OPTIMAL OPERATION OF VIRTUAL POWER PLANT MODEL IN DATONG AREA

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A thesis submitted in fulfilment of the
requirements for the award of the degree of
Master of Engineering (Electrical)

Faculty of Electrical Engineering
Universiti Teknologi Malaysia

JANUARY 2018

To My Beloved Family

ACKNOWLEDGEMENTS

Throughout my graduate study, I am indebted to the enthusiasm of many people. First of all, the successful completion of this paper could not be possible without the careful guidance of my supervisor. She influenced me with her rich professional knowledge, pioneering and innovative spirit, steadfast rigorous academic attitude.

I also like to extend my heartfelt thanks to my family for their continued support and encouragement. I will work hard in the future, and repay their kindness with the greatest enthusiasm and outstanding achievements. I also like to thank all my relatives and friends who helped me in my pursuit of master study.

ABSTRACT

Wind energy is a type of clean energy technology that has been developed rapidly in recent years. Wind power integration with existing grid will bring many problems such as deterioration of power quality, system security and system stability. In order to solve the problems of wind power integration, a virtual power plant model is used to integrate a wind farm into the power grid. On the basis of summarizing the current research situation of the virtual power plant operation, this thesis puts forward the idea that the environmental benefit is one of the optimization objective of the virtual power plant operation. A small scale simulation grid including wind farm, pumped storage power station, thermal power plant, system load and control system is constructed. Through the power grid, the principle of the operation of the virtual power plant and the energy balance relationship are analyzed. The mathematical model of the virtual power plant is built with the goal of maximizing economic and environmental benefits. For verifying the model feasibility and correctness, a case study of a power plant in Datong area is used to derive the mathematical model, and the joint optimal operation condition of power generation, pumping condition and power output smoothness. In this thesis, genetic algorithm and particle swarm optimization algorithm are used to optimize the virtual power plant model. Simulation results show that the virtual power plant is capable of smoothing output power and achieve good economic benefits. The wind power benefit has risen by 56.9% through the integration of the virtual power plant system. It can also bring certain environmental benefits. The result shows that it can reduce 32.76 tonnes carbon dioxide. Virtual power is a good way to relieve the bottleneck of the difficult operation of the wind farm.

ABSTRAK

Tenaga angin merupakan sejenis teknologi tenaga bersih yang berkembang pesat pada kebelakangan ini. Integrasi janakuasa angin bentuk grid sedia ada akan menyebabkan pelbagai masalah seperti kemerosotan kualiti janakuasa, keselamatan sistem dan kestabilan sistem. Untuk menyelesaikan masalah integrasi janakuasa angin, model loji janakuasa maya digunakan untuk mengintegrasikan loji janakuasa angin ke dalam bentuk grid janakuasa. Dengan dasar merumuskan penyelidikan semasa mengenai keadaan pengoperasian loji janakuasa maya, tesis ini mengemukakan idea bahawa manfaat alam sekitar merupakan salah satu objektif optimum bagi pengoperasian loji janakuasa maya. Grid simulasi berskala kecil termasuk loji janakuasa angin, stesen janakuasa simpanan berpam, loji janakuasa haba, sistem muatan dan sistem kawalan telah dibina. Melalui grid janakuasa, hubungan antara prinsip pengoperasian loji janakuasa maya dengan keseimbangan tenaga telah dianalisis. Model matematik loji janakuasa maya dibentuk dengan matlamat untuk memaksimumkan manfaat ekonomi dan alam sekitar. Untuk mengesahkan kesauran dan ketepatan model, satu kes kajian loji janakuasa di kawasan Datong telah digunakan untuk mengenalpasti model matematik, syarat pengoperasian optimum bagi penjanakuasa, keadaan pam, dan kelancaran kuasa output. Dalam tesis ini, algoritma genetik dan algoritma pengoptimuman zarah kawanan telah digunakan untuk mengoptimumkan model loji janakuasa maya. Hasil simulasi menunjukkan bahawa loji janakuasa maya mampu menyelaraskan kuasa output janakuasa angin dan mencapai manfaat ekonomi yang baik. Manfaat tenaga angin telah dipertingkat sebanyak 56.9% melalui integrasi sistem loji janakuasa maya. Ia juga membawa manfaat alam sekitar tertentu. Keputusan menunjukkan bahawa ia boleh mengurangkan 32.76 tan karbon dioksida. Janakuasa maya merupakan cara yang baik untuk mengurangkan kesulitan bagi pengoperasian loji janakuasa angin.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS

