OPTIMAL RESERVE REQUIREMENTS FOR INTEGRATING INTERMITTENT WIND ENERGY RESOURCES

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This thesis is dedicated to my late father and my beloved mother.

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ABSTRACT

Limitations of conventional power generation reserves and environmental restrictions have encouraged the adoption of natural renewable energy resources to be implemented for electricity generation. However, the problem of renewable energy is the uncertainty associated with its integration to the power grid due to its variable output. The emergence of wind power as an electrical power generation resource has developed great benefits with diminution in emissions and the render of zero cost fuel. Beside all this, it also has brought many challenges for the operation of power systems due to the increased variability and uncertainty. To account for such intermittent characteristics, operating reserves should be managed to balance out generation deficiency in a timely manner.

The objective of this project was to estimate the optimal level of operating reserves for any power system that is having an integrated intermittent Wind energy as a source for electric generation. By using mathematical models, operating reserves were optimized on the basis of different forecasted wind conditions.

The Mathematical model was designed and tested on the IEEE-30 Bus system. For optimization, a scheduled 24 hours system load and a wind curve was used. Firstly pre-determined generation cost for each hour was calculated without optimization on the basis of base case study. Later cost of optimized generation was calculated and compared with previous case. The designed model was successful in achieving the optimised results and justifies its existence to help in future power planning. Such optimization was done by using General Algebraic Modelling System (GAMS) simulator while graphical results were presented by using Matlab.

ABSTRAK

Batasan terhadap rizab penjanan kuasa konvensional dan sekatan alam sekitar menggalakkan penggunaan sumber tenaga asli yang boleh diperbaharui untuk dilaksanakan dalam penjanaan elektrik. Walau bagaimanapun, masalah ketidaktentuan tenaga yang boleh diperbaharui pengenalan dengan integrasi ke grid kuasa adalah disebabkan oleh keluaran yang berubah-ubah. Pengenalan kuasa angin sebagai sumber penjanaan kuasa elektrik telah memberi manfaat yang besar dalam pengurangan pelepasan dan memberi kos bahan api sifar. Selain itu, ia juga telah memberi banyak cabaran di dalam operasi sistem kuasa disebabkan oleh kebolehubahan dan ketidaktentuan yang meningkat. Untuk menampung kelemahan ini, operasi rizab patut diuruskan bagi mengimbangi kekurangan generasi suyapa tepat pada masanya.

Objektif projek ini adalah untuk menganggarkan tahap optimum operasi rizab untuk sistem apa-apa kuasa pelbagai yang mempunyai tenaga Angin bersepadu yang terhad sebagai sumber penjanaan elektrik. Dengan menggunakan model matematik, Operasi rizab dioptimumkan berdasarkan ramalan keadaan angin yang berbeza.

Model Matematik direka dan diuji pada sistem IEEE-30 Bus. Bagi engoptimuman, 24 jam sistem beban dijadualkan dan lengkung angin digunakan. Pertama telah ditetapkan terlebih dahulu generasi kos bagi setiap jam dikira tanpa pengoptimuman berdasarkan kajian kes asas. Kemudian kos generasi dioptimumkan adalah dikira dan dibandingkan dengan kes yang sebelumnya. Model yang direka telah berjaya dalam mencapai keputusan yang optimum dan mewajarkan kewujudannya untuk membantu dalam perancangan kuasa pada masa hadapan.. Semua pemodelan dilakukan dengan menggunakan alat simulasi yang bernama *General Algebraic Modelling System* (GAMS), manakala hasil grafik telah dibentangkan dengan menggunakan Matlab.

