RISK LEVELS ASSOCIATED WITH WIND GENERATION PENETRATION USING MONTE CARLO SIMULATIONS

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Dedicated to

My beloved and supportive parents,

Mohd Usman Bohari and Zuraida Bt Robert Sanawi,

My dearest brothers and sisters.

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ABSTRACT

An adequate installed capacity in generation system is an important criterion to know the reliability of power system in supplying the demand. The introduction of renewable resources of different types such as wind, solar, wave and tidal energy, has increased the generation capacity. However, these renewable resources are intermittent in nature which can significantly disrupt system reliability. This research is focusing on evaluating how intermittent wind generation contributes to the generation system reliability. By using the reliability indices, the performance of new generation capacities can be decided. Traditionally, a method called Capacity Outage Probability Table (COPT), probabilistic-based, was used to determine risk associated with generating units in a power system. But, by using the COPT method, system operator is unable to get a meaningful interpretation, since the loss of load probability (LOLP) is a tiny probability number. The objective of this research is to develop a new risk-based assessment method by using Monte Carlo simulation to quantify the risk amount in MWs. Value at Risk (VaR) is a method, used in finance as a risk measurement tool, which can summarize the expected maximum loss (or worst loss) over a target horizon within a given confidence level. Thus, in this thesis, an evaluation using the VaR is developed and presented extensively for the first time in the context of power system reliability assessment. A Wind Turbine Generation (WTG) model is constructed. A multi-state model is developed for modelling wind generation due to the randomness of wind speed. Probability models describing uncertainties in system generation and projected load demand are first constructed. By using Monte Carlo Simulation (MCS), Loss of Load Probability (LOLP) has been calculated by applying the proposed study on two practical test systems; RBTS (6 bus) and IEEE RTS (24 bus). LOLP is further used to quantify the exact amount of lost load and the Expected Demand Not Supplied (EDNS) due to contemplated uncertainties. The effect of WTG penetration is discussed in the case studies such as variable penetration, increasing load demand, number of multistate WTG, carbon emission and different wind distribution. The analysis shows that the capacity credit of a WTG is not equivalent to the conventional generator. An exact capacity of conventional generator need to be replaced with multiple WTGs unit in order to have same reliability. Besides, high penetration of WTGs in a power system shows a great risk for the system load to be unsupplied. On top of that, from the environmental point of view, tons of CO_2 emissions can be avoided if conventional generation is replaced by WTGs. The study also shows that the evaluated VaR produces close results as compared with the EDNS in the same case studies. The benefit of using the VaR is that the system risk is simply reflected in a single quantity in MW. The proposed approach can be a great tool for power system operators in decision making concerning uncertainties arising in the generation side of the system.

