AI technology, in particular the deep learning technique.

With the rapid development of AI technology, new techniques like deep learning are widely implemented in various fields, such as image recognition, speech recognition, predictive analysis, decision making and intelligent transportation[4]-[6]. A famous example is the AlphaGo[7], an application of deep learning technique in Go game. The AlphaGo system successfully won two professional human Go game players in 2015 and 2016, respectively. Recently, the system beats the best Go game player in the world by. The AlphaGo shows the power and potential of the deep learning technology in the areas that the traditional computer programs were not good at. In these areas, human experience or abstract thinking is usually required, but the conventional programs or algorithms can only follow the fixed procedures. Similarly, many works in power systems are fixed procedures, such as the control and monitoring, so the conventional programs and algorithm are good enough to finish the job. However, there are still some works that require the experience and abstract thinking from humans. For these works, the deep learning technology has the potential to be applied and to complete the tasks better than human beings as demonstrated in the Go game. There have been some research about AI in power systems. For example, fault detection and fault diagnosis with AI techniques are studied. Another most applied area for the AI techniques is the power consumption prediction. Also, some works are focused on the intelligent energy systems. But, among these research, the deep learning technologies only take a small portion. So the application of deep learning in power system is just in the early stage. Also, there is very few application of deep learning in some important works in power system, such as power system analysis and power system operation. Therefore, this paper proposes the smart operating robot to explore the potential applications of deep learning methods in power systems.

In order to develop the smart operating robot, the authors have done a field study of power system control and operation in Tianjin, China. The demands and possible applications of AI in current power systems are explored. Based on the results of the field study in Tianjin control center, this paper proposes the framework of the smart operating robot in power system. Since this smart operating robot system is a big system, it is hard to include all the details in one paper. So, this paper only covers the concept and the framework of the entire system, the details of each part of the system and the case studies will be introduced in future papers.

The rest of the paper is organized as follows: In Section II, the demands and the potential applications of deep learning in power systems is discussed based on the field study in Tianjin power system control center. According to the discussion in this section, the paper will focus on two major applications of deep learning in power systems - the intelligent power system analysis system and the smart operation ticket compiling system.

Related works

According to field research in Tianjin power system control center in China, the most requested demands from the operators are better power system analysis tool and automatic compiling of operation ticket.

One important demand of the power system control center is the better analysis system. The current power system analysis tool is called dynamic security assessment (DSA) system. The DSA system can provide the power system stability indices for the operators. These indices include: frequency compliance rate, voltage compliance rate, area control error (ACE), spinning reserve rate, N-1 contingency stability, power supply margin, stability margin, short circuit current, voltage instability, small perturbation alarm and transient instability. In a typical power system, the readings of the sensors in the power system are collected by the supervisory control and data acquisition (SCADA) system in the control center.

The SCADA system calculates the states of the power system based on the collected information. The calculation of the SCADA usually takes 3-5 mins. Then the power system states are input into the DSA system for analysis. The analysis usually takes another 5 mins. Therefore, there is a 8-10 mins delay to get the final analysis results of the power system. Also, the power system analysis and the information collection are performed for every 15 mins. Therefore, the analysis results are not in real-time. When the power system experiences a perturbation or there is an incident in the power system, the delayed analysis result is not very useful for the operators to operate the power system. To solve the problem, AI techniques can be adopted to develop better analysis system.Unsupervised learning is the machine learning task of inferring a function to describe hidden structure from unlabeled data. There is a huge mass of unlabeled data which traditional artificial neural network has difficulty processing during operation period of power system.

The reason for the slowness of the traditional analysis system is that the algorithms, such as Newton-Raphson method, of many analysis tasks in power systems are recursive methods, so the calculation may take a lot of time. But, for most AI techniques, once the neural network is trained, the analysis procedure could be very fast. So, AI technique is a better choice to develop analysis systems for power systems. There are some research aiming to develop the DSA system with advanced AI methods, but the research of the deep learning based DSA system is pretty rare. So this paper will introduce the deep learning based intelligent power system analysis system to improve the speed and quality of the power system analysis, so that the operators can better understand the power system during the operation, especially during any incidents.

In power system control centers, one of the most important tasks for the operators is to compile the operation tickets. In a power system, if there is any incident or damage on any equipment, e.g., a short circuit on the transmission line, the staff will report to the control center via the repair ticket to request an outage at the faulted area, so that the repair workers can repair the equipment safely. Once the operators receive the repair tickets, they will manually compile the operation ticket according to the requests in the repair tickets. Finally, maintenance crew take actions, e.g., turn on or off related switches and breakers, according to the operation ticket. Since the operations in power systems are based on the operation tickets, it is very important to keep the operation ticket error free.Also, the compiling of the operation ticket usually relies on the experience of the operators, so the operation tickets compiled by different operators for the same incident may be different, and usually there is no criterion to determine which one of these operation tickets is better.

Therefore, in order to prevent mistakes in the operation ticket, the operation ticket compiled by an operator should be checked by the chief-operator. So the operation ticket is checked by two persons, and thus the possibility of error can be reduced. In addition, in order to prevent the error due to the weariness of the operators, the compiling of operation ticket must be completed before 10 p.m. every day. On the other hand, since the compiling of the operation ticket relies on the operators experience, the operations specified in the operation tickets from the operators may not be the optimal ones. So, the manual compiling of operation ticket by operator is not the best choice. In order to reduce the possibility of human error due to the tiredness and carelessness of the operators, and improve the quality of the operation ticket, an automatic operation ticket generation system is desired.

