AVAILABLE TRANSFER CAPABILITY BASED ON RANDOMLY GENERATED PROBABILISTIC DISTRIBUTION FUNCTION OF WIND SPEED USING MONTE CARLO SIMULATION

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Dedicated to

My beloved parents and family for their boundless support and encouragement

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ABSTRACT

Recent trend has focused on the importance of renewable energy resources in the electrical energy production system. Although a number of appealing advantages are expected, a large penetration of generation from renewable energy resources may cause some undesirable impact on system security and reliability due to the uncertainty of their generation output. One of the problems is the fluctuation character of wind energy where the output of wind power generation system is unpredictable due to the intermittent of wind speed. However, the probability of a particular wind speed occurring can be estimated. These can cause the output of a wind power plant is neither continuous nor controllable. Power system analysis should be able to cope with the influences resulting from the presence of this generation scheme. In this thesis, the influences of the integration of the renewable energy into power system via determination of Available Transfer Capability (ATC) are investigated. To calculate ATC incorporating wind generation, a power flow algorithm based on Newton-Raphson technique is used. The output of wind generation is determined by Monte Carlo Simulations (MCS). The limits considered in this work are bus voltage limit and line thermal limit. Meanwhile the power output of a Wind Turbine Generation (WTG) is obtained using the relationship between the power output and the wind speed. To model wind speed, common wind speed is used in terms of the mean and standard deviation of the wind speed. The proposed method has been applied on 5-bus system and IEEE 30-bus system. The result shows the improvement of ATC value due to inclusion of wind energy into the power system. For 5-bus system, the improvement of ATC value is about 0.28-2.56%, while for IEEE 30-bus system the improvement is about 10-23.53%. The ATC value will increase based on the variation of power output of wind energy. Meanwhile, WTG will contribute to the increase of ATC based on the available wind profile to compliment the contribution of ATC from conventional generation.

ABSTRAK

Menjadi kebiasaan pada masa kini untuk memberi tumpuan kepada kepentingan sumber tenaga diperbaharui dalam sistem pengeluaran tenaga elektrik. Walaupun ia mempunyai beberapa kelebihan, penembusan besar penjanaan daripada sumber tenaga diperbaharui boleh menyebabkan beberapa kesan yang tidak diingini terhadap sistem keselamatan dan kebolehpercayaan kerana ketidaktentuan pengeluaran penjanaannya. Salah satu masalah adalah sifat tidak menentu tenaga angin di mana pengeluaran sistem penjanaan kuasa angin tidak dapat diduga disebabkan kelajuan angin yang terputus-putus. Walau bagaimanapun, kebarangkalian kelajuan angin untuk tempoh yang tertentu boleh dianggarkan. Hal ini menyebabkan pengeluaran loji kuasa angin adalah tidak berterusan dan tidak dikawal. Analisis sistem kuasa yang dilakukan hendaklah dapat mengatasi kesan yang terhasil daripada kehadiran skim penjanaan ini. Dalam tesis ini, pengaruh integrasi tenaga diperbaharui ke dalam sistem kuasa melalui penentuan Keupayaan Pindahan Tersedia (ATC) dikaji. Untuk mengira ATC dengan penjanaan angin, algoritma aliran kuasa berdasarkan teknik Newton-Raphson telah digunakan. Keluaran penjanaan angin ditentukan oleh *Monte Carlo Simulations* (MCS). Had yang diambilkira dalam kajian ini adalah had voltan bas dan garisan had haba. Sementara itu, keluaran kuasa penjana turbin angin (WTG) diperolehi dengan menggunakan hubungan antara keluaran kuasa dan kelajuan angin. Untuk mencipta kelajuan angin, model angin biasa digunakan dalam segi nilai kelajuan min dan sisihan piawai. Kaedah yang dicadangkan ini telah diuji pada sistem 5-bas dan sistem IEEE 30-bas. Hasil kajian menunjukkan peningkatan nilai ATC disebabkan oleh kemasukan tenaga angin ke dalam sistem kuasa. Untuk sistem 5-bas, peningkatan nilai ATC adalah kira-kira 0.28-2.56%, manakala bagi sistem IEEE 30-bas peningkatan kira-kira 10-23.53%. Nilai ATC akan meningkat berdasarkan perubahan keluaran kuasa tenaga angin. Sementara itu, WTG akan menyumbang kepada peningkatan ATC berdasarkan profil angin yang ada selaras dengan sumbangan ATC daripada penjana konvensional.

