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FINANCIAL ENGINEERING FOR

ENERGY SYSTEM CAPITAL BUDGETING

by

CHIN-CHUEN TEOH

A dissertation submitted in partial fulfillment of the
requirements for the degree of

DOCTOR OF PHILOSOPHY
in
ELECTRICAL AND COMPUTER ENGINEERING

Portland State University

DISSERTATION APPROVAL

The abstract and dissertation of Chin-Chuen Teoh for the Doctor of Philosophy in Electrical and Computer Engineering were presented June 23, 2008, and accepted by the dissertation committee and the doctoral program.

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ABSTRACT

An abstract of the dissertation of Chin-Chuen Teoh for the Doctor of Philosophy in Electrical and Computer Engineering presented June 23, 2008.

Title: Financial Engineering for Energy System Capital Budgeting

The United State energy industry is experiencing a major paradigm shift. This conventional vertically integrated energy industry is gradually transformed to a competitive market environment – a deregulated energy market. The market and regulatory frameworks are expected to continue to evolve in the future. Market participants are emphasizing more on profit maximization as returns on investment are no longer guaranteed. Therefore, risk management and capital budgeting play critical roles in energy system planning. Planning always involves uncertainties. When there are uncertainties, there are risks involve. This dissertation concentrates on the application of Real Options Analysis, ROA, especially lattice method, to energy system capital budgeting.

Lattice method has one major weakness: massive bush of lattice. This dissertation proposes a method known as Binomial Lattice-Value at Risk approach to solve the curse of lattice dimensionality. Due to deregulation, market participants' incentives have changed. Generation companies, GENCOs, are no longer willing to release their cost information or strategic plans. Thus, this dissertation introduces the

implementation of Profit at Risk ideology into decision analysis, which created an efficient approach known as Binomial Lattice-Profit at Risk, BL-PaR.

With the price of fuels soaring and environmental concerns growing larger, the expansion of ROA into renewable energy sector is desirable. Renewable energy has significant advantages as it does not contribute to greenhouse gases. This research focuses on wind energy, which is uncontrollable and unpredictable. A decision based solution of incorporating wind energy with pump storage hydro, PSH, and financial contract hedging is introduced. This energy technology integration is capable of increasing the available-capability of wind energy to be as effective as thermal unit. A physical asset hedging known as the Look Ahead Optimization, LAO, method is then applied to both wind unit and PSH system. This optimization method minimizes the size of hedging and maximizes profit by obtaining the optimal energy storage. The combination of the LAO method with BL-PaR approach achieves several critical goals. Together with the inclusion of financial contract hedging via financial transmission rights, FTRs, a double-protections mechanism is established. The evaluation of FTRs portfolio using ROA enables the risk management process to run efficiently.

DEDICATIONS

I dedicate this dissertation to my wonderful family: my dear father, Chew-Hoo Teoh, my lovely mother, Hooi-Hooi Tan, my little sister, Chin-Bern Teoh, and my little brother, Chin-Chia Teoh, with my deep appreciation for their love, encouragement, support, and patience.

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I would also like to thank my committee members for their willingness, efforts, and contributions to this work: Dr. Loren Lutzenhiser, Dr. Chen-Ching Liu, Dr. Robert Dasch, Dr. and Dr. Timothy Anderson.

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GLOSSARY

AEO2007	Annual Energy Outlook 2007
AWEA	American Wind Energy Association
BL-PaR	Binomial Lattice-Profit at Risk
BL-VaR	Binomial Lattice-Value at Risk
CAPM	Capital Asset Pricing Model
DESS	Discrete Event System Simulation
DOE	US Department of Energy
EIA	Energy Information Administration
ESA	Electricity Storage Association
FTRs	Financial Transmission Rights
GENCOs	Generation Companies
GHG	Greenhouse Gases
LAO	Look Ahead Optimization Method
LMP	Locational Marginal Prices
NPV	Net Present Value Analysis
PaR	Profit at Risk
PSH	Pump Storage Hydro
PUCs	Public Utility Commissions
R&D	Research and Development
ROA	Real Options Analysis
SPCs	Strategic Planning Committees

VaR	Value at Risk
VWC	Virtual World Creation

CHAPTER 1. INTRODUCTION

1.1 Motivation

The United States energy industry has been going through major changes. The energy industry has been a monopoly for more than a century and has now been moving toward an open retail market. When the energy industry was regulated, the energy system in most of the United States was vertically integrated. In other words, one large utility owns and operates all three major aspects (generation, transmission, and distribution) of energy operations, and the utility has a guaranteed fair rate of return in exchange for an obligation to serve in a given service territory.

Due to deregulation policy, a number of state proposals mandate the dissolution of vertically integrated energy system. The utilities must dispossess one or more of the energy operations. Restructuring the energy industry is a complicated process, as delivering the energy product to the market in an efficient, reliable, and well-timed manner, involves establishing a complex set of procedures. The deregulation policy introduces uncertainties into the energy market. Under this new environment, there are two factors that play significant roles in decision analysis: managerial flexibility, and financial risks [Trigeorgis 1987, 1988, 1995, 1996], and [Teoh 2004]. As a result of uncertainties, the realization of cash flow of a utility may change anytime and can be significantly different from what is expected initially. When new information arrives, and uncertainties about the market conditions become clearer, the utility needs to reevaluate the previous decision to maximize the utility's rate of return. In other words, under uncertain market conditions, expected values such as expected profit or expected rate of return have become less meaningful without the corresponding financial risks. Therefore, in the deregulated market, there is no guarantee of a fair rate of return. Utilities seek to find the most economical and feasible way to operate their assets, as they are obliged to meet demand and maximize profit. Real Options Analysis, ROA, which applies option valuation techniques to capital budgeting decision, enables such flexibility to management. So, what is the difference between Real Options Analysis, ROA, and the traditional Net Present Value (discounted cash flow) analysis, NPV? "The traditional approach to valuing investment projects, based on NPV, essentially involves discounting the expected net cash flows for a project at a discount rate that reflects the risk of those cash flows (the risk-adjusted discount rate). In this approach, the adjustment for risk is made to the discount rate" [Schwartz 2001]. According to [Mun 2002], the traditional NPV analysis can be seen as a special case of ROA when there is negligible uncertainty. In other words, when the underlying asset's volatility approaches zero, the real options value approaches zero, and the value of the project is exactly as defined in a discounted cash flow model. Therefore, it is only when uncertainty exists, and management has the flexibility to defer making mid-course corrections until uncertainty becomes resolved through time, that a project has option value. "The traditional NPV analysis assumes a single decision pathway with fixed outcomes, and all decisions are made in the beginning without the ability to change and develop over time. The

Real Options Analysis, ROA, considers multiple decision pathways as a consequence of high uncertainty coupled with management's flexibility in choosing the optimal strategies options along the way when new information becomes available" [Mun 2002]. Using deterministic models like the discounted cash flow may potentially underestimate the value of a particular project. Deterministic discounted cash flow model assumes at the outset that all future outputs are fixed. If this is the case, then the discounted cash flow model is correctly specified as there would be no fluctuations in business conditions that would change the value of a particular project. In essence, there would be no value in flexibility. However, the actual business environment is highly fluid, and if management has the flexibility to make appropriate changes when conditions differ, then there is indeed value in flexibility, a value that will be grossly underestimated using a discounted cash flow model.

Dr. Johnathan C. Mun, the founder and CEO of Real Options Valuation, Inc., has demonstrated a simplified analogy to why optionality is important and should be considered in corporate capital investment strategies:

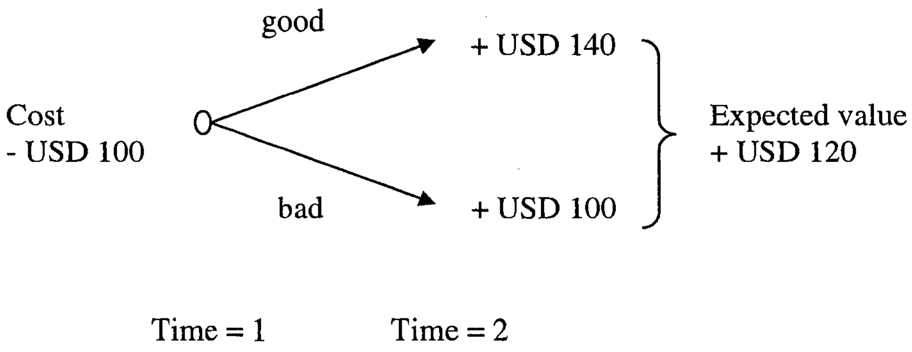
> "Suppose you have an investment strategy that costs USD 100 to initiate and you anticipate that on average, the payoff will yield USD 120 in exactly one year. Assume a 15 percent weighted average cost of capital and a 5 percent risk-free rate, both of which are annualized rates. As the example below illustrates, the net

present value of the strategy is USD 4.3, indicating a good investment potential because the benefits outweigh the costs.

$$\text{Net Present Value} = \frac{120}{(1.15)^1} - 100$$

$$= \text{USD } 4.3$$

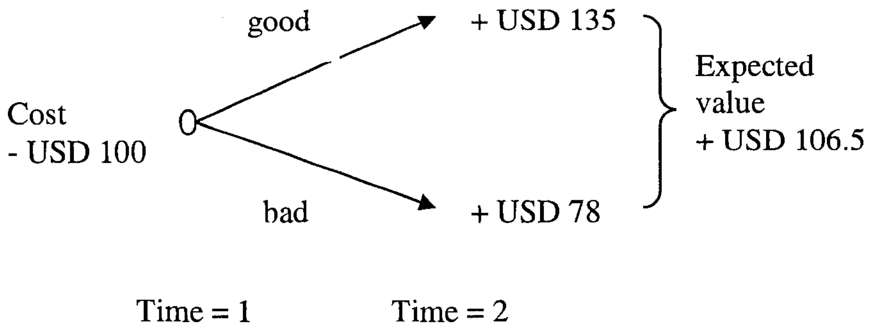
However, if we wait and see before investing, when uncertainty becomes resolved, we get the profile below, where the initial investment outlay occurs at time one and positive cash inflows are going to occur only at time two. Let us assume that your initial expectations were correct and that the average or expected value came to be USD 120 with good market demand providing a USD 140 cash flow and in the case of bad demand, only USD 100. If we had the option to wait for a year, then we could better estimate the trends in demand and we would have seen the payoff profile bifurcating into two scenarios. Should the scenario prove unfavorable, we would have the option to abandon the investment because the costs are identical to the cash inflow (- USD 100 versus + USD 100), and we would rationally not pursue this avenue. Hence, we would pursue this investment only if a good market demand is observed for the product, and our net present value for waiting an extra year will be USD 10.6. This analysis indicates a truncated downside where there is a limited liability because a rational investor would never knowingly enter a sure-loss investment strategy. Therefore, the value of flexibility is USD 6.3.



$$\text{Net Present Value} = \frac{140}{(1.15)^2} - \frac{100}{(1.05)^1}$$

$$= \text{USD } 10.6$$

However, a more realistic payoff schedule should look like the example below. By waiting a year and putting off the investment until year two, you are giving up the potential for a cash inflow now, and the leakage or opportunity cost by not investing now is the USD 5 less you could receive (USD 140 – USD 135). However, by putting off the investment, you are also defraying the cost of investing in that the cost outlay will only occur a year later. The calculated net present value in this case is USD 6.8.



$$\text{Net Present Value} = \frac{135}{(1.15)^2} - \frac{100}{(1.05)^1}$$

$$= \text{USD } 6.8$$

Therefore, there are several potential problem areas in using a traditional discounted cash flow calculation, which is based on NPV, on strategic optionalities. These problems include undervaluing an asset that currently produces little or no cash flow, the estimation of an asset's economic life, forecast errors in creating the future cash flows, and insufficient tests for plausibility of the final result. Real options, when applied using an options theoretical framework, can mitigate some of these problematic areas" [Mun 2002].