ABSTRAK

Kapasiti yang dipasang dan mencukupi dalam sistem generasi adalah satu kriteria penting untuk mengetahui kebolehpercayaan sistem kuasa untuk membekalkan permintaan. Penggunaan sumber yang boleh diperbaharui pelbagai jenis seperti angin, solar, gelombang dan tenaga pasang surut, telah meningkatkan kapasiti generasi. Walau bagaimanapun, sumber-sumber boleh diperbaharui adalah berubah-ubah sifatnya yang boleh mengganggu kebolehpercayaan sistem. Kajian ini memberi tumpuan terutamanya kepada penilaian bagaimana generasi angin yang terputus-putus memberi kesan kepada kebolehpercayaan sistem generasi. Dengan menggunakan indeks kebolehpercayaan, prestasi kapasiti penjanaan baru boleh ditentukan. Secara tradisinya, kaedah yang dipanggil Kapasiti Gangguan Kebarangkalian Jadual (COPT), berasaskan kebarangkalian, telah diguna untuk menentukan risiko yang berkaitan dengan unit penjanaan dalam sistem kuasa. Tetapi, dengan menggunakan kaedah COPT, pengendali sistem tidak boleh mendapatkan tafsiran yang bermakna, dimana Kebarangkalian Kehilangan Beban (LOLP) ialah nilai kebarangkalian yang kecil. Objektif kajian ini adalah untuk membangunkan satu kaedah penilaian baru berasaskan risiko dengan menggunakan simulasi Monte Carlo untuk menentukan kuantiti risiko dalam unit MW. Nilai-pada-Risiko (VaR) adalah satu kaedah yang diguna dalam kewangan sebagai alat penentu risiko, yang boleh merumuskan kerugian maksimum yang dijangka (atau kerugian paling teruk) untuk tempoh tertentu dalam tahap keyakinan yang diberikan. Oleh itu, di dalam tesis ini, penilaian menggunakan VaR dibangunkan dan dibentangkan dengan meluas untuk kali pertama dalam konteks penilaian kebolehpercayaan sistem kuasa. Generasi Turbin Angin (WTG) model dibina. Model berbilang peringkat dibangunkan bagi model generasi angin kerana kelajuan angin yang rambang. Model kebarangkalian menggambarkan ketidaktentuan dalam generasi sistem dan unjuran permintaan beban mula-mula dibina. Dengan menggunakan Simulasi Monte Carlo (MCS), Kebarangkalian Kehilangan Beban (LOLP) telah dikira dengan melaksanakan kajian yang dicadangkan ke atas kedua-dua sistem ujian praktikal; RBTS (6 bus) dan IEEE RTS (24 bus). LOLP turut digunakan untuk menilai jumlah sebenar beban hilang dan Permintaan Dijangka Tidak Dibekalkan (EDNS) berikutan ketidaktentuan yang dipertimbangkan. Kesan penembusan WTG dibincangkan dalam kajian kes seperti kepelbagaian penembusan, peningkatan permintaan beban, jumlah berbilang peringkat WTG, pelepasan karbon dan taburan angin yang berbeza. Analisis menunjukkan bahawa kredit kapasiti WTG adalah tidak sama dengan penjana konvensional. Kapasiti sebenar penjana konvensional perlu diganti dengan berbilang unit WTG untuk mempunyai kebolehpercayaan yang sama. Selain itu, penembusan tinggi WTG dalam sistem tenaga menunjukkan risiko yang besar untuk sistem beban tidak akan dibekalkan. Selain itu, dari sudut pandangan alam sekitar, beberapa tan pelepasan CO_2 boleh dielakkan jika generasi konvensional diganti dengan WTG. Kajian ini juga menunjukkan bahawa penilaian VaR menghasilkan keputusan yang hampir sama dengan EDNS di dalam kajian kes yang sama. Manfaat menggunakan VaR ialah risiko sistem ini hanya dilihat dalam kuantiti tunggal dalam unit MW. Pendekatan yang dicadangkan boleh menjadi alat yang hebat untuk pengendali sistem kuasa dalam membuat pemilihan hasil ketidaktentuan yang timbul dalam sistem generasi.

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LIST OF SYMBOLS

c	-	Scale parameter
k	-	Shape parameter
Vco	-	Cut-off wind speed
Vr	-	Rated wind speed
Vci	-	Cut-in wind speed
Vm	-	Wind speed
L	-	Load system
G	-	Generation system
MW	-	Mega watt
μ	-	Repair rate
λ	-	Unit failure

LIST OF ABBREVIATIONS

WTG	-	Wind turbine generator
CGU	-	Conventional generating unit
LOLP	-	Loss of load probability
EDNS	-	Expected demand not served
VaR	-	Value at risk
CVaR	-	Conditional Value at risk
ARMA	-	Auto regressive and moving average
CO_2	-	Carbon dioxide
RBTS	-	Roy Billinton test system
IEEE RTS	-	IEEE Reliability test system
MCS	-	Monte Carlo simulations
COPT	-	Capacity outage probability table
LPT	-	Load probability table
NWP	-	Numerical weather prediction
IEA	-	International energy agency
FOR	-	Forced outage rate
MTTR	-	Mean time to repair
MTTF	-	Mean time to failure
VBA	-	Visual Basic for application