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LIST OF ABBREVIATIONS

US	-	United State
ATC	-	Available Transfer Capability
FERC	-	Federal Energy Regulatory Commission
OASIS	-	Open Access Same Time Information Network
MW	-	Mega Watt
IPP	-	Independent Power Producer
ISO	-	Independent System Operator
AC	-	Alternating Current
IEEE	-	Institute of Electrical and Electronic Engineering
NERC	-	North American Electric Reliability Council
TTC	-	Total Transfer Capability
TRM	-	Transmission Reliability Margin
ETC	-	Existing Transmission Commitments
CBM	-	Capacity Benefit Margin
DC	-	Direct Current
PROCOSE	-	Probabilistic Composite System Evaluation
CPU	-	Central Processing Unit
PTDF	-	Power Transfer Distribution Factor
DCPTDF	-	Direct Current Power Transfer Distribution Factor
ACPTDF	-	Alternating Current Power Transfer Distribution Factor
LODF	-	Line Outage Distribution Factor

CPF	-	Continuation Power Flow
OPF	-	Optimal Power Flow
ANN	-	Artificial Neural Network
WTGS	-	Wind Turbine Generator System
SCIG	-	Squirrel Cage Induction Generator
DFIG	-	Double Feed Induction Generator
WFSG	-	Wound Filed Synchronous Generator
PMSG	-	Permanent Magnet Synchronous Generator
PQ	-	Power Quality
RX	-	Resistance Reactance
PX	-	Power Reactance
MCS	-	Monte Carlo Simulation
ELCC	-	Effective Load Carrying Capability
GCE	-	Generation Capacity Equivalence
MVAr	-	Mega Volt Ampere Reactive
WTG	-	Wind Turbine Generation
P-V Bus	-	Generator Bus or Voltage-Controlled Bus
P-Q Bus	-	Load Bus
GHz	-	Giga Hertz
MB	-	Mega Byte
MVA	-	Mega Volt Ampere
WF	-	Wind Farm
WT	-	Wind Turbine
WS	-	Wind Speed

LIST OF SYMBOLS

%	-	Percentage
V	-	Speed
P_{wind} , P_W	-	Power generated by wind turbine
C_p	-	Power coefficient
ρ	-	Air density
A	-	Rotor swept area
u	-	Wind speed
V_{ci}	-	Cut-in speed
V_{co}	-	Cut-out speed
μ	-	Mean wind speed
σ	-	Standard deviation
Q_W	-	Reactive power of wind energy
P_R	-	Rated power
V_R	-	Rated speed

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CHAPTER I

INTRODUCTION

1.1 Introduction

Renewable energy resources boast promising potentials for future use, and it has become a recent trend among electric power utility providers to integrate these resources into their energy production system. Renewable energy comes from natural resources such as sunlight, wind, rain, tides and geothermal heat, which are naturally replenished. Renewable energy is derived from natural processes, either directly or indirectly from the sun or from heat generated deep within the earth. These sources are expected to be able of supplying energy to humanity for almost another one billion years. It produces little to no pollution or greenhouse gases, and they will never run out. Besides that, renewable energy sources have promising potentials in the future of electricity production due to its sustainability, and it being environmental-friendly, apart from a source of low cost energy.