Real Options Analysis, ROA, has the capability of handling future uncertainties, while the traditional NPV approach does not have the capability of handling future uncertainties. However, ROA has its own disadvantages and limitations! This is the starting point where I embark my doctoral research journey. Fig. 1 shows the overall logical development of my research.

This dissertation provides a detailed understanding regarding the major disadvantages and limitations of ROA and presents unique solutions to solve these issues. As the deregulated energy market is increasingly competitive, as transactions are based on prices set by market forces instead of regulated rate of return, the profitability of each business decision is becoming more significant. In a competitive energy industry, profit represents everything. Any electric utility that does not produce any profit in a medium-to-long run is likely to be eliminated. Profit has become the center of attention for the deregulated energy industry. Thus, the term profit instead of loss is one of the focus points of this dissertation. As the prices of fuels rise and environmental degradation concerns grow larger, wind energy has become one of the fastest growing sources of electricity throughout the world.

This dissertation is closely related to capital budgeting. According to Wikipedia, capital budgeting is the planning process used to evaluate, select, compare, and determine whether a firm's long term investments (5-year, 10-year, or even longer time period) such as new machinery, replacement machinery, new plants, new products, and research and development projects are worth pursuing.

Basically, capital budgeting is concerned with the justification of capital expenditures. Faced with limited sources of capital, strategic planning committees, SPCs, must carefully identify and decide the projects that will contribute most to profits and consequently, to the value (or wealth) of the company.

However, nowadays, shorter term goals (3-month, 6-month, 1-year, or 2-year) have been gaining tremendously attentions due to the volatility of energy market. As mentioned earlier, any electric utility that does not produce any profit in a medium-to-long run is likely to be eliminated. Even in the financial world, every company is presenting its financial report every quarter. Therefore, the phrase "long term investment under capital budgeting" (which usually refers to 5-year, 10-year, or even longer time period) has been cut down to 3-month (quarterly), 6-month, 1-year, or even 2-year time period. For any project to run forward, the project needs to be justified economically. "Operation" determines how much a project will cost and thus enables the calculation of a company's cash flow with respect to each project. Operating budgeting determines the budget that plans a company's business activities.

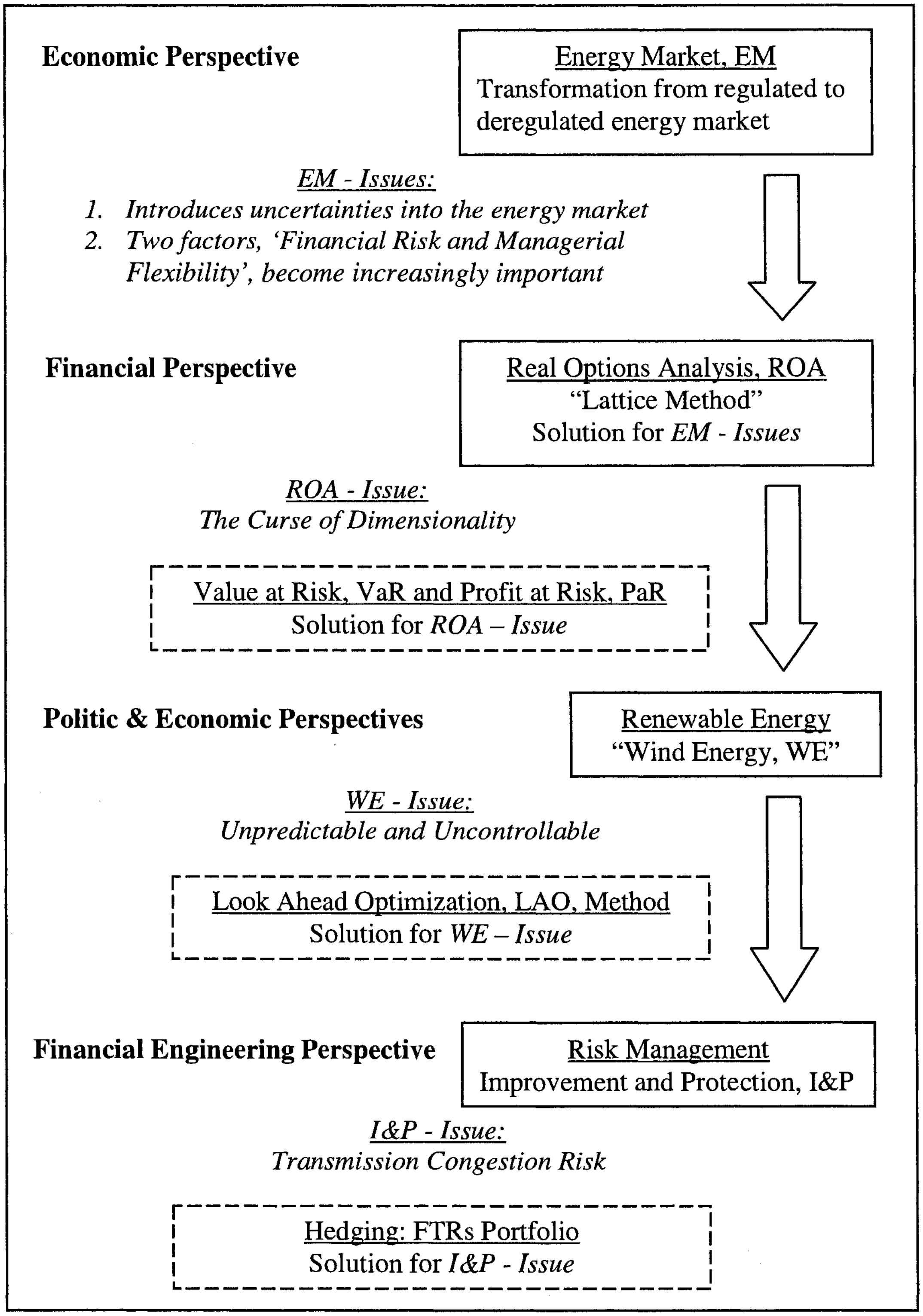


Figure 1.1 Logical Development of Research

A decision analysis based solution of incorporating the wind energy with either pump hydro plants (also known as physical asset hedging) or financial contract hedging is presented in this dissertation. This energy technology integration increases the available-capability of wind energy to be as effective as thermal unit. Since wind energy is an unpredictable and uncontainable energy source, the conversion of the electric energy produced by the wind into a different form of energy that can be stored for future use is necessary. A new and efficient physical asset hedging approach known as the look ahead optimization, LAO, method is applied to both wind farm facilities and pump storage hydro, PSH, system for the purpose of obtaining the optimal energy storage and to minimize the size of hedging. Hedging is part of risk management. In a competitive energy market, risk management plays an important part in analyzing, recognizing possible risks, and developing strategies to respond appropriately should any of the risks occur. One of the most critical risks is the transmission congestion risk. To protect against unfavorable situations, generation companies, GENCOs, often hedge against transmission congestion risk via financial transmission rights, FTRs. This dissertation evaluates the total worth of FTRs portfolio using Real Options Analysis, ROA.

1.2 Organization of Dissertation Flow

This dissertation consists of nine chapters. After this introduction in Chapter 1, Chapter 2 provides an explanation of several major methods used in Real Options Analysis, ROA:

(a) Traditional Black-Scholes Option-Pricing Method
(b) Monte Carlo Simulation Method
(c) Binomial and Trinomial Lattice Methods
(d) Finite Element Method

Chapter 3 presents the literature reviews of the main topics on the dissertation. Chapter 4 provides an efficient approach Binomial Lattice-Value at Risk, BL-VaR, to solve the curse of lattice dimensionality. Chapter 5 introduces real options impact on capital budgeting. Chapter 6 presents a new physical asset hedging approach of integrating pump storage hydro, PSH, system with wind energy. Chapter 7 establishes a new and efficient approach by combining the Binomial Lattice-Profit at Risk, BL-PaR, with the physical asset hedging approach introduced in Chapter 6. Chapter 8 evaluates the total worth of financial transmission rights', FTRs', portfolio using ROA. Chapter 9 summarizes the dissertation.

1.3 Summary of Contents

The organization from Chapter 4 to Chapter 8 is as follows:

1.3.1 Chapter 4: Lattice Method of Real Options Analysis, ROA, – Solving the Curse of Dimensionality and Strategic Planning

The deregulation policy introduces uncertainty into the power market. In the new power economic uncertainties, there are two factors that play important roles in decision analysis: financial risks and managerial flexibility. Under an uncertainty economy, the realization of cash flow of a company may change from time to time. When new information arrives, the uncertainties about the market become clearer. Company needs to reevaluate their original plan. Therefore, the cash flow of a company can differ considerably from what is expected initially. Real Options Analysis, ROA, enables such flexibility to management.

ROA has become one of the most famous valuation tools in analyzing the deregulated power industry. There are several major methods of ROA. The major methods include traditional Black-Scholes Option-Pricing Method, Monte Carlo Simulation Method, Lattice (Binomial and Trinomial) Methods, and Finite Element (Explicit, Implicit, and Crank-Nicolson) Method. This chapter concentrates on the lattice method. To define a lattice model, the investment duration under consideration and the length of model period need to be established. The investment duration under consideration refers to the total investment time-frame. The investment duration can be in terms of weeks, months, or years. The length of model period refers to the step size of each period. When the investment duration is small (or the length of model period is large), the lattice model is easy to appreciate and understand. However, when the investment duration is large (or the length of model period is small), the lattice model becomes a massive bush of lattice, which is also known as the curse of dimensionality. This chapter proposes a new efficient methodology of solving the curse of dimensionality for the lattice method. The massive bush of lattice method can be reduced by analyzing the boundary of the lattice where the decision changes. This is done using the analysis of "sensitivity and importance" of each factor along the investment duration. Analyzing the major factors that cause significant changes in decision making will lead to an in-depth understanding of the overall model strategic planning. Together with the new methodology, the curse of dimensionality for the lattice method can be solved. Besides reducing the degree of dimensionality, this new methodology also specifies when any decisions changed, which play a very critical part in strategic planning. Timing and simplification yet maintaining high accuracy in analysis are essential in the new deregulated power economic uncertainties.