In order to solve this problem, several automatic operation ticket generation softwares are developed by different companies. However, the existing products cannot totally replace the operators to compile the operation tickets. The reason is because the compiling of operation tickets requires the experience, reasoning, and abstract thinking of humans, so the softwares which are based on certain rules can only deal with some simple tasks in power systems. But, for most problems in power systems, different factors may interact with each other due to the complexity of the power system. For example, in order to repair a transformer in the city, the operators should consider not only the power system itself but also the weather, the traffic and the schedule of the repairers during the compiling of operation tickets. So the problems and solutions in the incidents cannot be easily categorized into any rule in the softwares, and thus optimal operation ticket cannot be generated by the softwares. The newly emerged AI techniques, such as deep learning, provide a better solution for this problem. As shown in Go game, the AI can accomplish the tasks requiring experience, reasoning and abstract thinking, and performs better than human beings. So, AI can also be applied in power systems to generate operation tickets.To solve the problems given, deep learning is an efficient method because of its training mechanism that parameters iterate and update in each layer. Specifically, the weights of encoders are only restricted to the input of a layer and after training, the better parameters are propagated to the next layer.

2.1 Supervisory control and data aquisition

Supervisory control and data acquisition (SCADA) is an industrial control system which is used in many modern industries like energy, manufacturing, power, water transportation, etc. SCADA systems organize multiple technologies that allows to process, gather and monitor data at the same time to send instructions to those points that transmit data. In todays world, almost anywhere you can observe SCADA systems, whether its a waste water treatment plant, supermarkets, industries or even in your home.

SCADA systems range from simple to large configurations. Most of the SCADA applications use human machine interface (HMI) software that permits users to interact with machines to control the devices. HMI is connected to the motors, valves and many more devices.

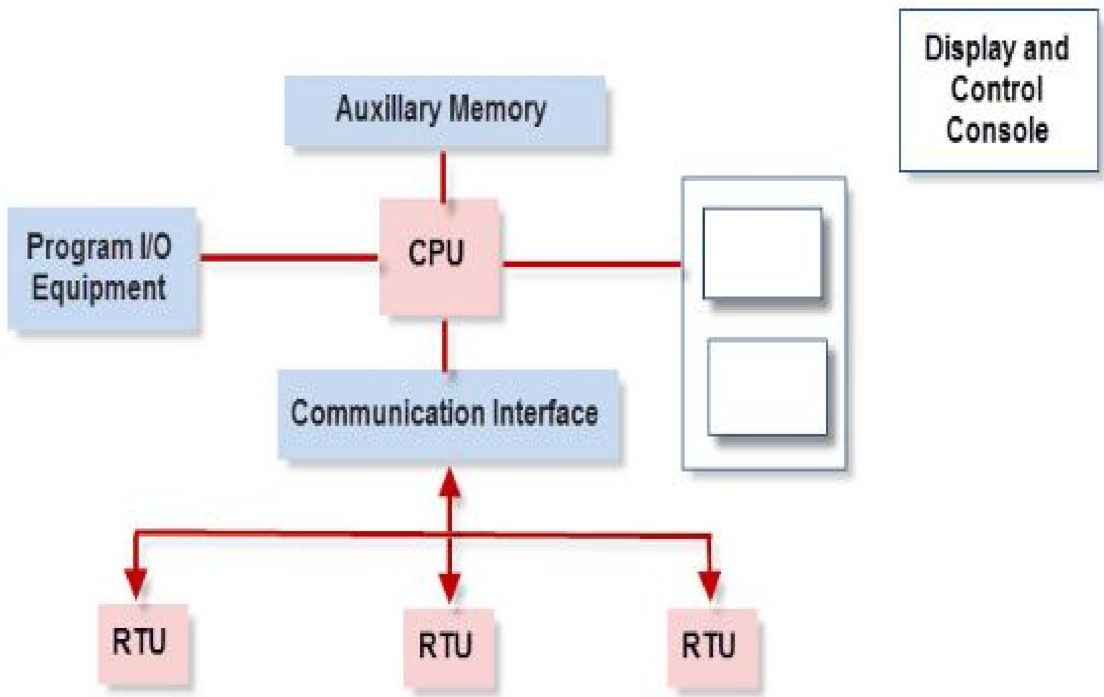

Fig. 2.1: Functional Units of SCADA.

In Fig. 2.1, SCADA software receives the information from programmable logic controllers (PLCs) or remote terminal units (RTUs), which in turn receive their information from the sensors or inputted values which we have given manually. SCADA in a power system is used to collect, analyze and monitor the data effectively, which will reduce the waste potentially and improve the efficiency of the entire system by saving money and time.

A SCADA system is a common industrial process automation system which is used to collect data from instruments and sensors located at remote sites and to transmit data at a central site for either monitoring or controlling purpose. The collected data from sensors and instruments isusually viewed on one or more SCADA host computers that arelocated at the central site. Based on the information received from the remote stations, automated or operator-driven supervisory commands can be pushed to remote station control devices, which are often referred to as field devices.The figure shown above is a simple SCADA system with a single computer, which represents the simplest configuration of SCADA with a single computer. The computer receives data from remote terminal units through the communication interface. One or more CRT terminals for display is controlled by operators. With this system, it is possible to execute supervisory control commands and request the display of data in alphanumerical formats.