These advantages have attracted both researchers and scientists from various countries such as Europe, United States (US), Japan, India, and China to focus their studies on this field. It is reported that US is targeting to increase their renewable energy resources to more than 55 % as their additional generation capacity [1]. With the prominent trend of integrating renewable energy into the energy production systems around the world, the Malaysian government has also shown a keen interest on the potential of renewable energy [2]. In 9th Malaysian Plan (2006-2010), the Government of Malaysia also increased the fund for research and development (R&D) of renewable energy research [3]. It has been reported that by Renewable Energy Policy Network (REN2007), the potential of wind energy in Malaysia has increased by 28 %. The research from Universiti Kebangsaan Malaysia (UKM) at 2005 shows that Weibull distribution is the fit distribution for the wind speed data at Terumbu Layang-Layang, Sabah [4]. Meanwhile, in 2007 two wind turbine was installed at Pulau Perhentian, Terengganu and it shows that 50 % of the electricity required at Pulau Perhentian can be fulfil by these wind turbines [5].

The most common types of renewable energy currently in practice are wind, hydropower, solar, hydrogen fuel cells, biomass and geothermal. Among all these available sources, wind power is generally considered as one of the most viable alternative energy resources [6]. The wind energy is an inexhaustible natural resource as well as a truly indigenous energy resource. As such, wind power has been receiving considerable attention as one of the most promising source of renewable energy.

Countries such as the United States, Spain, Denmark and India utilize the wind to produce electricity in their country. According to Blanco and Rodrigues [7], wind energy already covers 3% of electricity demand in Europe, 23 % in Denmark and approximately 8% in Spain and Germany respectively. By 2050, wind energy is expected to provide half of Europe’s power [8]. There is also a research on the potential of wind energy in Malaysia, and it has been concluded that wind energy is the most suitable energy source to be applied and the wind energy system has great potential to be developed in Malaysia [5].

Wind energy’s cost of production is relatively lower compared to solar energy [9]. The installation of wind farm does not require excessively large area as the land area within a wind farm is still available for development. Also, it has very little impacts on the environment [9]. To generate electricity, the operation of wind energy does not pollute the atmosphere and is considered a clean energy because there are no greenhouse gas emissions.

Despite the many advantages of renewable energy, it also has its disadvantages where it is considered as an unstable, unreliable, expensive source of energy. Naturally, any kind of energy resource is bound to have its own pros and cons. As such, one of the problems with wind energy is its intermittent characteristic. It is universally known that wind energy is highly dependent on wind speed but unfortunately, the wind does not always blow in a constant manner. If the wind speed is too low, wind turbine will not be able to produce electricity. On the other hand, if the speed is too strong, the wind turbine will shutdown to prevent damage. Besides that, it also depends on the location of the wind farm. Some regions have low probability of wind speed which renders wind harvest as a source of energy useless.

In a deregulated power system, the computation of Available Transfer Capability (ATC) is important to ensure the reliability and security of the system. The Federal Energy Regulatory Commission (FERC) requires that the information of ATC be made publicly available through Open Access Same Time Information Network (OASIS) [10-12]. This information will help power marketers, sellers and buyers in reserving transmission services. Furthermore, these participants can plan their strategies in securing access to transmission network. Source bus is also called seller, who is a generation company that sells the generated power, while sink bus or the buyer is a distribution company who purchases power generated.

1.2 Available Transfer Capability in Deregulated Power System

ATC in a transmission network is quantified by the allowable highest magnitude of power (MW) that can be transferred from the source to the sink over and above the already committed uses (base case) of the network as a whole without violating any constraints related to the transmission network security. These constraints are transmission elements' thermal limits for power flow and bus voltage limits when the system remains in steady state [13]. By considering these limits, one can also include aspects of security assessment in the analysis of the state of any given power system. Meanwhile, United States FERC has defined ATC as the amount of transfer capacity that is available at a given time for purchase or sale in the electric power market under various system conditions [14].