1.3.2 Chapter 5: Real Options Impact on Capital Budgeting

Since the power industry has entered into the deregulation era, two critical decision analysis factors have become significant: managerial flexibility and financial risks. The deregulation policies introduce uncertainties and financial risks into the power industry. Thus, the management needs to have the flexibility to reevaluate its decision from time to time (as new information arrives) in order to maximize the company's return. ROA, which has the capability of managing, modeling, and combining various uncertainties or risks, enables such flexibility for the management. There are four major methods of ROA. This chapter focuses on the binomial lattice method. Together with the integration of profit at risk, PaR, this new efficient approach BL-PaR achieves four critical goals: timing, simplicity, flexibility, and reliability. PaR measures the minimum expected profit of a portfolio over a holding time. It sets the benchmark for future operations. Strategic planning committees, SPCs, designate a certain percentage of the portfolio profit requirements above the benchmark, which is known as the comfort zone. Both PaR and comfort zone enable flexibility for management to set a company's operation target and to solve for the curse of lattice dimensionality as well.

1.3.3 Chapter 6: Integration of Pump Storage Hydro, PSH, with Wind Energy

Renewable energy has significant advantages as it does not contribute to greenhouse gases, GHG. Wind energy is a renewable energy alternative that is being installed throughout the world. However, wind energy is an unpredictable and thus, unavailable source as compared to conventional generation. The availability of wind energy compared to conventional power plants is a cause of contention. Currently, the wind energy availability rate is approximately fifty percent. The reliability for the thermal unit may reach as high as ninety percent. It is necessary to express and standardize the availability of wind energy and the reliability of thermal unit in equivalent units for the purpose of comparison. Besides that, it is highly desirable to construct the availability of wind energy to be equivalent with the thermal unit. Therefore, the conversion of the electrical energy produced by the wind into a different form of energy that can be stored for future use (physical asset hedging) together with the implementation of financial contract hedging are necessary. This chapter introduces a decision analysis based solution of incorporating the integrating either hydro or fossil plants with the wind energy, and financial contract hedging. The main purpose of this energy technology integration is to increase the availability and reliability of the wind energy to be as effective as any thermal unit.

1.3.4 Chapter 7: Integration of Physical Asset Hedging with Binomial Lattice-Profit at Risk, BL-PaR

Renewable energy sources continue to experience rapid growth. As the prices of fuels rise and environmental concerns grow larger, the demand for renewable energy sources continues to increase. Renewable energy has significant advantages since it does not contribute to GHG. Wind energy is a renewable energy alternative that is being installed throughout the world. However, wind energy is an unpredictable and uncontainable energy source. Thus, the conversion of the electrical energy produced by the wind into a different form of energy that can be stored for future use is necessary. This paper introduces a decision analysis based solution of integrating pump storage hydro, PSH, system with wind energy. A physical asset hedging approach known as the look ahead optimization, LAO, method is applied to both wind farm facilities and PSH system. The main purpose of the LAO method is to obtain the optimal energy storage and to minimize the size of hedging. By combining the LAO method and the BL-PaR model, several important goals can be achieved: increase the availability, reliability, and available-capability rate of wind energy, reduce the computation time, lattice dimension, and size of hedging, and allow managerial flexibility and risk management.

1.3.5 Chapter 8: Risk Management – Financial Transmission Rights', FTRs', Portfolio Value corresponding to Energy Contracts Termination

In a competitive energy market, risk management plays an important part in analyzing and recognizing all possible risks and developing strategies to respond appropriately should any of those risks occur. Whenever GENCOs engage in any energy bilateral contracts, they face various types of risks that can lead to adverse impact. Currently, one of the most critical risks is the transmission congestion risk. With the help of probability theory and historical data, the probability distribution of potential transmission congestion is predictable to some extent. GENCOs hedge against the transmission congestion risk via financial transmission rights, FTRs. The total worth of FTRs portfolio is evaluated using Real Options Analysis, ROA, which has the capability and flexibility of incorporating various future uncertainties into the model. Of the four major methods of ROA, this chapter concentrates on the lattice method. Looking from a different perspective, the size and bid price of FTRs by generation companies, GENCOs, indicate

(a) The potential losses that arise from the energy contracts termination due to transmission congestion and

(b) The maximum risk GENCOs are willing to shoulder.

CHAPTER 2. REAL OPTIONS ANALYSIS, ROA

2.1 Introduction

ROA is based on the observation that most of the investment projects usually have three main characteristics that are not taken into account in traditional theories. Traditional investment theory is based on the Net Present Value Analysis, NPV. An investment project is not accepted if the difference between the present value of the anticipated future flow of profits of the project does not exceeds the present value of the costs of the project and vice versa. The three important characteristics that are neglected in the traditional theories are [Kambil 2004]:

(a) Investments are partly or completely irreversible. The investment is therefore at least partially sunk cost.

(b) Future profits from the investment are uncertain.

(c) The timing of investment can be decided by the firms any time. For example, in order to obtain more information, firms can delay their investment.

The relationship between these three key characteristics in an investment project is similar to a financial call option or put option. These options are referred to as "Real Options" because it relates to an opportunity to invest in real assets (or commodity). The opportunities for corporate investment can be viewed as financial opportunities because the company has the right, with no obligation to acquire the underlying asset.

The basic types of financial options are: Call and Put. A call option on an asset (with current value, V) gives the option holder the right, with no obligation, to acquire the underlying asset by paying a prespecified price (the exercise price, I) on or before the maturity date [Ward 1994] and [Hull 2000]. A put option on an asset (with current value, V) gives the option holder the right, with no obligation, to sell the underlying asset and receive a prespecified price (the exercise price, I) on or before the maturity date. If the option can be exercised before the maturity date, it is known as an American option. A European option can only be exercised on the maturity date [Ward 1994] and [Hull 2000]. An option, which relates to an opportunity to invest in real assets, is known as "Real Option". Few basic types of real options are as follows [Trigeorgis 1987, 1996]:

- Option to Defer

  Management holds a lease on (or an option to buy) valuable land or resources. Management can wait several years to see if the output prices justify constructing a building or a plant or developing a field.

  Option to Defer can be employed in all natural-resource-extraction industries, real-estate development, farm, and paper products.

- Time-to-build Option

  Staging investment as a series of outlays creates the option to abandon the enterprise in midstream if new information is unfavorable. Each stage can be viewed as an option on the value of subsequent stages and valued as a compound option.

Time-to-Build Option is important for all research and development, R&D, intensive industries especially pharmaceuticals, long-development capital intensive projects (for example, large-scale construction or energy generation plants), and startup ventures.

- Option to Alter Operating Scale

  If market conditions are more favorable than expected, the firm can expand the scale of production or accelerate resource utilization. Conversely, if conditions are less favorable than expected, it can reduce the scale of operations. In extreme cases, production may be halted and restarted.

  Option to Alter Operating Scale is used for natural-resource industries (for example, mining), facilities planning and construction in cyclical industries, fashion apparel, consumer goods, and commercial real estate.

- Option to Abandon

  If market conditions decline severely, management can abandon current operations permanently and realize the resale value of capital equipment and other assets on secondhand markets.

Option to Abandon is applicable to capital-intensive industries, financial services, and new product introductions in uncertain markets

- Multiple Interacting Options

  Real-life projects often involve a collection of various options. Upward-potential-enhancing and downward-protection options are present in combination. Their combined value may differ from the sum of their separate values; that is, they interact. They may also interact with financial flexibility options.

  Multiple Interacting Options is applicable for real-life projects in most industries listed above.

- Option to Switch

  If prices or demand change, management can change the output mix of the facility (product flexibility). Alternatively, the same outputs can be produced using different types of inputs (process flexibility).

  Option to Switch can be employed in:

  Output shifts: Any good sought in small batches or subject to volatile demand (for example, consumer electronics), toys, specialty paper, machine parts, and autos.

  Input shifts: All feedstock-dependent facilities, electric power, chemicals, crop switching, and sourcing.

- Growth Option

  An early investment is a prerequisite or a link in a chain of interrelated projects, opening up future growth opportunities. Like interproject compound options.

  Growth Option is important for all infrastructure-based or strategies industries – especially high tech, R&D, and industries with multiple product generations or applications (for example, computers, pharmaceuticals), multinational operations, and strategic acquisitions.

The value of an option depends upon the value of the underlying asset because an option is a derivative instrument of an underlying asset. For example, if the value of a particular stock increases, the value of the call option increases and the put option decreases. The underlying asset of a stock call or put option is the stock.

When a project has operation flexibility, the value of an option can be determined more accurately by applying Real Options Analysis, ROA. Therefore, a more accurate estimate of the value of a project can be achieved. This will lead to making a better decision and at the same time, increase the firm's management efficiency under uncertainties.

2.2 Introduction of Real Options Analysis, ROA, Methodologies

There are four major methods of ROA:

2.2.1 Closed-Form Solution – Black-Scholes Option-Pricing

The Black-Scholes model was the first and the most widely used model for option pricing. This model can be described as the expanded version of the Net Present Value, NPV, Analysis [Trigeorgis 1996], [Mun 2002], and [Teoh 2004]. The Black-Scholes option-pricing model enables the traditional NPV approach to properly reflect management's flexibility to adapt and revise later decisions to unexpected market developments. The definition of the expanded NPV is as follows [Mun 2002]:

Expanded NPV (the whole project)

= *traditional NPV (phase I asset)*

+ *present value of an option (Phase II asset)*

Where

Phase I Asset	The initial investment of a new generation unit (net cash flows)
Phase II Asset	The values of option

In general, the key assumptions of the Black-Scholes model are [Hull 2000], [Mun 2002], and [Teoh 2004]:

(a) The asset does not pay dividends until option expiration at some future date.

(b) The price of the underlying asset S_t follows a geometric Brownian motion with constant drift μ and volatility σ, and the price changes are log-normally distributed.

(c) The option is exercised only at maturity (European exercise).

(d) There are no arbitrage opportunities.

(e) The riskless instantaneous interest rate remains constant and known over time until maturity.

(f) Capital markets are efficient, complete, and frictionless. There are no transaction fees or differential taxes. The trading takes place continuously. There is allowance of unlimited borrowing and short selling. The borrowing and the lending rate are equal. Assets are infinitely divisible (for example, it is possible to buy any fraction of a share).

Basically, the Black-Scholes model is associated with the call option and put option formula. Black and Scholes use the equilibrium Capital Asset Pricing Model, CAPM, to derive the equation for the call and put option. For valuation reasons, the Black-Scholes model assumes the option has expected return equal to the risk free rate. Thus, the option equation can be solved using the Black-Scholes model. In other words, the Black-Scholes formula is the result obtained by solving the Black-Scholes Partial Differential Equation for European put and call options. Please refer to

[Hull 2000] for detailed explanation regarding the Black Scholes model. In practice, there are two types of solutions to differential equation: closed-form solutions and numerical solutions. The Black-Scholes formula is a closed-form solution to the Black-Scholes differential equation [Mun 2002]. A closed-form solution is an actual equation that satisfies the differential equation for all possible values of the input parameters. "Closed-form solutions are exact, quick, and easy to implement with the assistance of some basic programming knowledge but are difficult to explain because they tend to apply highly technical stochastic calculus mathematics," [Mun 2002]. Besides that, the Black-Scholes option-pricing model cannot accurately price the American-style options as this model only calculates the option price for a given single maturity or expiration time. This model cannot consider the steps along the way where the possibility of early exercise of an American option exists. The model assumes that the stock pays no dividend during the option's life. This is sometimes a significant limitation as higher dividend yields lower call premiums. Most companies pay dividends to their shareholders. The Black-Scholes option-pricing model cannot compute more complex derivative models without appropriate adjustments.