The I/O SCADA programming is used to change the supervisory software. In the basic SCADA system, all the data and programs are stored in the main memory. The more complicated version of SCADA has additional secondary memories in the form of magnetic disc units.

2.2 Dynamic security assesment system

Security assessment has always been an important topic in power system operation. It refers to the analysis and quantification of the degree and risk in a power systems ability to survive imminent disturbances (contingencies) without interruption to customer service. Corresponding actions are designed and applied, if necessary, to reduce the risk. The security assessment of power systems includes steady-state security assessment (SSA) and dynamic security assessment (DSA). SSA studies the system steady state operating points between dynamic transitions, whereas DSA focuses on the security of system dynamics in various timescales, from transients of several seconds to slow dynamics of several minutes or even hours. In DSA, many security aspects of power systems are assessed, including transmission line thermal loading, voltage, rotor angles and frequency deviation. This is very computationally burdensome and requires many efforts. Historically, DSA is performed only off-line. The system dynamic security is assessed under forecasted operating scenarios, which should be exhaustive to cover the uncertainties. On the other hand, online DSA relies only on current operating scenario and assesses the ongoing real-time (or near real-time) dynamic security status, thus is able to give timely control actions to maintain system stability.

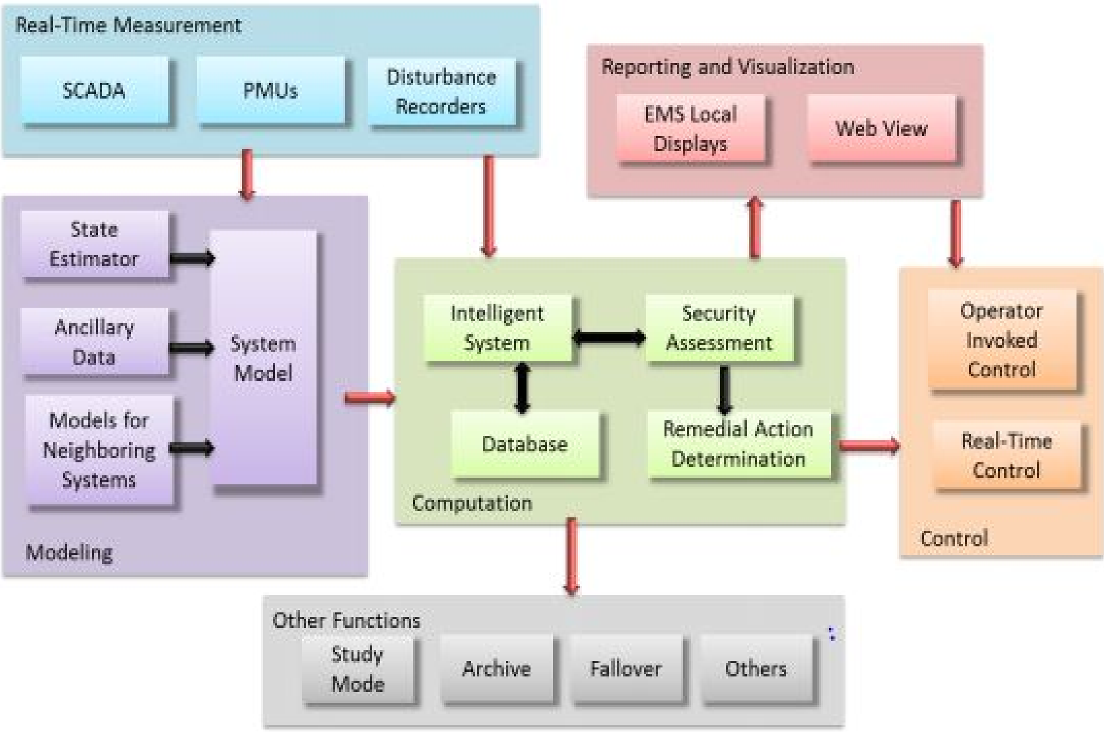

Fig. 2.2: Dynamic Security Assesment System.

This dissertation designs dynamic security assessment processing system (DSAPS) to improve existing online DSA industrial practice and add new functions taking advantage of fast computing facilities and communication technologies. Figure 2.2 shows the major components of current online DSA implementation in industry. DSAPS enables power system operators to have a better sense of system dynamic security and provides them with technical support for online decision-making to enhance power system dynamic security.

Modern power system is one of the most complex artificial systems in the world. It is operated to maintain a continuous process of electricity generation, transmission, and distribution. However, the operation of a power system is inevitably exposed to kinds of disturbances and faults, such as short-circuit of a transmission line or an unexpected generator outage, etc. Depending on the severity of the disturbances and faults, the power system may lose its security, which can result in catastrophic consequences, such as wide-spread blackouts. Generally speaking, power system security can be divided into static security and dynamic security, where the former examines if there is overloading of transmission lines and overvoltage of buses in the post-disturbance state, and the latter studies if stability criterion is violated during the system dynamic transition procedure. From the mathematical point of view, static security problem can be modeled by a set of algebraic equations and can be solved quickly, while the dynamic security problem is in the form of a large number of nonlinear differential-algebraic equations. Thus, one has to solve the equations via step-by-step integration for a transient time frame, which is referred to as time-domain simulation. In practice, time-domain simulation method is however very time-consuming and is difficult to provide useful information on dynamic security control. To accelerate the speed of time-domain simulation, distributed computing architecture is usually needed.