ATC has become an important indication for all market participants in electrical power such Independent Power Producers (IPPs), retailer, distributor and customer. IPPs are private companies that participate in the generation sector and they sell electricity to the utilities. Besides that, ATC computation also determines the reliability of the system in unsecured situations. It becomes a significant index to indicate the amount of further usable transmission capacity for commercial trading.

The Independent System Operator (ISO) may receive every energy demand from utility in the interconnected power system. All of these demands may be accepted if they are less than the ATC between two areas. ATC must also be calculated by ISO in real time for all the areas under its territory. Deregulation is significant to keep the transmission network secure and ISO needs to encourage the participant market such buyer and the seller and honour the viable transactions. For this objective, ISO determines an index on the unutilised transmission capacity which is ATC. Thus, ATC intimation by ISO is an important issue in deregulated power market.

1.3 Problem Statement

Many researchers have extensively explored the ATC. Nowadays, researchers have shown interest in addressing renewable energy into ATC calculation in power system. As mentioned before, wind energy is the most dynamic in the world because it is the most viable alternative energy. Although renewable energy has many advantages, but it is also have disadvantages for example, its generation may cause some problem and complications due to the uncertainty of their generation output.

There have been attempts to include renewable energy sources in ATC determination but many of them proved to have some drawbacks. X. Tong *et al.* [15], attempted to assess transfer capability with wind energy. However, it appears that this attempt had setbacks of impairment of ATC after the addition of wind energy into the system. Meanwhile, Quoqing *et al.* [16] and N. Paensuwan [17] did not taken uncertain nature of wind energy into consideration in ATC calculation. Since the power produced by wind energy strongly depends out on fluctuated wind speed, so the issue of uncertainty of the generation output from wind energy resources integrated into the calculation of ATC also need to be addressed by the proposed method.

In this thesis, the effects of integrating wind energy into power system on the security aspects of the system via determination of ATC are to be investigated. Besides that, the power system analysis should be able to cope with and examine the influences resulting from the presence of this sector. The issue of fluctuation of wind energy or the uncertainty of generation output of wind energy integrated into the calculation of ATC also need to be addressed.

1.4 Objectives of the Research

The objectives of the research are:

1. Construct a Wind Turbine Generation (WTG) model to represent fluctuation in wind energy for power system analysis.
2. Develop ATC determination of a power system with the peresent wind energy based on AC power flow method.

1.5 Scope of the Research

The scopes of the research are listed below:

i. The bus-to-bus power transfer based ATC will be determined by considering the steady-state limit, namely the line thermal and a bus bar voltage limit of transmission line.

ii. The ATC determination is based on bus-to-bus transaction, while area-to-area transactions are not considered.

iii. The uncertainty of wind energy will be considered by using Monte Carlo Simulation technique.

iv. The wind energy model is based on typical power output model. The converter and control point of the wind system are not considered.

1.6 Contributions of the Research

The contribution of this thesis can be summarized as follows:

i. Methodology to evaluate the power output of wind energy at multistate level using Monte Carlo simulation.
ii. Comprehensive evaluation of ATC with integration of wind energy at different penetration level using power flow method.
iii. Evaluations of the factors need to consider in the ATC calculation with integration of wind energy.

1.7 Thesis Organization

This thesis is divided into five chapters. Brief descriptions of each chapter are as follows:

Chapter 2 discusses the basic concepts of ATC and wind energy system. Besides that, this chapter also reviews the methodology in determination of ATC with and without wind energy previously done in prior work.

Chapter 3 details the methodology that has been applied in calculation of ATC incorporating wind energy by using AC power flow analysis. This section also explains the process to obtain wind energy power output based on Monte Carlo Simulations.

Chapter 4 presents results and discussions of the proposed method. The comparisons between ATC before and after adding wind energy are also discussed. Furthermore, the impacts of wind energy implementation into the system on ATC are also described in this chapter.

Chapter 5 concludes the thesis by providing conclusions of this research and several recommendations for future improvement of the work.

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