ROA often faces harder or more 'exotic' problems compared to the financial derivatives pricing problems. As an example, several underlying variables or several factor models are typically included. Thus, numerical techniques play an important part in ROA. This is due to the fact that finding closed-form solutions to more 'exotic' problems (partial differential equations) is not easy. The numerical techniques basically can be divided into three groups: Monte-Carlo, lattice, and finite element.

2.2.2 Numerical Method – Monte Carlo Simulation

Monte Carlo simulation is a statistical technique. Through the Monte Carlo simulation, a quantity is calculated repeatedly by using randomly selected "what-if" scenarios for each calculation. The result summarizes the full range of possible outcomes, and the likelihood of each. The basic idea of this kind of simulation is when one plays a game long enough or repeats the same procedure countless times; one will have a very clear insight of the distribution of the possible result.

2.2.3 Numerical Method – Binomial and Trinomial

The binomial tree and trinomial tree methods are an improved extension of the Black- Scholes model. Both of these models are based on the idea of a finite tree structure that branches out from the current asset price and from the current time until the expiration time. The lattice methods segment time to maturity into a large number of time intervals or steps. A tree of asset prices is then produced working forward from the present to the maturity.

For the binomial lattice method, the asset price is assumed to take on one of two possible values:

(a) going up

(b) going down

This produces a binomial distribution of the underlying asset prices. As for trinomial lattice method, the asset price over a single period can have three possible values:

(a) going up with the probability of P_u

(b) stay at the original value with the probability of P_m

(c) going down with the probability of P_d

The formula for probabilities p_u, p_m and p_d is as follows:

$$p_u = \frac{1}{2}(\frac{\sigma^2 \Delta t + v^2 \Delta t^2}{\Delta x^2} + \frac{v \Delta t}{\Delta x})$$

$$p_m = 1 - (\frac{\sigma^2 \Delta t + v^2 \Delta t^2}{\Delta x^2})$$

$$p_d = \frac{1}{2}(\frac{\sigma^2 \Delta t + v^2 \Delta t^2}{\Delta x^2} - \frac{v \Delta t}{\Delta x})$$

Both binomial tree and trinomial tree methods value an option by backward induction, which is extending the replicating and related portfolio values back one period at a time from the claim values to the starting time.

2.2.4 Numerical Method – Finite Element

The finite element method generalizes the binomial method concept as a method for solving a partial differential equation. The finite element method also numerically solves the Black-Scholes equation and extensions with other partial differential equations (PDEs-based) techniques. The finite element method uses 'grids' to replace the 'trees' in the binomial method. Once an equation has been found, it is easier to use the finite difference grid to solve numerically.

2.3 Reasons behind Real Options Selection

The selection of Real Options Analysis, ROA, is based on three critical elements. They are financial risk, managerial flexibility, and information. Whenever any new information arrives, the initial decisions need to be reevaluated or updated. In other words, when the market uncertainties become clearer, necessary actions need to be performed in order to maximize the utility's rate of return. Fundamentally, the critical factor that modifies any decision is information. Therefore, the lattice method, which can be treated as a discrete event method, is preferred in comparison to stochastic processes. Stochastic process is a family of random variables that describes the evolution through time of some (physical) process [Ross 1980].

Events, just like data, can be classified as continuous or discrete. Continuous events are a function of time, while discrete events depend on the information. Discrete event obtains information that result from a process of counting. In general, information relating to asset prices is discrete due to rules set by individual markets regarding price quotations and minimum price movements [Schnapp 2007]. Continuous event data can take on any value within a continuum. The data are measured on a continuous scale and the value of the measurement is limited only by the degree of precision. Typical continuous data is related to time, distance, and speed.

The market is a social arrangement that offers the opportunity to buy and sell. It involves two important elements: trading and contract. Trading refers to any buying and selling of securities or commodities. A contract is an agreement between two or more parties, including one that is written and enforceable by the law. In the energy industry, bilateral and hedging contracts are the two most common types. A bilateral contract is a direct contract between the power producer and either the user, a broker outside of a centralized power pool or power exchange [Schnapp 2007]. A hedging contract represents an agreement which establishes future prices and quantities of electricity independent of the short-term market [Schnapp 2007]. Under bilateral and hedging contracts, information such as quantity, price, and specific time of delivery are negotiated and included. Information that forces changes in value can be categorized as a discrete event. Due to contract characteristics, the lattice method, which focuses on discrete events, is an ideal tool for the deregulated power industry.

Dr S. S. Oren and Dr S. J. Deng are actively involved in this area. Table 2.1 summarizes some of their works and published papers.

Table 2.1 Contributions from Dr. S.S. Oren, Dr. S.J. Deng, and Dr. J. Yao

Category	**Published Papers/Journals**
Simulation	• Pricing the hidden options in power contracts: a case with tolling agreements [Deng 2003] • Exotic electricity options and the valuation of electricity generation and transmission assets [Deng 2001] • Two-settlement electricity markets with price caps and Cournot generation firms [Yao 2005]
Lattice	• Integrating real and financial options in demand-side electricity contracts [Oren 2001] • Incorporating operational characteristics and start-up costs in option-based valuation of power generation capacity [Deng 2003]
Stochastic	• Pricing the hidden options in power contracts: a case with tolling agreements [Deng 2003] • Exotic electricity options and the valuation of electricity generation and transmission assets [Deng 2001] • Stochastic models of energy commodity prices and their applications: mean-reversion with jumps and spikes [Deng 2000] • Incorporating operational characteristics and start-up costs in option-based valuation of power generation capacity [Deng 2003] • Cournot equilibria in two-settlement electricity markets with system contingencies [Yao 2007] • Two-settlement electricity markets with price caps and Cournot generation firms [Yao 2005]

Simulation is an imitation of some real situations. It observes the situation, and uses a mathematical model to recreate the situation. This mathematical model is set as the benchmark. It is performed repeatedly so that the likelihood of various outcomes can be more accurately estimated. Basically, it refers to a process of a dynamic model in order to obtain a sequence of outcomes that could occur in a real world system. Discrete event system simulation, DESS, discretizes a continuous random variable into multiple discrete events (variables). A binomial lattice is then used to model these events where each path along the binomial lattice represents a specific event, i.e. each specific path therefore represents a known, deterministic variable. In other words, all of the random variables along each respective path become deterministic. The main difference between simulations and the lattice method is that the lattice method considers every possibility at each point of time.

2.4 Comparison of Real Options Approaches

Three Virtual World Creation, VWC, cases are presented for the purpose of comparing various approaches of Real Options Analysis, ROA. These approaches are the Black-Scholes option-pricing method, the lattice methods, the Monte Carlo Simulation method, and the Finite Element method. Please refer to Appendix: Virtual World Creation, VWC, for explanation regarding each case.

From Table 2.2, the value of option, which is calculated from the lattice method, the finite element method, and the Monte Carlo Simulation method, for each case respectively is pretty consistent (or close).

Table 2.2 Virtual World Creation Results for Various Approaches of ROA

		Basic Model	**Power Outage**	**Transmission Line Effect**
Traditional Method	Black-Scholes Option-Pricing	*2.022*	*2.994*	*1.565*
Lattice Method	Binomial	*3.585*	*3.621*	*2.199*
	Trinomial	*3.436*	*3.9*	*2.2*
Finite Element Method	Explicit	*3.456*	*3.9*	*2.2*
	Implicit	*3.605*	*4.1*	*2.4*
	Crank-Nicolson	*3.532*	*4*	*2.3*
Simulation Method	Monte Carlo	*3.552*	*3.92*	*2.27*

The Black-Scholes option-pricing method always has lower calculated option value for every case compared to other methods. This is due to the fact that the Black-Scholes model only calculates the option price for a given single maturity or expiration time. This model cannot consider the steps along the way where the possibility of early exercise of an American option exists. Therefore, the result obtained from the traditional Black-Scholes option-pricing method is usually used as a benchmark. The positive option value indicates higher positive rate of return compared to normal operation rate of return.

CHAPTER 3. LITERATURE REVIEW

3.1 Introduction

This dissertation covers financial engineering for power system capital budgeting. Within this topic, this dissertation focuses on:

(a) Real Options Analysis, ROA

(b) The integration of Pump Storage Hydro, PSH, system with wind energy

(c) Risk management – Evaluation of FTRs' portfolio

This chapter provides a thorough literature review for these main topics.

3.2 Real Options Theory and Energy Market

Options on stocks were first traded on an organized exchange in 1973 [Hull 2000]. The option markets have experienced a dramatic growth since then. The idea of treating discretionary investment opportunities as "growth options" and valuing them as call options was first suggested by [Myers 1977], [Kester 1984], [Mason 1985], [Trigeorgis 1987], [Trigeorgis 1988], [Kulatilaka 1988], [Brealey 1991], and [Kulatilaka 1992] then discussed various concept of real options frameworks. For instance, [Kester 1984] discusses the growth opportunities' strategic and competitive aspects. [Mason 1985] provides the connections between investment decisions and financial options. [McDonald 1986] is the first to model what is termed as the "value of waiting to invest", the sequential investment decisions. [Myers 1987] acknowledges that option pricing presents the best method for valuing complex investment problems. Future investment opportunities valued as corporate growth options are discussed in [Myers 1977], [Trigeorgis 1987], and [Trigeorgis 1988].

Since the energy industry entered into the deregulation era, two factors in decision analysis have become significant: financial risks and managerial flexibility. Some papers in the literature have discussed the applications of real options frameworks into deregulated energy market uncertainties. [Denton 2003] and [Roark 2005], both describe how the energy market risks in operations can be measured and managed using real options models and stochastic optimization techniques. [Botterud 2005] presents a novel model for optimization of investments in new power generation under uncertainty with the aid of real options. [Wang 2006] develops a real options model for general *n* interrelated power projects. To provide a better and comprehensive understanding, the procedures and methods discussed by [Denton 2003], [Roark 2005], [Botterud 2005], and [Wang 2006] have been summarized into graphical representation as shown from Fig. 3.2 to Fig. 3.5. Besides those papers mentioned above, some other papers that are closely related to the application of real options theory into energy market are as follows:

(a) [Yu 2003] introduces a new fuzzy approach to implement ROA to valuate and operate generation assets.

(b) [Botterud 2004] examines the use of stochastic dynamic optimization, which is the mathematical foundation of real options theory, to improve power generation investment decisions in restructured and competitive power systems.