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CHAPTER 1

INTRODUCTION

1.1 Introduction

Nowadays, the industry mostly uses fossil fuel-based technologies to improve our quality of life, but at the same time, these advancements have come at a very high price. The depletion of these sources might cause insufficient energy sources in future to cover the demand needed, since these sources are non-renewable. The future is certainly not set in stone, but by just depending on the world reserve of energy resources, and if the energy usage today is maintained at the current rate, there is a possibility that oil will run out in 40 years, natural gas reserves will be depleted in less than 60 years, and coal reserves will be exhausted in 200 years [1].

On the other hand, fossil fuel also is a major cause of environmental pollution and degradation; since it has irreversibly destroyed aspects of our environment. This is because, fossil fuelled technologies have the largest carbon footprints, as they need to burn these fuels during operation. Due to that, carbon dioxide in the atmosphere has substantially increased; thus worsening the greenhouse gas effect. In fact, this environmental problem is also a matter of concern in power system industry, since electricity generation is a major contributing factor to air pollution, as it releases a massive amount of carbon dioxide (CO_2) into the atmosphere [1-4].

Moreover, according to the International Energy Agency (IEA), the forecast electricity demand for an average annual growth rate is 2.5% which at this rate, during 2030, the electricity demand will double with today's amount [1]. Indeed, from the scenario above, it can be concluded that our energy sources are incapable of supporting electricity demand in future, and even, if energy resources are enough it will increase the pollution; if fossil fuels are continuously consumed at the same current rate.

Owing to this emerging environmental problem, a solution needs to be done to preserve the environment. Since, fossil-fuel based energy resources are non-renewable, the usage of these sources should be reduced, which will consequently reduce the carbon released into the atmosphere. Since the need for environmentally friendly methods of transportation and stationary power is urgent, green and renewable energy sources are introduced to reduce reliance on fossil fuels as well as to maintain a sustainable growth and a cleaner environment. Among the renewable and sustainable energy sources, wind energy is one of the alternatives chosen [1].

Wind energy as one of our most abundant resources, is the fastest growing renewable energy technology worldwide [5, 6]. It comes as the second highest resource after hydroelectric power. Despite possessing a great potential for future energy generation, wind generation is not fully dispatchable. The generated output power from a wind turbine generator (WTG) is fluctuating since it is dependent on wind speed characteristics. These procreated fluctuations could seriously challenge the system's capability to serve committed load demand to the full extent. Hence, in order to attach WTGs to the grid system, the current power system will possibly encounter much higher levels of risk.

Risk from the association with WTG output actually increases the uncertainties in the power system. Fluctuating WTG power output can cause generation deficiency, making the system incapable of supplying its load demand. Since the primary function of an electric power system is to provide electrical energy to its customers as economically as possible and with an acceptable degree of continuity and quality, the intermittency of WTGs should be monitored and managed properly with a better reliability assessment through risk-based approaches.

Random failures in equipment and the system have constrained the modern society's expectation to get continuous supply of electrical energy on demand. Electricity supply generally involves a very complex and highly integrated system. Due to that, risk based assessment must be applied to help identify the reliability of power system which include probabilistic and deterministic assessment into calculation.

The context of this study will cover system reliability evaluation using a risk based approach; considering conventional and wind generation (intermittent generation). Besides, the effect of intermittent wind generation on system reliability will be investigated in this research. As wind shows a great potential among other renewable technologies, it is expected that wind power will play a key role to achieve 2010/2020 targets for high penetration of renewable generation in grid system according to [7, 8]. This adds to the importance of the current study.