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LIST OF ABBREVIATIONS

AGC - Automatic Generation Control

CPU - Central Processing Unit

EENS - Expected Energy Not Served

GAMS - General Algebraic Modelling System

GO - General Optimising

GRG - Generalization of Reduced Gradient

IEEE - Institute of Electrical and Electronics Engineering

ISO - Independent System Operator

LOLP - Loss of Load Probability

NERC - North American Reliability Corporation

OPF - Optimal Power Flow

PSO - Particle Swarm Optimization

RG - Reduced Gradient

RR - Regulating Reserve

RTS - Reliability Test System

SR - Spinning Reserve

CHAPTER 1

INTRODUCTION

1.1 Background

Clean energy acts as a great part in protecting the environment in addition to derogate the emissions that crusade global warming [1]. It preserves nonrenewable forms of energy, abridges environmental damage caused by exploration and extraction of fossil fuels, and denigrates exposure of people and wildlife to large energy production plants. Among all renewable energies, Wind energy is gaining a raising grandness throughout the world. Its zero-cost fuel and emissions-free turnout provides a capital benefits to consumers and society [1][2]. It is comparatively a new resource and is heightening at such a rapid rate that the utilities and system operators are becoming implicated about the integration issues and the integration costs that it bestows. Wind power integration studies have been performed by numerous researchers to understand and quantify these impacts. Studies are made for such power systems to cope with the variability of demand and generation on the system through reserves. Reserves are operated for various purposes across multiple timescales [3]. The impact of wind integration on reserve requirements is a current area of interest for integration studies and power system operators.

1.2 Integration of wind power into grid

At the beginning of modern industrialization, the use of the fluctuating wind energy resource was substituted by fossil fuel fired engines or the electrical grid, which provided a more consistent power source. But now with the development of new engineering technologies and demand of time has made Wind as an ideal source for electricity generation. Developing countries in the west have already installed many wind farms that provide a large fraction of their overall electric demand [4]. A global cumulative wind installed capacity till 2010 is plotted in Fig.1.1.

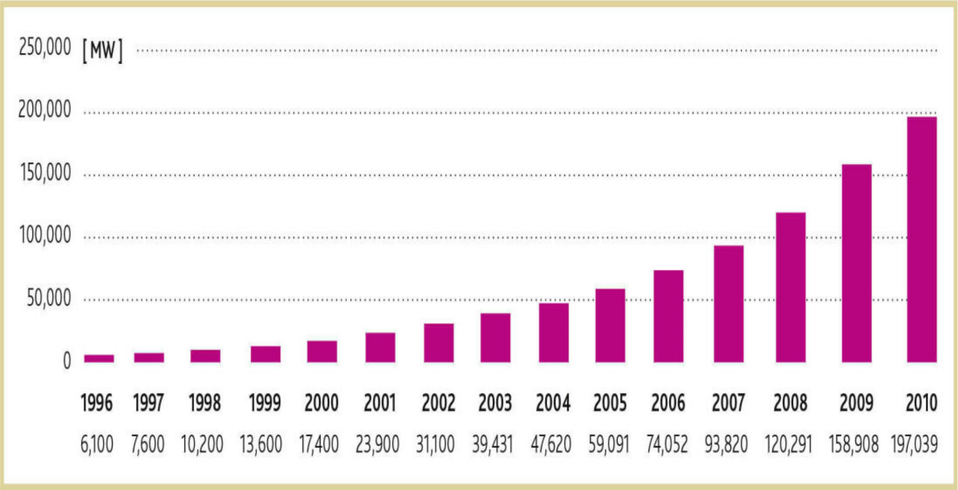

Figure 1.1 Global cumulative wind installed capacity 1996-2010

Integration of wind power in large electrical power systems is primarily the subject of theoretical studies, as actual wind power penetration levels are still modest. Integrating wind power into existing conventional power systems means taking into account the time varying patterns of wind power production while scheduling the generation and reserve units in the power system [5]. The integration of significant penetration levels of wind power is not only possible but also often does not require a major redesign of the existing power system. However, in this context it is important to point out the areas with very high penetration levels. From a technical perspective, power system engineers have to keep in mind that the main aim of a power system is to supply network costumers with electricity whenever the customers have a demand for it. Now, if wind power is to be introduced into the power systems, the main aim of the power system must still be fulfilled. The challenge that wind power introduces into power system design and operation is related to the fluctuating nature of wind.