2.3 Deep learning

Machine-learning technology powers many aspects of modern society: from web searches to content filtering on social networks to recommendations on e-commerce websites, and it is increasingly present in consumer products such as cameras and smartphones. Machine-learning systems are used to identify objects in images, transcribe speech into text, match news items, posts or products with users interests, and select relevant results of search. Increasingly, these applications make use of a class of techniques called deep learning.

Conventional machine-learning techniques were limited in their ability to process natural data in their raw form. For decades, constructing a pattern-recognition or machine-learning system required careful engineering and considerable domain expertise to design a feature extractor that transformed the raw data (such as the pixel values of an image) into a suitable internal representation or feature vector from which the learning subsystem, often a classifier, could detect or classify patterns in the input.

Representation learning is a set of methods that allows a machine to be fed with raw data and to automatically discover the representations needed for detection or classification. Deep-learning methods are representation-learning methods with multiple levels of representation, obtained by composing simple but non-linear modules that each transform the representation at one level (starting with the raw input) into a representation at a higher, slightly more abstract level. With the composition of enough such transformations, very complex functions can be learned. For classification tasks, higher layers of representation amplify aspects of the input that are important for discrimination and suppress irrelevant variations. An image, for example, comes in the form of an array of pixel values, and the learned features in the first layer of representation typically represent the presence or absence of edges at particular orientations and locations in the image. The second layer typically detects motifs by spotting particular arrangements of edges, regardless of small variations in the edge positions. The third layer may assemble motifs into larger combinations that correspond to parts of familiar objects, and subsequent layers would detect objects as combinations of these parts. The key aspect of deep learning is that these layers of features are not designed by human engineers: they are learned from data using a general-purpose learning procedure.

Deep learning is making major advances in solving problems that have resisted the best attempts of the artificial intelligence community for many years. It has turned out to be very good at discovering intricate structures in high-dimensional data and is therefore applicable to many domains of science, business and government. In addition to beating records in image recognition14 and speech recognition57, it has beaten other machine-learning techniques at predicting the activity of potential drug molecules8, analysing particle accelerator data9,10, reconstructing brain circuits11, and predicting the effects of mutations in non-coding DNA on gene expression and disease. Perhaps more surprisingly, deep learning has produced extremely promising results for various tasks in natural language understanding14, particularly topic classification, sentiment analysis, question answering15 and language translation.

Deep learning will have many more successes in the near future because it requires very little engineering by hand, so it can easily take advantage of increases in the amount of available computation and data. New learning algorithms and architectures that are currently being developed for deep neural networks will only accelerate this progress.

The safety and high quality operation of power system are faced with challenges as the load increases and the scale of grid expands. The fault of power system can cause largescale power outage, which leads to a huge loss. Therefore, power system fault diagnosis is increasingly important and attracts high attention. Power system fault diagnosis is the process of analysing historical fault data to detect and predict current or future fault. It aims to provide assistance for staffs of power system to prevent fault or make a reasonable decision after fault, thereby reducing the negative effects. Research scholars have put forward some feasible methods in the field of power system fault diagnosis, which include diagnosis method based on expert system, Bayesian networks, Petri net, neural network, etc. Expert system is mainly used in power system equipment diagnosis. The automatic modeling and knowledge update ability of Bayesian networks is still immature. The modeling of Petri net is complex and difficult. Neural network easily runs into local optimum and turn up gradient diffusion problems. However, deep learning, improvement of Neural network, has great advantages in fault diagnosis. The concept of deep learning is the result of artificial neural network research.

Deep learning is a machine learning method proposed by Hinton, a prominent researcher in the field of machine learning and artificial intelligence in 2006, which imitates the mechanism of human brain to analyze data, such as images, sounds, and so on. In recent years, LeCun and Bengio also made a tremendous contribution to the development of deep learning. Deep learning has been applied to signal recognition, image identification, and target recognition, but it has just started in the field of power system fault diagnosis.

Unsupervised learning is the machine learning task of inferring a function to describe hidden structure from unlabeled data. There is a huge mass of unlabeled data which traditional artificial neural network has difficulty processing during operation period of power system. Therefore, sample acquirement is an important problem of artificial neural network. However, deep learning uses the unsupervised machine learning method in training, and makes use of a large amount of data to reflect hidden features. It is an effective method of unsupervised learning. Training a shallow network using traditional artificial neural network usually results in the parameters converging to reasonable values, but it is easy to run into local optimum when training a deep network, so that it fails to build a proper network for fault diagnosis. Moreover, since the training mechanism of traditional artificial neural network is updating each layer of the whole network from an iteration and each layers weight is restricted to the output layers error function, the traditional artificial neural network has gradient diffusion problems. Specifically, the gradients reduce sharply as the depth of the network increases, which are propagated backwards from the output layer to the earlier layers of the network. Then, the overall cost in relation to the weights in the earlier layers is very small. Therefore, the weights of the earlier layers update so slowly when using gradient descent that the earlier layers fail to learn effectively.

The proposed method

3.1 The intelligent power system analysis system

The DSA system is performed for every 15 mins but not in real-time, so it is not very useful for the operators to deal with the perturbations and incidents in the power system. In order to solve this problem and help the operators to better understand the status of the power system, the intelligent power system analysis system is introduced in this paper. This system has the ability to fast analyze the power system, predict the states of the power system, and provide the operation suggestion. The system includes fast analysis system, incident prediction and warning system and decision support system.

