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Analyzing the research subjects and hot topics of power system reliability through the Web of Science from 1991 to 2015

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ABSTRACT

Electric energy is an important ingredient for the development of industrial and it also makes our lives comfortable. The electric energy from conventional generation system is mainly obtained by conversion from fossil fuels, nuclear and other non-renewable energy. In the last few decades, due to the environmental pollution and energy exhaustion, more and more researchers began to study the renewable energy (wind power, solar energy, biomass energy, etc.) generation system. However, the random features of the new energy generation system may cause system easily failure. Thus related researchers emphasize on the renewable generation system's reliability and stability problem. The aim of this paper is mainly to explore the research contents of major countries, institutions and authors in the power system reliability research based on the Web of Science dataset and related software. And this paper further studies the collaboration network and cooperative contents among them. In addition, using the analysis of the cited frequency is to find the highly influential countries, institutions and authors. Author keywords frequency analysis and co-occurrence analysis are applied to explore the current hot topics, and predict future development direction. This study provides a useful perspective for the related researchers to undertake power system reliability research in future.

1. Introduction

The system reliability is usually defined as the probability that it will adequately achieve specified purpose for a specified period of time under specified environmental conditions [1]. With the development of mathematical statistics, the reliability engineering emerged from 1940s and the reliability theory began to apply in the military industry. After the nuclear submarine bombing event in 1965, the problem of system reliability received wide attention [2]. In 1960s, electrical faults and other system instability problems frequently occurred in many countries such as USA, Japan, Western Europe and so on. Since then, some researchers have begun to emphasize the power system reliability. For example, in 1978, National Electric Reliability Council (NERC) in USA was found to guarantee abundant and stable power supply for users; in 1981, China's Water Conservancy & Hydropower corps issued *Guidelines for safety and stability of power systems* which aims to avoid large-scale power outages and insufficient power supply.

It is well known that power system consists of three parts: generation system, transmission system and distribution system. Generation system can be divided into two categories: conventional electricity generation system such as fossil fuels power plants, and renewable energy generation system. The renewable energy generation system is usually defined as “system using the clean energy to generate electricity”. The clean energy usually refers to some renewable energy excluding the fossil energy and nuclear fission energy, for example solar energy, wind energy, biomass and other renewable energies. Because using fossil fuels can cause serious pollution problems, added by the shortage of coal, oil and other conventional energies, the development of renewable energy is attracting more and more attention in the electrical system. Thus people began to apply renewable energy to generation system due to its renewable, inexhaustible [3] and pollution-free nature [4]. In future, renewable energy will become a good substitute for conventional energy and the main generation source in the power generation system.

In 2009, America government carried out the “America Clean Energy and Security Act” which aimed at reducing the greenhouse emission meanwhile stimulating economic growing [5]. The main content in the bill is to reassess and redesign the electricity infrastructure so as to increase the proportion of renewable energy in generation system. At the same time, China pointed out that the ratio between renewable energy generation and the total generation shall get to 47.08% in 2012 [6]. Until 2015, the investment in clean energy infrastructure has reached 111 billion dollars according to the China financial sector report. This investment accounts for 33.6% of the world's

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total investment. And China government will continue to support the development of new energy sources. Compared with the conventional generation system, the biggest advantage of renewable generation system is the poor stability and reliability. With growing size along with economic and environmental pressures, more and more researchers are busy in coping up with the menace of the systems' instability and insecurity. At the beginning, Hegazy applied the Monte Carlo simulation method to assess precisely the power distribution network's reliability [7]. After that Li in 2012 proposed a multi-state model to assess a distributed generation system's reliability [8,9]. Except analyzing the distribution generation system's reliability, there are some researchers who study the hybrid energy system [10], wind energy [11] and solar energy [12].

Generating stations and a distribution system are connected through transmission lines, which also connect one power system (grid, area) to another [13]. The main aim of composite generation and transmission system is to supply enough power to every major load point [14]. In the transmission system, electrical fault is mostly caused by short circuit phenomenon or other severe disturbance events. Therefore, the reliability metrics in this system are mainly probability of failures, expected load curtailed (ELC), expected duration of load curtailment (EDLC). The function of distribution system mainly links the bulk power source to the consumer's facilities [15]. Thus the indices to evaluate distribution system reliability are used by customer average interruption frequency index (CAIFI), customer average interruption duration index (CAIDI), system average interruption frequency index (SAIFI), system average interruption duration index (SAIDI) etc. Only if the generation system, transmission system and distribution system are all in the working states, the whole power system will work normally. Therefore, studying simultaneously the three systems reliability is an important way to improve the whole power system reliability.