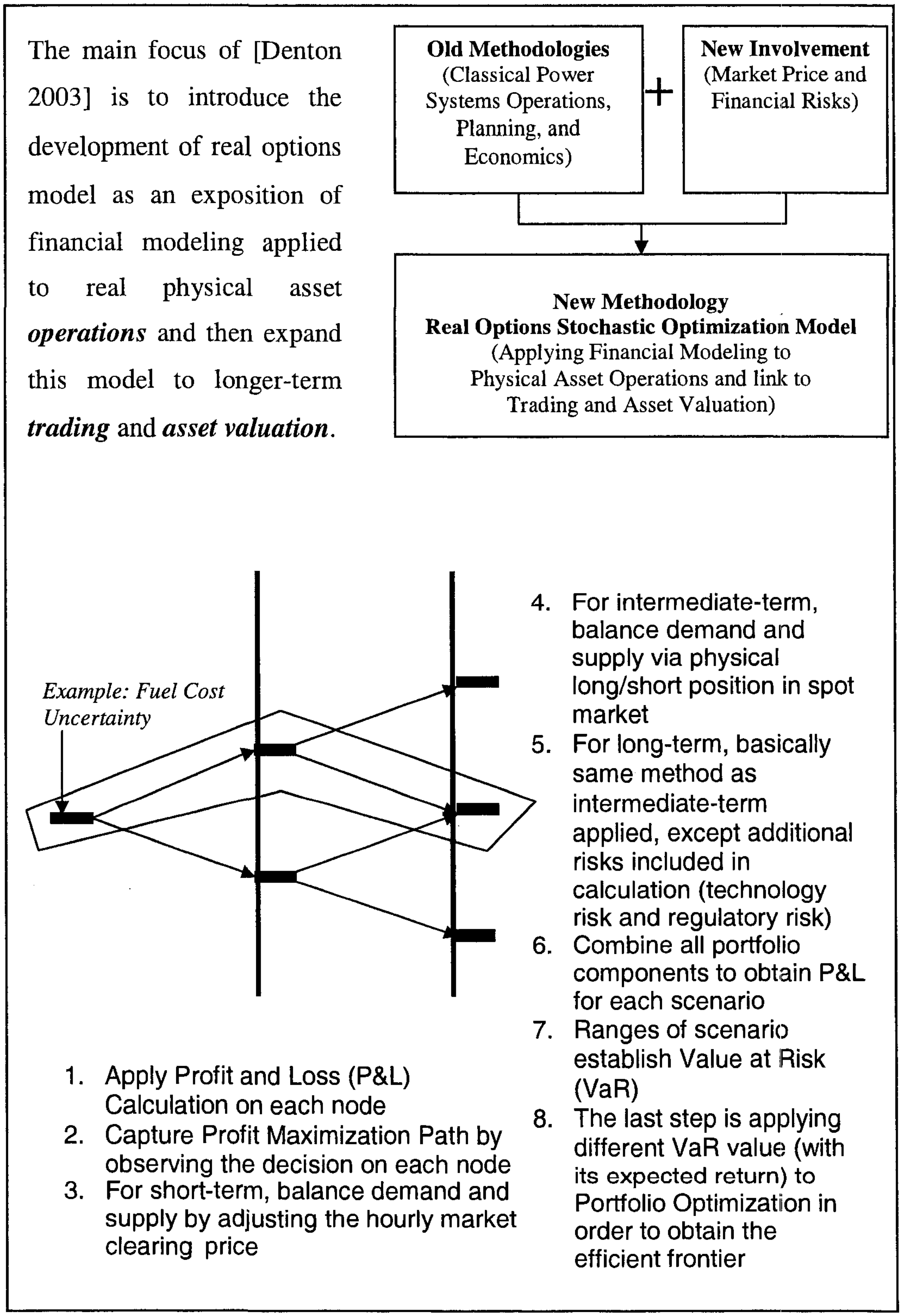
(c) [Imai 2005] analyzes the interaction between managerial flexibility and competition in a dynamic situation. The value of the flexibility is valued using real option while the competition is analyzed with game theory.

(d) [Lu 2006] proposes a ROA based transmission expansion planning framework, which is capable of handling the dynamic and uncertainties from the electricity market over the planning horizon, and compares the result with the traditional Net Present Value, NPV, approach.

(e) [Yu 2004] analyzes contingency services for wind energy. The contingency services are modeled as call options and prices are determined using option pricing theory.

(f) [Deng 2003] applies Real Options Analysis, ROA, to determine the value of a tolling agreement. A tolling agreement is like a call option since it gives the buyer the right but not obligation to operate a power plant, while providing the fuel for the plant, so that one can use the electricity or receive a financial payoff based on the spread between the price of electricity in the market and the heat rate adjusted fuel price.

With the introduction of deregulation policy, managerial flexibility has become one of the most important factors in decision analysis. Flexibility introduces a different treatment of uncertainties. ROA addresses the valuation of managerial flexibility in capital budgeting. Therefore, the application of ROA into deregulated energy market has gained tremendous attention lately.



The main focus of [Denton 2003] is to introduce the development of real options model as an exposition of financial modeling applied to real physical asset ***operations*** and then expand this model to longer-term ***trading*** and ***asset valuation***.

1. Apply Profit and Loss (P&L) Calculation on each node
2. Capture Profit Maximization Path by observing the decision on each node
3. For short-term, balance demand and supply by adjusting the hourly market clearing price
4. For intermediate-term, balance demand and supply via physical long/short position in spot market
5. For long-term, basically same method as intermediate-term applied, except additional risks included in calculation (technology risk and regulatory risk)
6. Combine all portfolio components to obtain P&L for each scenario
7. Ranges of scenario establish Value at Risk (VaR)
8. The last step is applying different VaR value (with its expected return) to Portfolio Optimization in order to obtain the efficient frontier

Figure 3.2 General Step-by-Step Real Options Stochastic Optimization Method

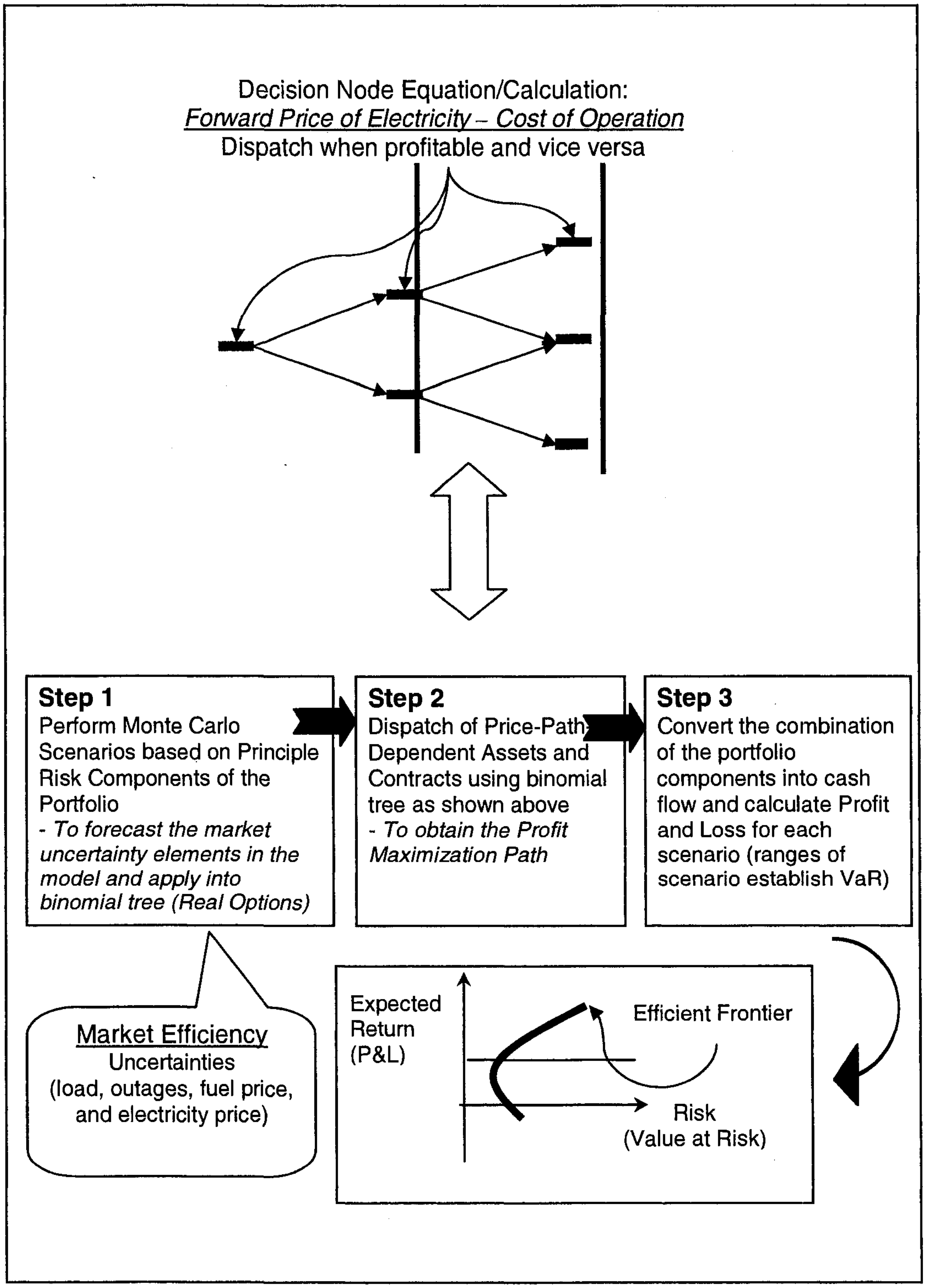


Figure 3.3 Overall Procedures for Real Options and Portfolio Optimization with Multiple Objectives