3.1.1 Fast analysis system

In the conventional power system analysis technologies, the analysis is mainly based on the physical model of the power system. The more detailed power system model can provide more precise analysis result, but the calculation speed is slower. For example, the DSA system in Tianjin power system control center usually takes about 8-10 mins to get the result, since the calculation is not only based on the power system network model of Tianjin city, but also based on the power system solution of the entire state grid. So, in order to obtain the accurate analysis result in a fast speed, the fast analysis system is proposed in this paper. The fast analysis system is a group of neural network as shown in Fig. 3.1. The system inputs the states of the power system such as the loads, the initial power flow, the equipment status, maintenance plan, generator status, unit commitment and weather forecasting information. Then, each neural network outputs different power system stability indices. Since the neural network is not an iterative method and it is not based on the physical model, the calculation could be very fast once the neural network has been trained. For example, when the DSA system calculates the

N-1 contingency stability of the power system, the system trips the lines in the power system model one by one, and calculates the power flow of the power system under each line trip. So, it requires a large amount of computation. Also, the power flow calculation is usually based on the iterative methods, such as Newton-Raphson method. So the calculation would be slow. However, the simple one layer neural network was used to compute the N-1 contingency of the IEEE 14-Bus system. The results are very close to the results of the traditional method, but the computation effort in the one layer neural network is much small than the iterative method, which means that the speed is much faster than the conventional method. Based on this concept, the other stability indices can be obtained in a fast and precise fashion with the neural network as well.

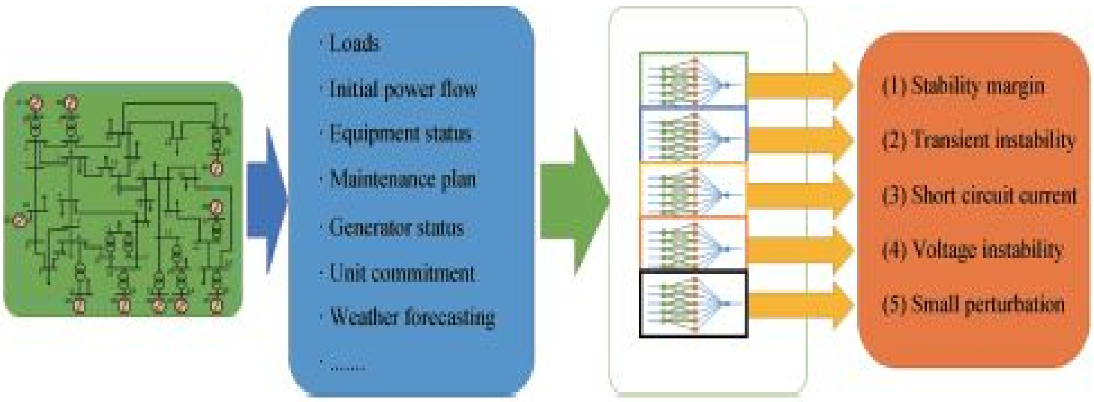

Fig. 3.1: The fast analysis system.

Also, the fast analysis system can be used to simulate the power system operation. In section IV, the operation checking and simulation part in the smart operation ticket system requires the power system simulation function to verify the stability of the power system under certain operations. The fast analysis system can be used to accomplish this task. First, the current power system states are collected from the SCADA system to form a power system model. Then, the operation checking and simulation system performs the operations in the operation ticket on power system model. Meanwhile, the fast analysis system analyze the power system model at each operation. If there is no anomaly for the stability indices for all operations, the operation ticket passes the test.

3.1.2 Incident prediction and warning system

Although the analysis can be very fast with the proposed fast analysis system, the operator may not be able to react and make good decision based on the analysis result quick enough during the incidents. So it is better to predict the potential incidents in the system and take preemptive action to prevent them happening before the incidents would actually happen. The incident prediction and warning system is designed to predict the power system status in the future, so that the operators can get prepared before any real incident happens. The system is based on the deep learning method. A deep neural network is used to predict the incidents in the power system. In power systems, the major factors causing the incidents are the weather condition, the construction and the aging of power equipment. So, the inputs of the neural network are the weather forecasting information, the construction schedule and the equipment status. The output of the neural network indicates which line or bus in the power system will likely have incident. The result will be provided to the operators to get warned before the incident happens.

3.1.3 Decision support system

In order to better help the operators to deal with the incidents in the power system, the decision support system is introduced in the intelligent power system analysis system. The decision support system provides the possible operations and actions for the operators, so that the operators can make better and faster decision during the incidents, and thus the impacts of the incidents can be reduced. The decision support system is based on the deep learning method. It is similar to the operation ticket generating system, but the object is to eliminate the faults in the power system and reduce the impact of the incident. The decision support system outputs the possible operations and actions for the operators to solve or prevent the predicted incidents from the incident prediction and warning system. So the operators can be prepared before the incident happens. The deep neural network in the decision support system is trained with the historical data of the operations and actions that the operators performed to solve the incidents. Also, the training data can be generated by simulating the incidents in the power system model.