This paper is firstly based on Web of Science dataset and related software to explore which countries, institutions and authors are studying the power system reliability, and who are their cooperation partners, and what are their cooperative contents. Secondly, the keywords frequency analysis and co-occurrence analysis are applied to explore the current hot topics, so we can predict future development directions. This result has indicated that researchers pay more and more attention on the renewable and sustainable energy development in the generation system. The general goal behind this research is to support the development of renewable energy and emerging technologies, thus this research provides a new pathway for developing power system reliability. This paper is divided into four parts: The first section gives the general introduction on the power system and reliability concepts; the Section 2 mainly describes the basic search strategy and methodology to obtain precisely dataset; Then the Section 3 analyzes the collected data at the national level, the institution level and personal level by the publication amounts, cooperative rate and cited frequency; The final section concludes this research and discusses future research direction.

2. Search strategy and data flow analysis

The theme of the paper is the power system reliability and we can divide it into two parts. One is power system, the other is reliability research. Through reading the review articles and visiting experts, we capture four categories core vocabularies. The more detail information can be seen in Table 1. Because the power system is composed of generation system, composite generation and transmission, distribution system, we classify power system into three main categories. Except the conventional power generation system, generation system consists of the renewable energy generation system which is mainly comprised of Solar energy generation system, Wind energy generation system, Geothermal energy generation system, Biomass energy generation system and Marine energy generation system etc. Due to the differences in expression of these systems, we expand these core lexical queried to several subgroup according to the above categories. For example, the solar generation systems are composed of solar thermal electric power generation system, solar PV electric power generation system and so on. And the detailed expression can be seen in the search formula below the Table 1.

According to the research topic, we mainly deal with the following three issues:

- Which countries, institutions and authors are studying the power system reliability? And who are their cooperation partners?
- What issues are they mainly discussing? What are the current hot topics?
- What is the future development direction on the power system reliability?

These issues will play an important role in the development of power system reliability. At the same time, it will provide better research directions for related researchers, helping them look for better cooperation partners. A key question is when to begin this research. First, we start our research in 1990, which is when big electrical faults have frequently occurred in USA [16]. Power system instability problem began to bring about more attention from related researchers. Second, due to shorted-energy and polluted-environment problem, energy structure for generation system changed considerably, and power reforms, restructuring has been put forward since 1990. It further indicates that 1990 is an important historical time. The last but the most important, the annual number of publication before 1991 is fewer than after 1991, and the publication amounts per year rapidly increases from 1991. The total publication amounts during the period of 1965–1990 are 148 papers, which are nearly equal to the sum of publication amounts of the three years from 1991 to 1993. Therefore, we conducted a retrieval of publications related to power system reliability from the Web of Science during the period of 1991–2015. The retrieval time is in September 2016. The database we adopted consists of:

- Science Citation Index Expanded (SCI-EXPANDED)
- Social Sciences Citation Index (SSCI)
- Conference Proceedings Citation Index – Science (CPCI-S)
- Conference Proceedings Citation Index - Social Science & Humanities (CPCI-SSH)
- Current Chemical Reactions (CCR-EXPANDED)
- Index Chemicus (IC)

In order to analyze the contents what institutions and individuals put emphasize on, the CiteSpace [17] and Gephi are used to carry out the cooperation network analysis. At the same time, we can also analyze the future research direction by keywords co-occurrence network analysis. The main steps are divided into the following five steps:

Step 1: Collect data from the Web of Science according to search query below the Table 1. Then export the research result and save it as text format that can be identified by CiteSpace.
Step 2: Clean data. First, merge synonyms such as energy and power that express the same meaning. Second, discard meaningless word such as conjunction words and meaningless noun words.
Step 3: Import the research results into CiteSpace software.
Step 4: Select the research content that needed to be analyzed, time period, and pruning method in the software.
Step 5: Visualize the result and analyze the graph.

After determining the search formula and databases, we can obtain 5960 records which related to our research topics and export the information: author, title, publishing sources, references, keywords and abstract. At the same time, we save it as text format. Among the 5960 papers, 44% papers relate to the generation system reliability while 34% papers study the distribution system reliability, which

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