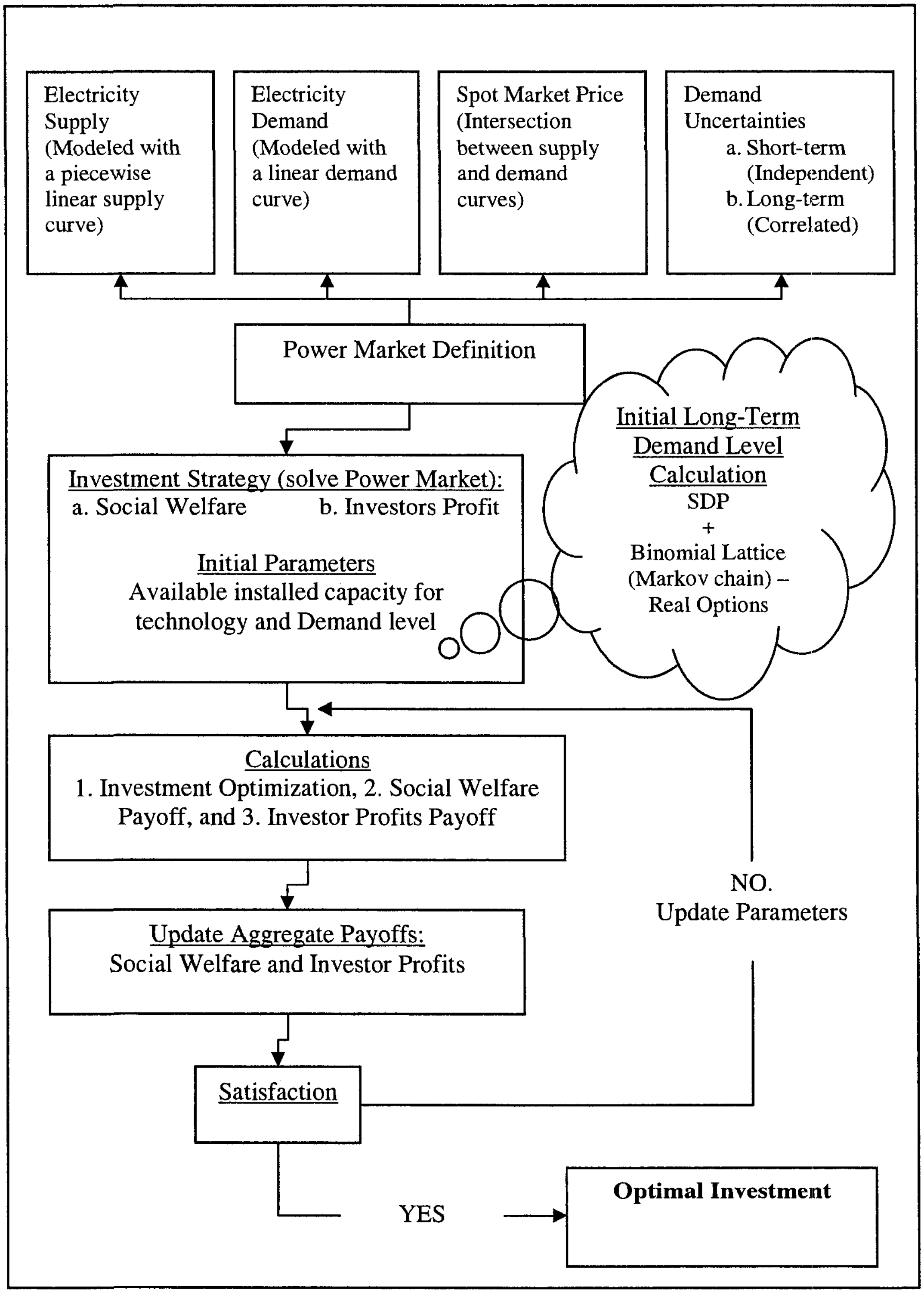


Figure 3.4 Power Market Descriptions and Stochastic Dynamic Optimization Simulator Model

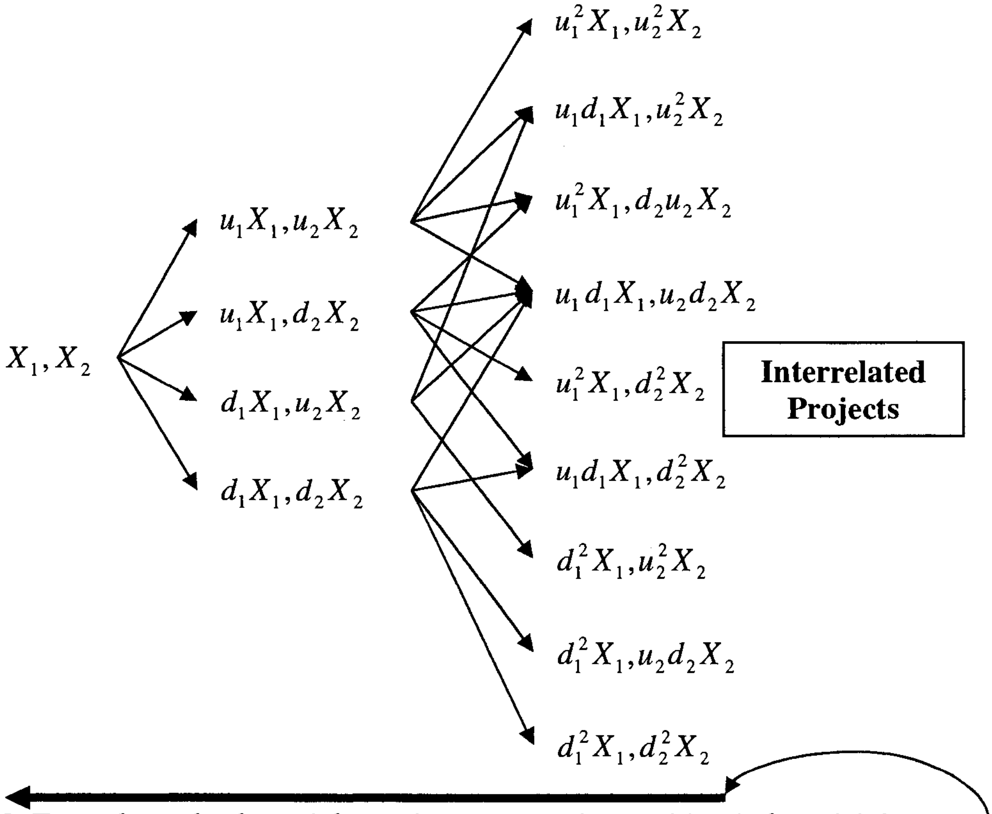
The Probabilities Equation for Independent Projects

$$p_u = \frac{e^{r*\Delta t} - d}{u - d} \qquad p_d = 1 - p_u$$

(probability - up) (probability - down)

The Unique Value Movement Probabilities Equation for Interrelated Projects (for more detailed explanation, please refer to [Wang 2006])

$$p_k = \prod_{i=1}^{n} p\delta_i(k) + \frac{1}{2^n}\sum_{i=1}^{n}\sum_{i=2}^{n}\delta_{ij}(k)\rho_{ij} \qquad \mathrm{k} = 1,\ldots,2^{\mathrm{n}}$$



2. Formulate a backward dynamic programming multiperiod model that maximizes the value of the investment
3. Solve for optimal strategic decisions over the options and the corresponding value of the investment

Figure 3.5 Evolution in Value of Two-Projects (Independent and Interrelated) and Systematic Steps of Real Options Approach

3.3 Energy Storage: Integration of Pump Storage Hydro, PSH, with Wind Energy

Wind energy is the fastest growing source of electricity in the world.

> “With increasingly competitive prices, growing environmental concerns, and the call to reduce dependence on foreign energy sources, a strong future for wind power seems certain.”
>
> [Clean 2007]

Wind power does not contribute to global warming as it does not produce toxic emissions and heat trapping emissions. However, wind energy is an unpredictable and uncontrollable energy source. There is no mechanism to make sure how much energy can be produced and at what time. Generally, this is not the norm in the energy industry. As wind is becoming more and more popular, engineers seek new and efficient methods to balance this aspect. Currently, there are several methods that address this issue by converting the electrical energy into a different form of energy, for example potential energy, that can be stored for future use:

(a) Pump storage hydro, PSH, system with wind farm facilities
(b) Compressed air energy storage
(c) Battery-based energy storage

This dissertation focuses on (a), which is the integration of PSH system with wind farm facilities. According to the Electricity Storage Association, ESA, PSH is the most widespread energy storage system in use on power networks and its main applications are for energy management, frequency control, and provision of reserve. The major advantage of energy storage is it provides “ride-through” for momentary outages, and extended protection from longer outages.

[Castronuovo 2004] presents a method of utilizing hydro plant and wind farm for the purpose of meeting a required supply level. Besides modeling the wind speeds, the objective of the research is also to establish a reliable forecast for the purpose of determining an optimal scheduling between the two facilities for the following 24 hours. [Leonhard 2004] introduces an approach of having a future energy supply based mainly on a “wind and water model.” In this paper, wind farms and pumped storage facility interact together and produce majority of the energy needed. [Guan 1994] presents an optimization-based method for scheduling hydrothermal systems based on Lagrangian relaxation technique. [Ni 2004] develops an integrated bidding and scheduling algorithm to optimize hourly offer curves for a hydrothermal power system to maximize profits. A stochastic mixed-integer optimization formulation having a separable structure with respect to individual units is first established. A method combining Lagrangian relaxation and stochastic dynamic programming is then presented to select hourly offer curves for both energy and reserve markets. [Contaxis 2000] discusses a linear programming approach to solve the optimal power flow in a power system, which includes wind farms facilities and PSH system under large-scale integration of dispatchable renewable energy sources. The operation of wind farm facilities and PSH system is based on special contractual agreements for buying or selling energy between independent power producers and power utility. [Roberts 2005] demonstrates the improvements in energy storage and indirectly also increases the value of renewable resources--wind energy is an example. [Schainker 2004] provides a general idea of different methods that are being proposed and used for energy storage. The two things being considered for wind energy is pumped storage and compressed air energy storage facilities. Papers and journals that are related to this topic are shown in Table 3.3:

Table 3.3 Papers and Journals related to PSH and Wind Energy

Topic	Reference
Integration of Large-Scale Wind Power and Use of Energy Storage in the Netherlands' Electricity Supply	[Pelgrum 2008]
Pumped-Storage Hydro-Turbine Bidding Strategies in a Competitive Electricity Market	[Ning 2004]
Pumping Station Design for a Pumped-Storage Wind-Hydro Power Plant	[Anagnostopoulos 2007]
Value of Bulk Energy Storage for Managing Wind Power Fluctuations	[Black 2007]
Bounding Active Power Generation of a Wind-Hydro Power Plant	[Castronuovo 2004]
Storage Options and Sizing for Utility Scale Integration of Wind Energy Plants	[Ingram 2005]
Maximizing Wind Generated Electricity with Hydro Storage	[Kaldellis 2006]
Comparing Hedging Methods for Wind Power: Using Pumped Storage Hydro units vs. Options Purchasing	[Hedman 2006]

3.4 Risk Management: Evaluation of Financial Transmission Rights', FTRs', Portfolio

Generation companies, GENCOs, operate in a dynamic environment. The future remains uncertain especially due to the natural characteristic of electricity, which cannot be stored. Both production and consumption of electricity have to take place simultaneously. However, physical transmission risk or constraint prevents electricity from being transferred freely across interconnections. Hence, managing transmission congestion risk plays an important part for GENCOs. Risk management is an integral part of managing a business. Companies who have active risk management programs are much better posed to deal with various unfavorable conditions. Therefore, many researches have proposed various ways of managing transmission congestion risk. Do keep in mind, not all risks can be eliminated, they can be [Hetamsaria 2005]:

(a) Transferred to another party, who is willing to take risk. For example, buying an insurance policy or entering into a forward contract;

(b) Reduced through the use of good internal controls;

(c) Avoided by choosing not to involve in risky business;

(d) Retained by either anticipating higher profits by taking on more risk, or avoiding the cost of trying to reduce risk;

(e) Shared by following a middle path between retaining and transferring risk

GENCOs hedge against the transmission congestion risk via FTRs. "FTR is a financial instrument that entitles the holder to be charged or receive compensation for Transmission Congestion Charges that arise when the transmission grid is congested in the (Day-Ahead) Energy Market and differences in (Day-Ahead) Locational Marginal Prices, LMPs, result from the dispatch of generators out of merit order to relieve the congestion" [PJM 2006]. [Hogan 2002] and [Kristiansen 2005], both have provided new models and methods for allocating long-term FTRs to investors in transmission expansion in meshed networks. [Bautista 2005] presents a framework for modeling competition in power markets for transmission right. This proposed framework, which is based on equilibrium conditions for all the entities that participate in the transmission market, allows one to model from a multiagent point of view the competition among FTRs bidder. [Kristiansen 2005] studies the credit risks faced by the FTRs' providers. It presents the key issues associated with provision of FTR obligations and options. [Bykhovsky 2005] investigates three potential risks--revenue inadequacy, infeasibility of monthly FTR auction solutions, and an increase in computer run time--associated with the introduction of Option FTRs into the New England market.