3.1.4 The framework of the analysis system

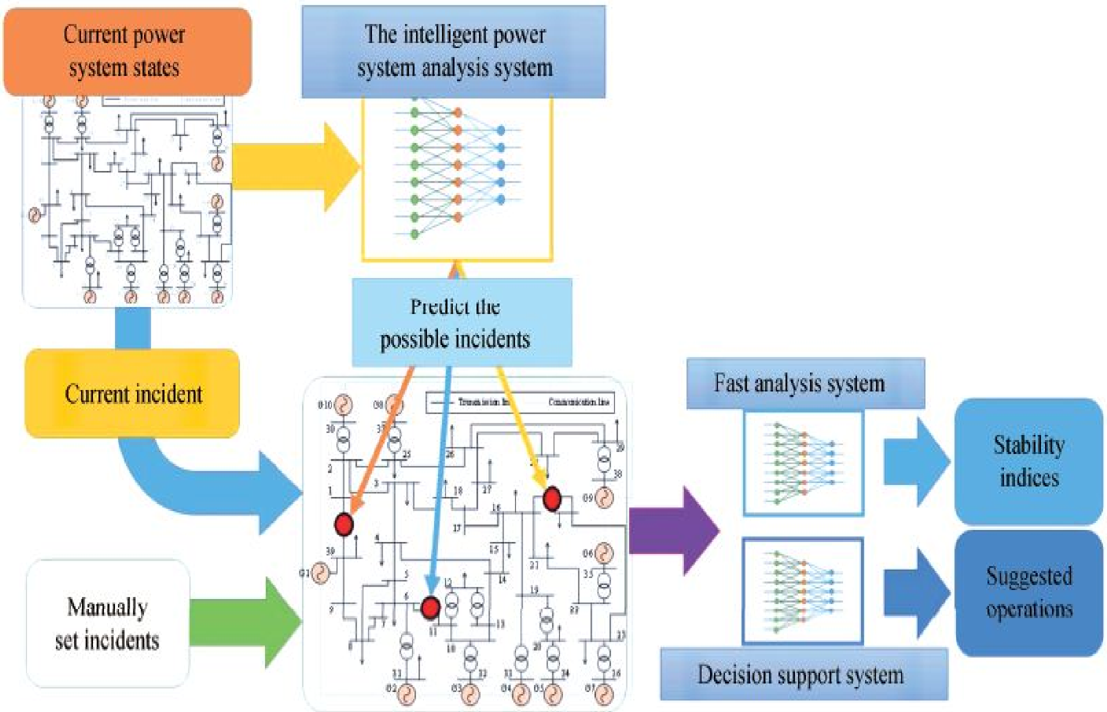

Fig. 3.2: The framework of the intelligent power system analysis system.

Finally, the entire intelligent power system analysis system is shown in Fig. 3.2 In this system, the current states of the power system is collected by the incident prediction and warning system at the first. The prediction system will predict the possible incidents in the power system based on the actual, current states of the power system. Also, the current incident in the power system can be input into the system for analysis, or the incidents can be manually set by the operators to simulate the incidents in the power system. Then, the fast analysis system will analyze the power system with the predicted incident, so that the operators can better understand the impacts of the incident. Meanwhile, the decision support system will provide the suggested operations and actions for the operators to deal with the incident.

Therefore, with the analysis result of the incident and the suggested operations from the intelligent power system analysis system, the operators can deal with the incidents without relying too much on their own experience, and thus the incidents can be better resolved.

3.2 The smart operation ticket compiling system

As discussed above, operation ticket is one of the most important tools in the operation of power systems. Many critical activities, e.g., facility maintenance and fault recovery, in power systems depend on operation tickets. So the stability of the power system is heavily influenced by the correctness and reasonableness of operation tickets. As discussed above, the smart operation ticket compiling system can be introduced into the power system to produce the operation ticket automatically, so that the quality of operation tickets can be improved, and the human errors during the compiling of operation tickets can be prevented.

However, since operation tickets are critical for the stability of the power system and the smart operation ticket compiling system is a new technology, the operation ticket generated by the smart operation ticket compiler should not be applied on the power system directly. Instead, the proposed smart operation ticket compiling system is a human-in-the-loop (HITL) system. In this way, the possible errors from the smart operation ticket compiling system can be prevented by the operators manual checking, and vice versa, the revised operation ticket from operators can also be checked by the automatic compiling system. So, the errors in the operation ticket could be reduced greatly in theory. Also, since the the operators only check and modify the result from the automatic system rather than compile the entire operation ticket, their workload are reduced.

On the other hand, as discussed in the beginning of this paper, the difficulty for automatic operation ticket generation is that the experience and reasoning of humans are required to decide the working procedure in the power system. Therefore, the machine learning technique is implemented in this system to learn the patterns in operation tickets. Also, many operations in the power system are not based on experience but certain rules. For example, to shut-down a line, the circuit breaker on the two sides of the line should be turned off first, then the dis-