Pm	-	Mechanical Power of Wind Turbine
J	-	Unit rotation speed
Mt	-	Water turbine torque
Mg	-	Electric generator load torque
H	-	Water turbine net water head
Ptotali	-	Total power generation during i-interval
Pwi	-	Wind power generation during i-interval
Phi	-	Pumped storage power plant generation during i-interval
Q	-	Water flow rate through water turbine
Ppi	-	Active power consumed by pump of pumped storage power plant
PDLi	-	Abandon wind power
Ei	-	Energy storage level in the reservoir during i-interval
Pwhi	-	Combined operation system grid connection power
ηp	-	Efficiency of pump units
ηh	-	Efficiency of hydro generator
X	-	Pump and water turbine rotate speed n at operating point deviation relative value.
ρ		Water density

LIST OF ABBREVIATIONS

VPP	-	Virtual Power Plant
GA	-	Genetic Algorithm
PSO	-	Particle Swarm Algorithm

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Background of Study

Energy is the material foundation for the survival of humans. Although China is among the world top in terms of its energy reserve, such as crude oil/coal/natural gas, but China has a large population, per-capita possession is much lower than the world. Average time limits to be mined for coal and other energy in China is far below the world average, the energy situation is not optimistic.

With the rapid development of economy, China has become the world's largest emitter of carbon dioxide. More than 80% of the carbon dioxide from coal fired, and more than half of the coals are used in the thermal power generation. By the end of 2006, China's thermal power installed capacity was 484.05 million kilowatts, went up 23.7% than the end of 2005. The installed capacity of thermal power plant proportion amounted to 77.8% [1]. This is expected to result in the growing lack of fuel resources and environmental pollution problems. Therefore, from the point of energy development strategy, China must seek a path towards sustainable development. The development of new renewable energy has grown up to be an inevitable trend. Wind power is the most mature new energy and its negative impact on the ecological environment is almost zero. To develop the wind power is not only can optimize the energy structure, but also to reduce carbon dioxide and other greenhouse-gas emissions, alleviate global warming.

Natural Wind energy resources are extremely rich. The world meteorological organization (WMO) estimated that the total wind power on earth is about 17,310 kW, with 10,210 kW usable wind energy is about, 20 times of the amount of available water resources. Wind energy resources are very abundant in China. Based on the measured data from more than 900 meteorological stations in China, the researchers made a complete and detailed estimate. The total amount of wind energy resources in China's 10 meters from the ground level is 3,226,000MW. Actual development capacity is 253,000MW [1]. This is only a conservative estimate of the wind- energy resources over the land. Offshore wind energy resources are more abundant. This shows that China's wind energy resources are rich. It will be an important measure in the field of energy to change the energy structure and improve the environment by using wind power.

In recent years, the level of wind power technology has been improved. China's demand for energy is growing. So the wind power market in China is developing rapidly. As shown in Figure 1.1, at the end of 2010, China's total installed wind power capacity was 31,070MW, a 76.6% increase than that of 2009. This is due to China's policy of vigorously developing clean energy [2].

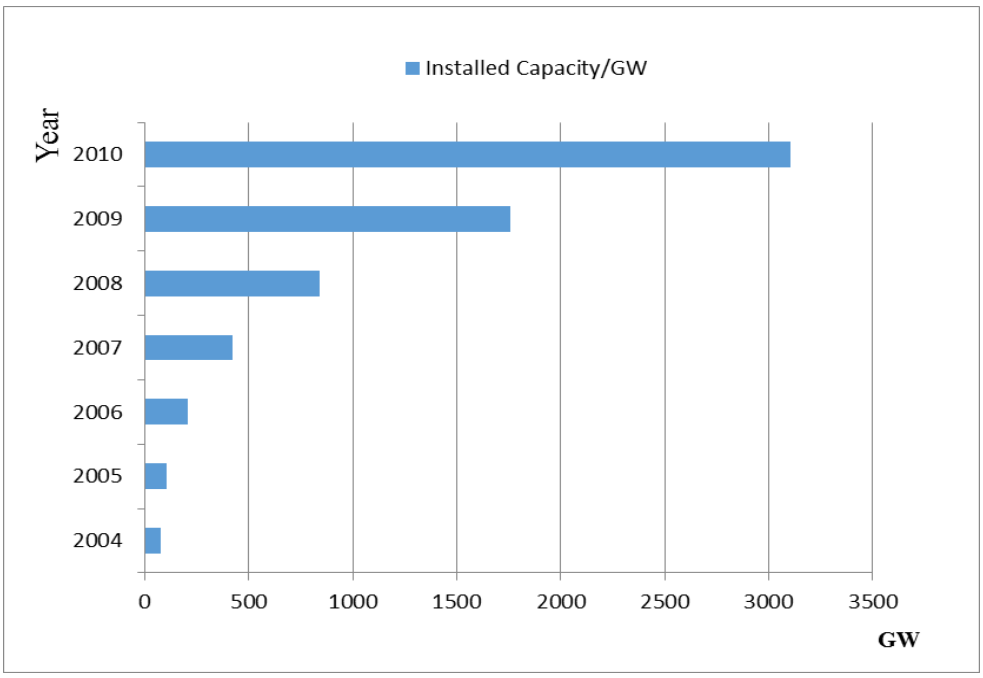

Figure 1.1 2004-2010 Schematic Diagram of Total Installed Capacity of Wind Power in China