FTR, which is used to hedge the cost associated with transmission congestion, is intended as a hedging method for curbing market power. However [Sheblé 2005], which explores the use of genetic algorithms to learn profit-maximizing strategies in a variety of simulated electric markets, and [Bautista 2005] both illustrate that FTRs may actually provide opportunities to exploit market power. FTRs can confer market power. Other papers and journals that are closely related to this topic are summarized in Table 3.4.

Table 3.4 Papers and Journals related to Financial Transmission Right, FTR

Topic	Reference
PJM Manual 06 Financial Transmission Rights	[PJM 2006]
Markets for Financial Transmission Rights	[Kristiansen 2004]
Interaction of Market Power and Financial Transmission Rights in Power Networks	[Bautista 2004]
Wind Energy, Congestion Management, and Transmission Rights	[Lehr 2002]
Transmission Rights and Market Power	[Bushnell 1998]
Transmission Risk Hedging Products – Solutions for the Market and Consequences for the TSOs	[ETSO 2006]
The New York Transmission Congestion Contract Market: Is It Truly Working Efficiently?	[Bartholomew 2003]
Role of Distribution Factors in Congestion Revenue Rights Applications	[Liu 2004]
Impact of Market Uncertainty on Congestion Revenue Right Valuation	[Sun 2005]

No papers or journals have discussed or demonstrated the application of ROA to evaluate financial transmission rights', FTRs' portfolio.

CHAPTER 4. LATTICE METHOD OF REAL OPTIONS ANALYSIS, ROA, - SOLVING THE CURSE OF DIMENSIONALITY AND STRATEGIC PLANNING

4.1 Introduction

The electric power industry in United State of America has been going through major changes. The deregulation policy has changed the power industry from a regulated monopoly toward market competition. Under the policy of regulated monopoly, a utility has a guaranteed fair rate of return in exchange for an obligation to serve. In deregulation market, there is no guarantee of fair rate of return [Teoh 2004]. The deregulation policy introduces uncertainties into the power market. Obliged to meet demand and maximize profit, generation companies seek to find the most economical and feasible way to operate their generation assets.

Since the power industry enters into the deregulation era, under the new economic uncertainties, there are two factors that play important roles in decision analysis: managerial flexibility and financial risks. Under uncertainty economy, the realization of cash flow of a company may change anytime and can differ significantly from what is expected initially. When new information arrives, and uncertainties about the market conditions become clearer, a company needs to reevaluate the previous decision from time-to-time to maximize the company's rate of return [Teoh 2004]. ROA enables such flexibility to management.

There are four major methods often used in ROA. This dissertation concentrates on the lattice method. To define a lattice model, the investment duration under consideration and the length of model period need to be established [Luenberger 1998]. The investment duration under consideration refers to the total investment time horizon. The investment duration can be in terms of days, weeks, months, or years. The length of model period refers to the step size of each period. When the investment duration is small (or the length of model period is large), the lattice model is easy to appreciate and understand. However, when the investment duration is large (or the length of model period is small), the lattice model becomes a massive bush of lattice, which is known as the curse of dimensionality. This paper proposes a new efficient methodology of solving the curse of dimensionality for the lattice model. The massive bush of lattice model can be reduced by analyzing the boundary of the lattice where the decision changes. This is done via the implementation of value at risk, VaR, into the lattice model. Besides reducing the degree of dimensionality, this new methodology also specifies "when" a decision changes. This is a very critical part in strategic planning. Timing and simplification yet maintaining high accuracy in analysis are essential in the new deregulated power economic uncertainties.

Section 4.2 provides an introduction and explanations of the binomial lattice model, and VaR. Section 4.3 introduces the new efficient approach, which is known as the binomial lattice–value at risk, BL-VaR, approach. This approach is capable of solving the massive bush of lattice model (curse of dimensionality) using: The combination of lattice method and VaR. The procedure of BL-VaR model is explained in Section 4.4. An example of BL-VaR calculation is performed in Section 4.5. Section 4.6 discusses the conclusions and potential extension to this research.

4.2 Binomial Lattice Model and Value at Risk, VaR

4.2.1 Binomial Lattice Model

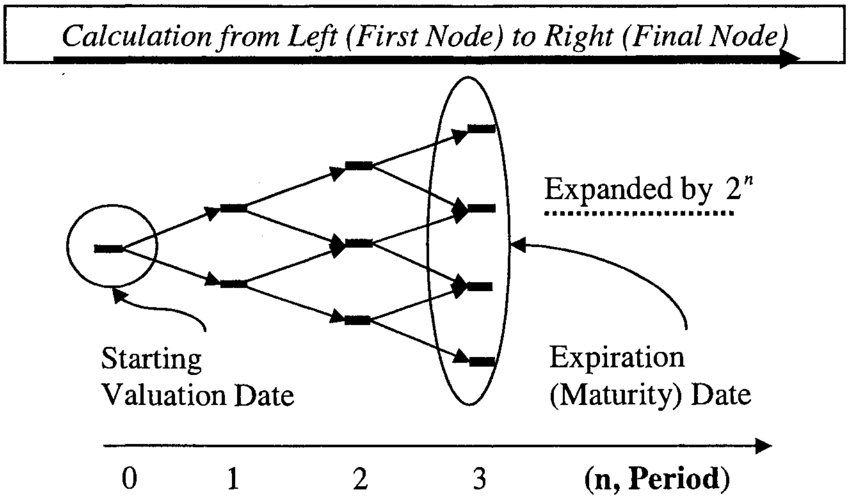


Figure 4.6 Binomial Underlying Asset Lattice for Simulation

The binomial lattice model is an improved extension of the Black-Scholes model [Teoh 2004]. Fig. 4.6 shows the basic (underlying asset) binomial lattice model. This model is based on the idea of a finite tree structure that branches out from the current asset price and from the current time until the expiration time [Hull 2000]. Decision tree is a graphical representation of the entire possible path pursued by the asset price over the specific operating time horizon. The leaves of the tree represent all possible outcomes. This model segments time to maturity into a number of time intervals or steps, which is known as the length of model period. A tree of underlying asset prices is produced by working forward from valuation date to the maturity date. The asset price is assumed to take on one of two possible values: one going up or one going down. This produces a binomial distribution of the underlying asset prices. All the possible paths that an asset price can take during the life of the option are being represented by the binomial tree. The binomial lattice model assumes [Trigeorgis 1995], [Trigeorgis 1998], [Hull 2000], [Clemen 2001], [Copeland 2001], and [Schwartz 2001]:

(a) No riskless arbitrage opportunity
(b) Asset price is represented by a binomial distribution

Normally, the binomial lattice model has two lattices:

(a) Underlying Asset Lattice (Fig. 4.6)
(b) Option Valuation Lattice (Fig. 4.7)

The option valuation lattice is a replication of the underlying asset lattice. The purpose of this lattice is to analyze the optimal decision for each node. For example, if a generation company has the option to expand its generation output anytime during the operation time horizon, then the option valuation lattice will evaluate each node in terms of whether it is more profitable to exercise the option, which is to expand its generation output, or to maintain current generation output.

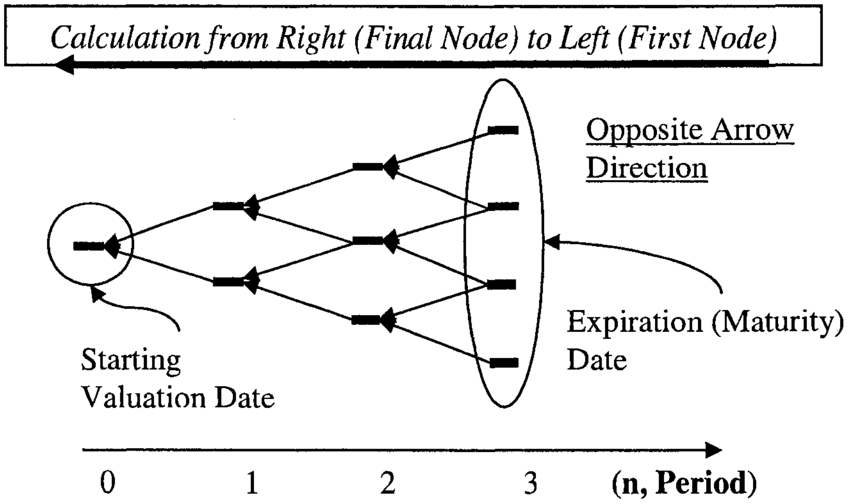


Figure 4.7 Binomial Option Valuation Lattice for Decision Analysis

The only difference between these two lattices is in terms of calculation. The calculation for the underlying asset lattice is from left to right – starting from the first node to the final node as shown in Fig. 4.6. However, the calculation for option valuation lattice is from right to left – starting from the final node to the first node as shown in Fig. 4.7. This is due to the fact that the binomial lattice model values an option by backward-flow tree induction, which is extending the replicating and related portfolio values back one period at a time from the claim values to the starting time [Teoh 2004]. In other words, the option values at each step of the tree are calculated backward from the expiration to the present. The binomial lattice model with higher uncertainty has a wider lattice. The main objective of the binomial lattice model is to calculate the option price at the initial node of the trees. Note: A more detailed step-by-step calculation explanation (with equation) of the binomial lattice model is presented in Section 4.4.

4.2.2 Value at Risk, VaR

VaR is a classic risk management tool widely used by financial institutions and corporate treasury functions in many industries [Denton 2003]. VaR measures the minimum expected loss of an asset or portfolio over a specific holding time horizon under normal circumstances. In general, VaR is a statistic that summarizes the exposure of an asset or portfolio to market risk. VaR has three critical parameters [Zask 1999], [Golub 2000], and [Dempster 2002]:

(a) The portfolio holding time horizon, which is the length of time to hold the assets in the portfolio
(b) The confidence level at which the estimate is made
(c) The expected portfolio loss amount, which can be expressed either in dollar or percentage terms

Therefore, value at risk, VaR, refers to the maximum amount at risk to be lost from an operation under normal conditions over a specific holding time horizon, at a specific confidence level. There are several methods with their own set of assumptions exist for estimating VaR [Zask 1999], [Golub 2000], and [Dempster 2002]:

(a) Historical VaR
    - Asset/portfolio returns in the future follow the same distribution as the past/history

(b) Variance-Covariance VaR

- Primitive asset/portfolio returns are (jointly) normally distributed
- Changes in portfolio value is linearly dependent on all risk factor returns

(c) Monte Carlo Simulation

- Future asset/portfolio returns are randomly simulated

This chapter mainly concentrates on the Historical VaR as this method is efficient in analyzing the model described in Section 4.4. The implementation of VaR into the lattice model to solve the curse of dimensionality is known as binomial lattice-value at risk, BL-VaR. The model of BL-VaR is presented in the following section.