1.3 Operating reserves

In electricity networks, the operating reserve is the generating capacity available to the system operator within a short interval of time to meet demand in case a generator goes down or there is another disruption to the supply [6]. The term operating reserves is defined as the real power capability that can be given or taken in operating timeframe to assist in generation and load balance and frequency control. Systems also require reactive power reserve as well to provide voltage support and require certain targets for installed capacity that is often referred to as planning reserve [1]. Spinning Reserve is the on-line reserve capacity that is synchronized to the grid system and ready to meet electric demand within 10 minutes of a dispatch instruction by the Independent System operator (ISO) [7]. Spinning Reserve is needed to maintain system frequency stability during emergency operating conditions and unforeseen load swings. In other side Non-Spinning Reserve is an off-line generation capacity that can be ramped to capacity and synchronized to the grid within 10 minutes of a dispatch. It is capable of maintaining that output for at least two hours.[7]

The types of operating reserves can be differentiated by the type of event they respond to [8], the timescale of the response and the direction (upward or downward) of the response. The first characterization of a reserve is the type of event it is responding to. Some forms of operating reserve are kept for continuous needs (non events). Other operating reserves can be used to respond to either contingency events or longer timescale events. Contingencies are instantaneous failures such as the loss of a generator or failure of a transmission line. Longer timescale events include net load ramps and forecast errors that occur over a longer amount of time [9]. In addition to the type of event, reserves can be categorized by the response time required and the physical capabilities needed of the responding participant. For instance, some reserves are required to be generating at part load to provide spinning reserve, others require automatic generation control (AGC), and still others require portions of their reserve to be directly responsive to frequency deviations. According to North American Reliability Corporation (NERC)[10] the difference between spinning and non-spinning reserves is that spinning reserves must be synchronized to the system while non-spinning reserves are not necessarily synchronized. Deployed of such reserves is shown in Fig.1.2.

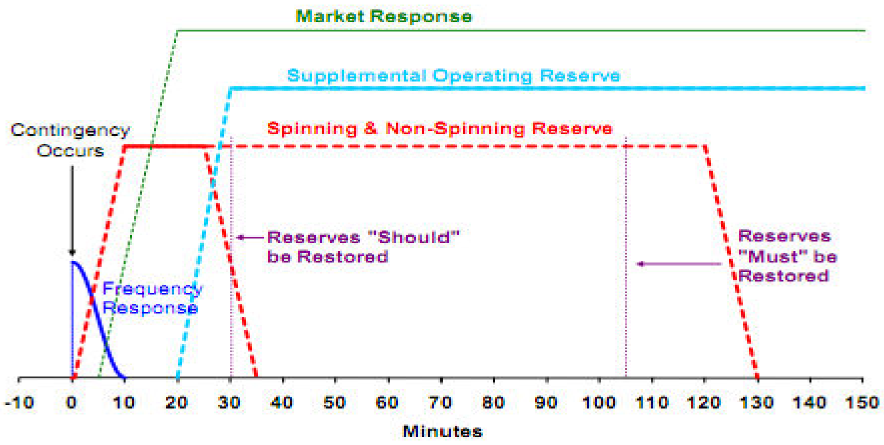

Figure 1.2 Reserves deployment as defined by NERC

Spinning reserves respond quickly as they are already synchronized to the system. AGC is a capability whereby a centralized party (system operator) sends controls directly to the resource on the desired output. Frequency responsive capabilities include governor systems that automatically adjust input when frequency deviations are sensed. Reserves may also be categorized by whether more or less supply is needed [11]. Such categorization of operating reserves is shown in Fig.1.3. Upward response is required when there is less generation than load and can be attained by additional generating power or a reduction in participating loads. Downward response is required when there is more generation than load and can be attained by a reduction in generating power or an increase in participating loads. Most power systems are designed so that, under normal conditions, the operating reserve is always at least the capacity of the largest generator plus a fraction of the peak load [11]. It is very important to have additional reserves to meet any violating condition that can cause and security and reliability issue.