1.2 Problem Statement

Smart grid fosters the development of a high performance, low investment, safe, reliable, and flexible power systems [9]. Smart grid is the structure needed to integrate renewable enrgy (WTG) into grid system. It encompasses elements such as renewables, storage, consumer options, and smart appliances. Smart grid will establish a two-way communications between the grid and consumers; thus turning the latter into the so-called "prosumers" or active consumers. The prosumers means the customer who can actively participate as part of the demand response tool of the smart grid. The introduction of consumer participation will enable wider choice for consumers, better utilization of resources, and increased efficiency. Nonetheless, it will add to the uncertainties in the system. On the other hand, renewable energy is a clean power generation alternative which offers attractive advantages of environment friendliness and sustainability. However, due to the intermittency of renewable energy resources, its output is unpredictable and its impact on the rest of the system is not well understood. In other words, the smart grid is bringing new opportunities in terms of communications, utilization and control but has inherent challenges of increased uncertainties in the system. In this thesis, the scope of work is focused on system uncertainties via risk assessment.

The risk consorted with uncertainties arising in system generation, due to wind energy contribution, can be approached either through deterministic or probabilistic techniques [10]. The deterministic assessment is carried out via analysing a predefined set of outages and enforcing a threshold criterion of acceptable risk on system variables. However, deterministic analysis could lead to an over-investment, since it prioritizes the severe consequence of outages (less occurring) and ignores the less severe but frequently occurring ones [11]. Therefore, probabilistic assessment is preferable for risk analysis in the presence of wind power [3, 11, 12].

Probabilistic assessment is not a new evaluation in power system, it has been used successfully in off-line reliability calculations of power system planning but failed to attract attention in industry. Deterministic methods have served the power system industry for so many years. However, due to increasing uncertainties in the system, this elementary evaluation is no longer appropriate to be applied in the modern power system that is becoming more complex by the day.

The value of energy trades can change over time as market conditions and the underlying price variables change. Due of that, Value-at-Risk (VaR) method is a concept imported from financial engineering to evaluate the risk. The method calculates the losses within a specific time interval and a defined confidence level in actual currency. The simplicity and objectivity of VaR insinuates the application of this method to power system risk assessment.

1.3 Importance of study

This study aims to analyse the capacity contribution of wind and the impact that it has on system reliability. Besides, the VaR assessment is a new tool proposed introduced in this study, which makes it easier for the system operator to make decisions. Indeed, the proposed method is capable of helping system operator to clearly interpret risks in power system. In addition, the introduced assessment is more flexible in making the decision with variable confidence levels. It is hoped that the methodology and tools developed can be useful for future studies in operational reliability for capacity expansion using intermittent renewable generation.

On the other hand, there are also various benefits from the implementation of WTGs in grid system. These benefit can be best described by categorizing them into three aspects; technical, economic and environmental. The technical benefits include a wide range of advantages, for instance, the efficiency of the power system can be improved through addition of generation capacity with renewable energy where it increases the reserve capacity [13]. Increase additional capacity increased the system reserve capacity which in term improve the overall power system capacity. The economic benefits cover reduction of fossil fuel cost, saving in electricity cost, and decreased health care costs as a result of environmental quality improvement. Environmental benefits include reductions in greenhouse gases (SO_2, NO_x, and CO_2)

emission, decrease in sound pollution, and preservation of resources for future use [14].

1.4 Aims and objectives of the thesis

The main objective of this research is to develop a risk based assessment method using Monte Carlo simulation which can quantify risk amount in MWs for measuring reliability in power system with attached wind turbine generation. It is carried out by employing the value-at-risk (VaR) method as the main proposed method in this research. The VaR method is an already well known risk calculator in portfolio analysis and in financial sector; however, the practicality of this method in power system will be introduced in this thesis. The specific objectives of this thesis are:

i. Develop the concept of Value at Risk (VaR) as a new measure of system reliability.
ii. Construct a wind turbine generation (WTG) model to represent the characteristics of renewable energy.
iii. Evaluate the power system reliability using the developed VaR method under the smart grid environment (WTG attached).
iv. Compare and verify the efficacy of VaR with capacity outage probability table (COPT) approach.