1.2 Problem Statement

Wind energy is intermittent, seasonal and random. The characteristic of wind farm output is fluctuation. A large proportion of wind power grid connection will bring potential risks, and also increase the pressure of peak load regulation and frequency regulation of the power grid. When the induction generator is connected in the grid, it will absorb the reactive power. The grid phase modulation ability has very high demands. This limits the capacity of wind power that can be accepted by the power system [3]. The proportion of the installed capacity of wind power within the power system is rising. However the power grid cannot consume so much wind power. The contradiction between supply and demand of wind power is increasing. According to incomplete statistics, in 2011 China abandoned the wind ratio of more than 12%. Due to the abandonment of the wind, the wind power companies lose more than 5 billion yuan, accounting for about 50% below the profit level of the wind power industry [4].

In order to solve the above-mentioned problems, the main measures adopted by China are to set the thermal power unit as a backup service for wind power generation. Although this can improve the consumption of the wind power by the power grid, but will cause environmental pollution. The operation of the thermal power units needs to burn a lot of coal, that results increasing the amount of greenhouse-gas emissions. Therefore, other backup services are needed to replace the thermal power plant. Pumped storage unit is characterized by large storage capacity, fast running speed, and flexible response. These features are not available for diesel engines and gas turbines. The pumped storage power station has many advantages, such as peak and valley filling. These advantages have been fully verified in practical application. In the power grid with large-scale wind power, the corresponding capacity of pumped storage power station can be configured, the energy complementary function and the flexibility of response of pumped storage power station can be used to make up the randomness and volatility of wind power output. This is also conducive to the safe and stable operation of the entire power grid system, effectively improving the economic efficiency of the entire power grid.

The concept of the virtual power plant can be combined with the wind farm

and pumped storage power plants across the region. The virtual power plant can be regarded as various power polymer. These power supplies can be the traditional thermal power units, can also be wind power, solar power and other new energy units, but also can be a power storage device.

Datong is a heavy industrial city in the north of China. There are abundant coal resources and a large number of coal-fired power plants. Due to excessive emissions of thermal power plants, local air pollution is very serious. But at the same time the local wind resources are rich, there are a number of wind farms. Pumped storage power stations are also available in the area. So it is very suitable to select the power plant in this area.

1.3 Objectives

The objectives of this thesis are:

(i) To construct a small-scale simulation grid, including wind farm, pumped storage power station, thermal power plant, system load and control system.
(ii) To develop the mathematical model of the joint optimization operation of the virtual power plant based on the maximum economic benefit.
(iii) To simulate the proposed mathematical model and verify the feasibility of the proposed mathematical model.

1.4 Scope of Research

From the current energy situation and the necessity on the development of wind power, this thesis discusses the virtual joint operation as an effective way to solve the problems of wind power integration. Then it summarizes the research status of the joint operation of virtual power plant, and puts forward the environmental benefits as one of the optimization objectives of the virtual power plant，and the

mathematical model of the joint optimization operation of virtual power plant is established.

1.5 Research Methodology

This thesis constructed a small scale simulation power grid including wind farm, pumped storage power station, thermal power plant, power system users and control system. Then analysis the principle of optimal operation and energy balance relation of the virtual power plant. Mathematical model of optimal operation of virtual power plant was built with the goal of maximum economic benefit and environmental benefit of the virtual power plant. Genetic algorithm and PSO are used to optimize the model of a virtual power plant.

1.6 Structure of Thesis

Based on the current energy situation and the development of wind power, this thesis discusses the effective way to solve the problem of wind power integration. Virtual power plant combined operation is a choice. The research status of virtual power plant is summarized. The study sets the environmental benefit as one of the optimization objectives of the virtual power plant. The mathematical model of the joint optimization operation is established. The main research work for this thesis includes the following parts:

Chapter 1 (Introduction) presented the background, problem statement, objectives, scope and significance of this study.

Chapter 2 (Literature Review) discussed more on the other methods of previous researcher in virtual power plant.

Chapter 3 (Virtual Power Plant) introduced the concept of virtual power plant.

Chapter 4 (Methodology) constructed a small scale simulation grid including

wind farm, pumped storage power station, thermal power plant, system load and control system. Then analysis the principle of optimal operation and energy balance relation of the virtual power plant.

Chapter 5 (Results and Discussions) simulated and analyzed the example in order to verify the correctness of the mathematical model of the optimization operation of the virtual power plant.

Chapter 6 (Conclusions and Recommendations) concluded all the inquiry and recommendations and direction was given to future research.

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