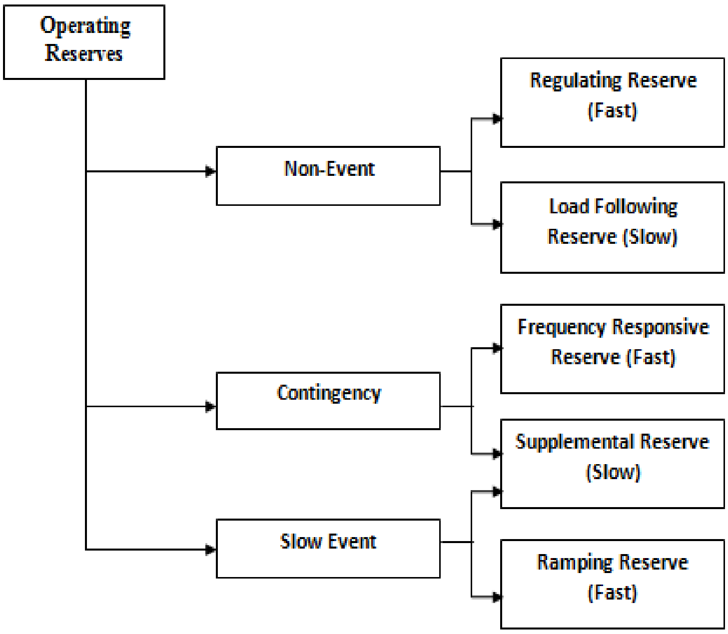

Figure 1.3 Types of operating reserves

1.4 Operating reserves and impact of wind

Operating reserve is essential in system operation & control [1][12]. Whenever a frequency incident occurs, one major function of the operating reserve is to provide adequate generation to support the network load and loss, and restore the frequency back to the nominal level. Because the response of the operating reserve could deeply influence the frequency restoration following the contingency, utilities are always interested in methodologies of allocating effective power sources for operating reserve to ensure system security. If there is a sudden disturbance in balance between production and consumption in the power system, such as the loss of a power plant or a large load, primary reserves known as regulating reserves are used to deal with this problem. The primary reserve consists of active and reactive power supplied to the system. Figure 1.4 shows the activation of reserves and frequency of the system as a function of time, for a situation where a large power plant is disconnected from the power system.

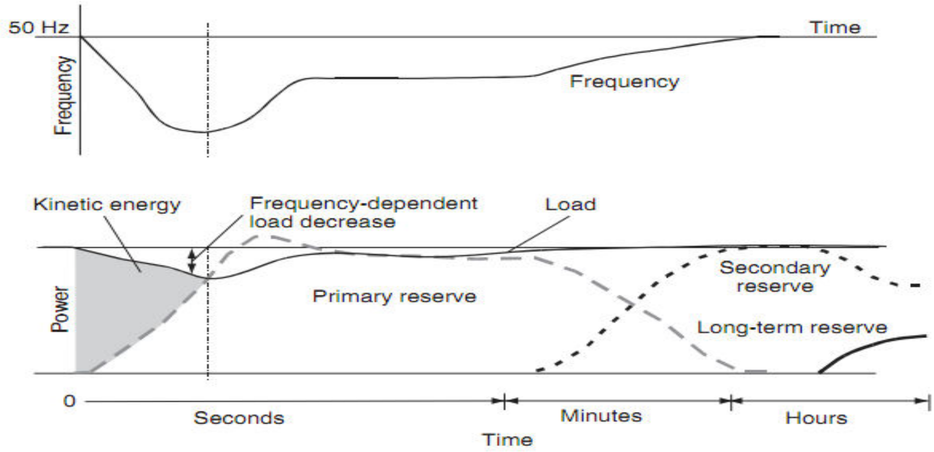

Figure 1.4 Activation of power reserves and frequency of power system as a function of time

The activation time divides the reserves into primary reserve, secondary reserve (also called fast reserve) and long-term reserve (also called slow reserve or tertiary reserve). Primary reserve is the production capacity that is automatically activated within 30 seconds from a sudden change in frequency. It consists of active and reactive power in power plants, on one hand, and loads that can be shed in the industry, on the other hand. Usually, the amount of reserve in a system is defined according to the largest power plant of the system that can be lost in a single fault. The secondary reserve is active or reactive power capacity activated in 10 to 15 minutes after the frequency has deviated from the nominal frequency. It replaces the primary reserve and it will be in operation until long-term reserves replace it. The secondary reserve consists mostly of rapidly starting gas turbine power plants, hydro pump storage plants and load shedding. Every country in an interconnected power system should have a secondary reserve. It corresponds to the amount of disconnected power during the dimensioning fault usually loss of the largest power unit in the country involved. In order to provide sufficient secondary power reserve, system operators may take load-forecast errors into account. In this case, the total amount of the secondary reserve may reach a value corresponding to about 1.5 times the largest power unit.