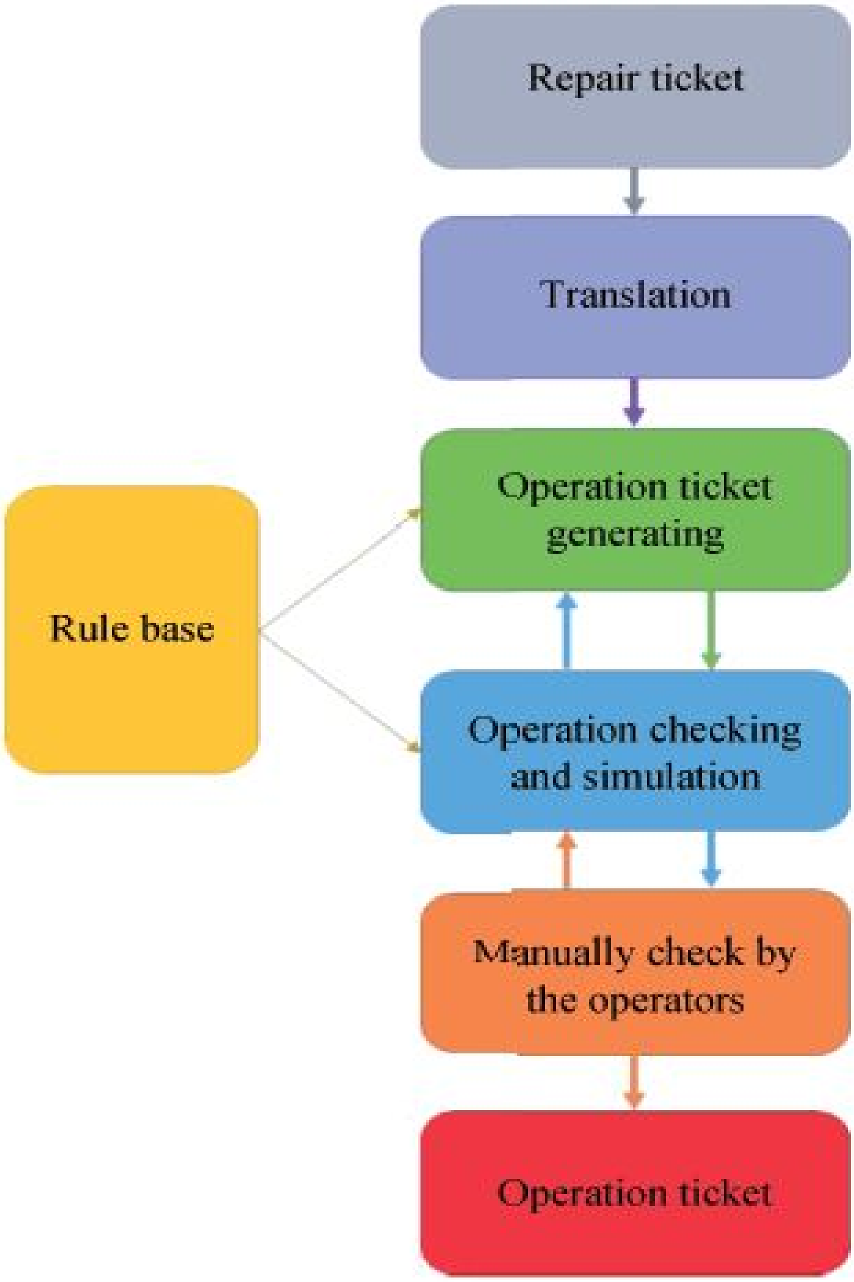

Fig. 3.3: The framework of the smart operation ticket compiling system.

connect switches are turned off. So, a rule base is implemented in the power system which contains all these fixed rules. In the end, the smart operation ticket compiling system generates the operation ticket based on both the fixed operation sequences from the rule base and the more complex operations from the machine learning.

In addition, the different order of the operation sequence in the operation ticket may have distinct influence on the economy and stability of power systems. So the optimization technique is implemented in the proposed smart operation ticket compiling system to optimize the operation ticket. The optimization technique helps the system to schedule the order of the operations in the operation ticket, so that the power system is economic and stable under the operations.

The framework of the system is shown in Fig. 3.3. In the conventional power system control center, the operators compile the operation tickets based on the repair tickets reported by the examiners and repairers. In the proposed smart operation ticket compiling system, the repair tickets are translated by a translation system into a standard format that can be read by the machine learning model. Then, the translated data is imported into the operation ticket generating system as the desired power system status, e.g., some lines should be tripped.

The operation ticket generating system can be developed based on the machine learning method, i.e. the deep neural network. The working procedure of the operation ticket generating system is shown in Fig. 3.4. The system first inputs the desired power system status from the repair tickets and the current status (structure and states) of the power system into the operation generation system. It compares the difference between the current status of the power system and the desired status in the repair ticket. According to the difference, the deep neural network outputs an operation that has the highest possibility to be the optimal one. Then, the system performs this operation in the power system model, and call the fast analysis system in the intelligent power system analysis system to analyze the influence of this operation. The fast analysis system will output a result as either pass or not pass. If the result is pass, it means that the power system keeps stable under the operation. So the operation will be placed in the operation ticket. Otherwise, the not pass means the operation will make the system unstable, so it cannot be listed in the operation ticket. Also, the system will choose another operation which has second highest possibility to be the optimal operation to replace the not pass operation. The new operation will also be checked by the analysis system.This process keeps repeating until one operation passes the analysis. Then, the system compares the status of the power system model after the operation had been performed with the desired power system status, and then generate the next operation. The process goes on until there is no difference between the status of the power system model and the desired power system status. Therefore, the operation ticket is obtained.