1.5 Research scopes

This thesis focuses on the technical and environmental aspects, which include identifying the risk level determined from the failure to meet the load amount and greenhouse gasses emission reduction. These aspects can be achieved by using suitable risk assessment tools that can inform the operational operator in their operation test system. This study develops the risk assessment tool which is imported from financial engineering named VaR. The evaluated VaR value represents the total failure to meet the load (losses). Consequently, a methodology of Monte Carlo simulation (MCS) is chosen to work out the proposed assessment.

The research scopes are divided into two main parts. Each part is conducted with different simulation approach. In the first part, the deterministic and probabilistic assessment is used, while the proposed Value at Risk (VaR) method is applied in the second part. The main reason to simulate both of these methods is to verify the results later. COPT is also the standard utility practice for generation reliability assessment. In other words, the first part of the study is set as a benchmark for the second part.

Besides, in this research, a comprehensive risk-based assessment methodology is highlighted. Risk evaluation of power system should not only recognize the likelihood of failure events, but also severity and degree of their consequences. The expected demand not supplied (EDNS) via loss-of-load-probability (LOLP) by using Monte-Carlo simulation is one of the risk-based indices used in this research. However, LOLP index is a probabilistic assessment which quantify only the likelihood. Both indices can work together to accomplish the risk definition.

On the other hand, the proposed VaR method is widely known risk quantification in finance. This method is simpler and does not have much of computational burden as compared to COPT method. COPT is able to measure EDNS and LOLP indices. COPT is a type of deterministic assessment. In this research, the risk results calculated using VaR are validated against the results using COPT method. The results obtained using proposed VaR method is validated against the result using this COPT method by implementing both of them on the same test system.

The proposed risk-assessment techniques in this thesis are applied to the Roy-Billinton Test System (RBTS) and IEEE Reliability Test System (RTS 97). In this work, there are two uncertainties taken into account; generation and load. However, other components in the power system are considered reliable such as transmission and distribution. Only generation and load system were taken into consideration. In this thesis, wind generation was introduced into the system to study the risk of fluctuating power on the power grid. As explained in the introduction, the application of renewable energy offers environmental friendly, sustainable and cheaper generation by reducing the contribution of conventional generation using gas or fuel.

1.6 Organization of the thesis

This thesis comprises six chapters. Chapter 1 gives an introduction about the project. The introduction contains of project background, problem statement, objective, scope and also overview of the project.

In Chapter 2, the background on reliability assessment of generation system with load and description of various reliability indices used by utilities are discussed. Different assessment methods are introduced with their advantages and disadvantages highlighted. Risk-based assessment techniques are selected due to its merits. The wind turbine generation (WTG) is used in the case studies to describe the wind generators simulation and the wind speed model.

Chapter 3 provides a description of the methodology and common assumptions used in this thesis. The concepts using Monte Carlo simulation is used in this study as the main structure for all the simulations used. There are two methods; (1) power system reliability assessment using COPT and VaR methods and (2) the simulation of WTG generated power from wind speed modelling.

In Chapter 4, the process of simulating reliability assessment using COPT method is described. This chapter will cover the computer model developed using MS Excel and Matlab to calculate reliability indices; Loss of Load Probability (LOLP) and Expected Demand Not Served (EDNS) using Capacity Outage Probability Table (COPT). Besides, conventional generation system data are used in order to develop the COPT. The case study also includes the WTG penetration level in the test system and a multiple WTG state structure is constructed in order to combine WTGs with conventional generation. The RBTS and IEEE RTS test system are used in this chapter, and the results obtained are compared with its counterparts in the literature.

Chapter 5 presents several case studies from Chapter 4. The difference is these cases applied the VaR method for the generation reliability assessment. Interestingly, VaR is able to withstand various WTG penetration levels in a much simpler way as compared to the COPT method. The results from both COPT method and VaR method are compared.

Chapter 6 gives a discussion and interpretation of results obtained and the contribution that this thesis has provided towards the reliability assessment of power system. Besides, this last chapter, will conclude the whole thesis, reviewing the objectives and what this thesis has achieved. Further recommendation in this field as well as possible further work that can, and should, be carried out are listed.

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