The impact of wind power on the power system depends on the size and inherent flexibility of the power system. It is also related to the penetration level of wind power in the power system. When studying the impact of wind power on power systems, we refer to an area that is larger than only one wind farm. According to the impact that is analyzed, we have to look at the power system area that is relevant. For voltage management, only areas near wind power plants should be taken into account. Even though there should be enough reactive power reserve in the system during disturbances, the reserve should mainly be managed locally.

Today for any power system operator, it is a challenge to estimate the optimal operating reserves to avoid any additional cost for electricity generation. Now when we are moving to integrate the intermittent energies like wind into our grids, then to find out basic operating reserves is a key to overcome any issue regarding to unexpected load demand as well price marketing. For minimal operational investments, the operating reserve requirement is computed periodically using different statistical methods. The traditional approach to determine reserve requirements is being used by practical experience through periodic load analysis. But if we are integrating wind energy into our Grids, then it is much necessary to optimize the additional reserves so that along with covering all load demand we can reduce the additional investment cost.

1.5 Project objective

The goal of this project is to:

I. Design a mathematical model to optimize the reserves required for any wind integrated power system by using the mathematical probabilistic simulation tool GAMS.
II. Tested the model on IEEE-30 bus system
III. Dispatched the wind at different buses and comparison of results
IV. Perform the optimization for each hour for a 24-hour load profile.

1.6 Scope of project

The electric grid requires that supply and demand must always be in balance, so it’s a challenge for operator to cover up supply when there is no wind. Available generation capacity in the system contains the difference between generation and consumption. Adequate spinning reserve is one of the main parameters to maintain the security of the power system operation. Calculating such margin for power system with the existence of wind energy is the focus of this project.

This project covers following topics:

I. Operating Reserves and their importance in power system
II. Regulating Reserves Margin
III. Impact of wind power integration on the grid
IV. Optimization of Generation
V. Load flow models
VI. Nonlinear Programming
VII. IEEE-30 Bus System

1.7 Problem statement

Integration of wind power in large electrical power systems is primarily the subject of theoretical studies, as actual wind power penetration levels are still modest. Integrating wind power into existing conventional power systems means taking into account the time varying patterns of wind power production while scheduling the generation and reserve units in the power system. The traditional approach to determine reserve requirements is carried out by practical experience through periodic load analysis. However if we are integrating wind energy into grids, then it is necessary to optimize the additional reserves so that along with covering all load demand, we can reduce the additional investment cost.

1.8 Organization of thesis

The project work consists of total five (05) chapters.

Chapter 2 illustrates the previous work done related to optimization techniques for calculating different types of operating reserves. It also covers topics related to the integration of wind and its variability effects on power systems. Optimization of generation is based on different constraints including power mismatch and line flows also. For such purpose a brief overview of power load flows and their applications are highlighted. Dealing with multivariable objects is always complex when calculating their actual values. A nonlinear programming approach is explained.

Chapter 3 describes the methodology used in the project simulation. It explains the step-by-step derivation of the mathematical model. Fundamental equations of DC load flow are also explained. It consists of all steps required for accomplishing the simulation. 'GAMS' is simulation software used for optimizing the mathematical models of very large and complex systems. An overview of this software is also included. Later the methodology algorithm chart is shown.

Chapter 4 presents the results of simulation done on IEEE-30 bus system. Wind is dispatched at different buses. Optimized cost of each bus is calculated on hourly basis, and a comprehensive summary of possible profitable margin for all buses is given.

Lastly chapter 5 describes the conclusion and future work related to this project.

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