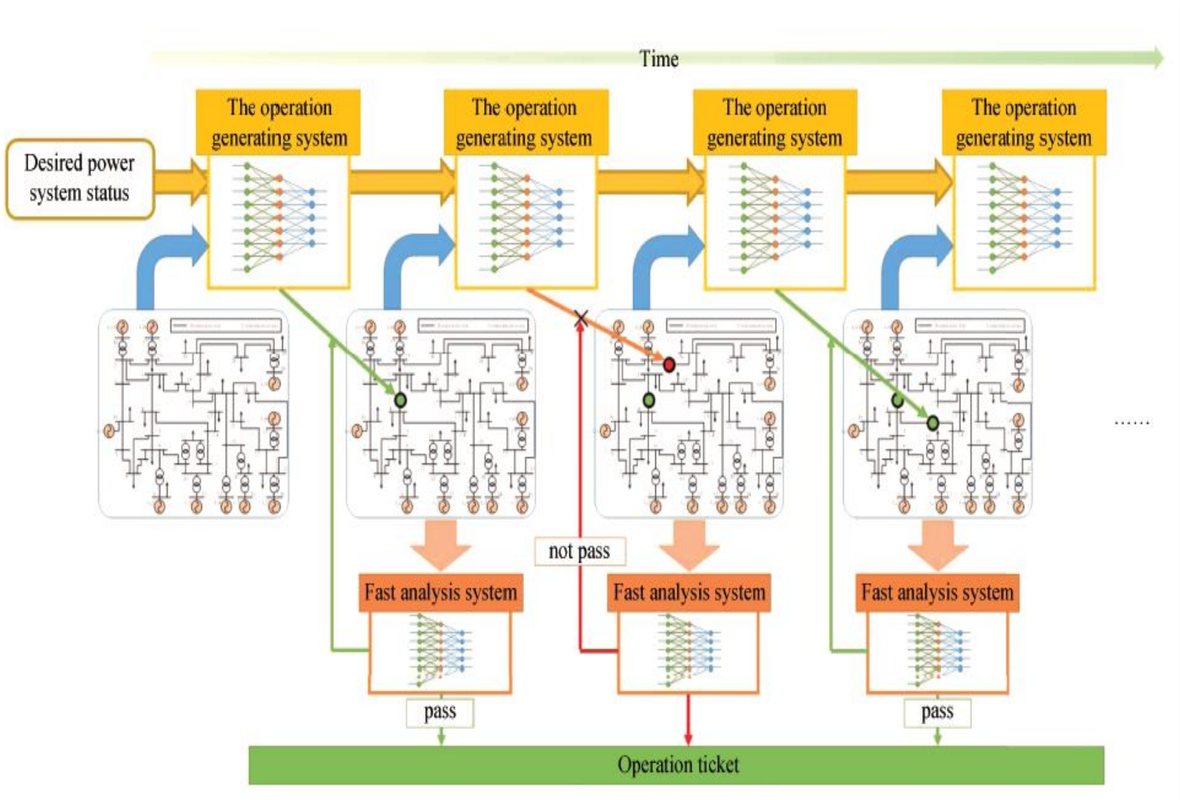

Fig. 3.4: The framework of the intelligent power system analysis system.

Since the machine learning methods involve randomness in the training, it is hard to make the output of the neural network to strictly follow the fixed sequences. But, according to the safety rules of power system operations, some operations should be done in a certain order. For example, when a line is reconnected, according to the rule base, the switches on the two sides of the circuit breaker must be connected first, then the circuit breaker is connected. So, to strictly follow the order of some operations, a fixed operation sequence can be modeled as a single operation in the system, e.g. the operation sequence disconnect circuit breaker-disconnect switches can be grouped into one operation break the line. So, in the neural network, this operation sequence is simply considered as a single operation to reconnect the line. Similarly, other fixed operation sequences can also be modeled as individual operations by the rule base. This method can help the system to avoid the basic mistakes when compiling operation tickets.

In the training of the neural network, the historical operation tickets can be used to train the neural network. However, historical operation tickets are sparse data, which means that any two operation tickets in the dataset are very different so that the patterns are hard to be extracted from the data. Thus, the operator training simulator (OTS) can be used to generate a large amount of training data for the neural network.

After the operation ticket is generated from the operation ticket generating system, the operation ticket is input into the operation checking and simulation system for verification.The system mainly includes two parts: the rule checking and operation simulation. The rule checking is to check the operation ticket with the rule base. The system will search and correct the basic errors in the operation ticket according to the safety rules. Then, the operation simulation part is to simulate and analyze the operations in the operation ticket, so that the stability and safety of the power system can be guaranteed. The operation simulation part is based on the intelligent power system analysis system.

The operations on the operation tickets are input into the intelligent power system analysis system to analyze the stability of the power system. If the stability indices of the power system do not meet the requirement under the operations, it means that the operation ticket does not pass the test, and the system will call the operation ticket generating system to generate a new operation ticket. If the operation ticket passes the simulation, it will be output to the operators for manual checking. This step makes the entire system into a HITL system.

After the manual checking, if the operator finds errors on the operation ticket, the operator can revise the operation ticket manually or call the operation ticket generating system to compile a new operation ticket. In the first case, the modified operation ticket will be checked by the operation checking and simulation system again to prevent the errors and evaluate the influence on the power system. This process keeps repeating until there is no error on the operation ticket. If the operation ticket passes the manual checking, the operation ticket can be output to operate the power system.

Conclusion

This paper discussed the demands and potential applications of AI in power systems based on field study in Tianjin power system control center in China. Based on the deep learning technique, the paper proposed the framework of the smart operating robot for power systems. The system includes two subsystems, the intelligent power system analysis system and the smart operation ticket compiling system. The intelligent power system analysis system is a better power system analysis tool than the current DSA system. The operators can have better understanding about the power system with the intelligent power system analysis system. So, in theory, the operators can make better decisions and thus the stability of the power system can be improved, especially during incidents. The smart operation ticket compiling system can help the operators to compile the operation ticket more efficiently and effectively, and thus the human error can be prevented. Since the major purpose of this paper is to discuss the demands of smart operating robot based on the field study in Tianjin power system control center and provide the overall framework of the smart operating robot according to the demands, the detailed discussions of each part of the system and simulation cases will be given in future papers.

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