4.3 Binomial Lattice–Value at Risk, BL-VaR, Model

The binomial lattice model is widely used as it has the flexibility of handling various conditions. This model is easy to understand and implement. The main disadvantage of the binomial lattice model is closely related to its lattice dimension. To obtain a good approximation, this model requires significant length of model period (time-steps). Therefore, when the investment duration is large and the length of model period is small, the binomial model becomes a massive bush of lattice, which is referred to as the curse of dimensionality as shown in Fig. 4.6. The binomial lattice dimension expands by 2^n for each additional model period. Besides that, the calculation becomes tedious and time consuming.

The massive bush of binomial lattice can be reduced by analyzing the boundary of the lattice where the decision changes. Therefore, the curse of lattice dimensionality can be solved by applying the ideology of value at risk, VaR, into the lattice model. As mention in Section 4.2, VaR is the maximum amount at risk to be lost from an operation under normal conditions over a specific holding time horizon, at a specific confidence level. The graphical representation of VaR is shown in Fig. 4.8.

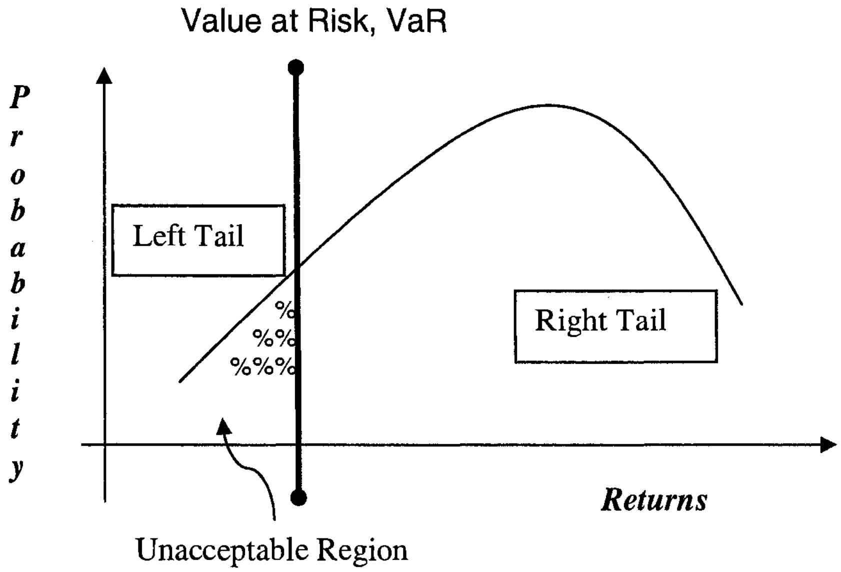


Figure 4.8 Value at Risk, VaR, Graphical Representation

Usually the order of returns is arranged from left to right. The worst are always at the "left tail". Therefore, the unacceptable region for a given confidence level is always at the "left tail".

For example, the owner of a generation portfolio only knows his/her portfolio market value for today. However, the holder does not know his/her portfolio market value after today. The holder of the portfolio may indicate his/her maximum expected portfolio loss amount (or maximum amount at risk to be lost from an operation) after today by observing and analyzing the historical portfolio returns data. Therefore, he or she can be expected to state that his/her portfolio has a 10-day VaR of USD 80,000 at 95% confidence level. Under normal conditions, the holder expects, with a probability of 95%, the maximum value by which his/her portfolio will decrease is USD 80,000, which is the threshold level [Zask 1999] and [Denton 2003]. Any amount that falls below the threshold level is considered to be unacceptable for the portfolio holder. For this chapter, all VaR calculations are based on the Historical VaR method [Zask 1999].

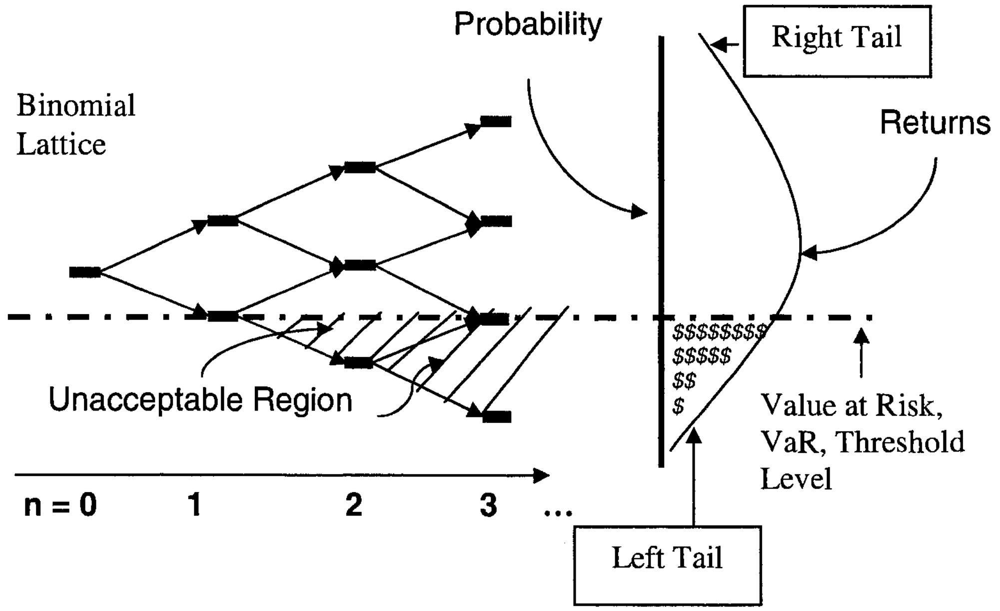


Figure 4.9 Graphical Representation of Binomial Lattice-Value at Risk, BL-VaR, Model

Fig. 4.9 shows the graphical representation of binomial lattice-value at risk, BL-VaR, model. The VaR threshold level represents the boundary of the portfolio holder's decision: to accept (commit) or to reject (not to commit). Once the holder sets his/her VaR threshold level, this threshold level can be applied to the binomial lattice. This is similar to as extending the VaR threshold line from the returns distribution to the binomial lattice as shown in Fig. 4.9. Any node that plunges below the VaR threshold level is categorized as the unacceptable node or eliminated node. This leads to the reduction of lattice dimensionality. Let us look at Fig. 4.9 as an illustration of a simple example. There are ten nodes in the binomial lattice. With the implementation of VaR threshold level, only eight nodes are being considered or evaluated. This is due to the fact that the remaining two nodes fall under the unacceptable region category. This example illustrates a twenty-percent binomial lattice dimension reduction. Note: by considering every feasible outcome/return from the binomial lattice, a normal distribution is established as shown in Fig. 4.8 and Fig. 4.9. Section 4.4 provides the standard procedure for BL-VaR model.

4.4 Binomial Lattice–Value at Risk, BL-VaR, Model Procedure

At the end of the operation time horizon, all feasible outcomes/returns from the binomial underlying asset lattice will form a normally distributed plot (probability/frequency versus return). This characteristic applies to all binomial lattice models regardless of the time duration or the length of model period. The first step is to apply the Historical VaR method to calculate the VaR threshold level. This method re-organizes the returns both profit and loss, positioning them in the order from worst to best - the worst are located at the "left tail" and the best are located at the "right tail". The X-axis represents return and the Y-axis represents either probability or frequency. The general equation of VaR calculation is as follows [Zask 1999]:

- VaR = CGPMV* R^p

  Where

  CGPMV = Current Generation Portfolio Market Value

  R^p = p percentile return

Fig. 4.9 shows the implementation of value at risk, VaR, into the binomial lattice model: VaR threshold level line is extended to the binomial lattice. Therefore, any node that falls below the VaR threshold level (the unacceptable region) is ignored.

The next step is to construct the underlying asset lattice. Fuel cost is one of the most critical cost components for a generation plant. Thus, the model in this chapter has natural gas cost (fuel cost) as the only uncertainty element. All other elements are assumed to be known. Natural gas price is treated as the underlying asset price for the binomial lattice model shown in Fig. 4.9. To estimate the natural gas volatility used in Real Options Analysis, ROA, (lattice method), this chapter focuses on the logarithmic asset price return approach. This approach uses the individual forecasted asset price estimates and their corresponding logarithmic returns. First, all the forecasted asset prices are converted into their relative returns, each respectively. Then, each of these relative returns is converted into its natural logarithms. The standard deviation of these natural logarithm returns is the volatility of the asset price. The equation for volatility estimation is as follows [Mun 2003]:

- $Volatility = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}(x_i - \bar{x})^2}$

  Where

  n = the number of returns

  x = natural logarithm of cash flow returns

  $\bar{x}$ = average of x value

The proposed binomial lattice-value at risk, BL-VaR, model has three different lattices:

(a) Underlying Asset (Natural Gas) Lattice
(b) Decision Analysis (Profit & Loss) Lattice
(c) Option Valuation Lattice

For the underlying asset (natural gas) lattice, every natural gas price (node) has two possible movements for the following period: one goes up or one goes down, as shown in Fig. 4.10.

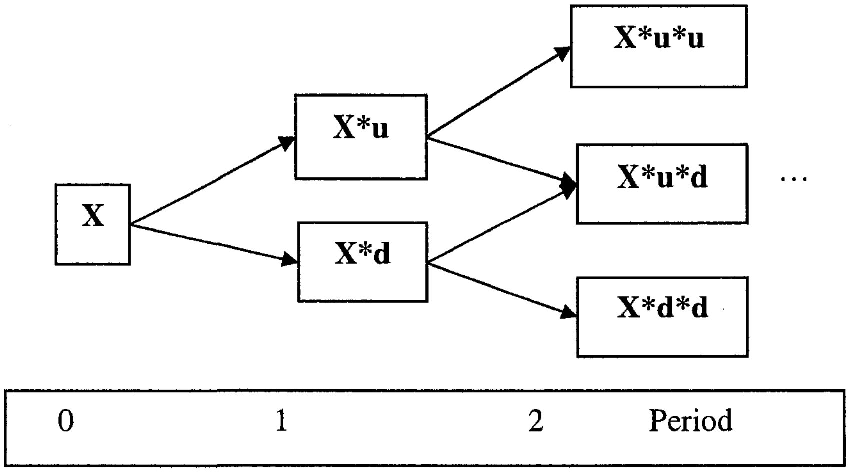


Figure 4.10 Example: 2-Step Binomial Underlying Asset Lattice

Where

- X = underlying asset → natural gas price
- u = upward movement → $e^{\sigma\sqrt{\Delta t}}$
- d = downward movement → $e^{-\sigma\sqrt{\Delta t}}$
- σ = volatility
- Δt = stepping time (the time scale between steps)

The forecasted natural gas price is used to calculate the cost of the generation company. Together with the revenue equation, the calculation of Profit and Loss, P&L, at each node is achievable – the realization of decision analysis lattice.

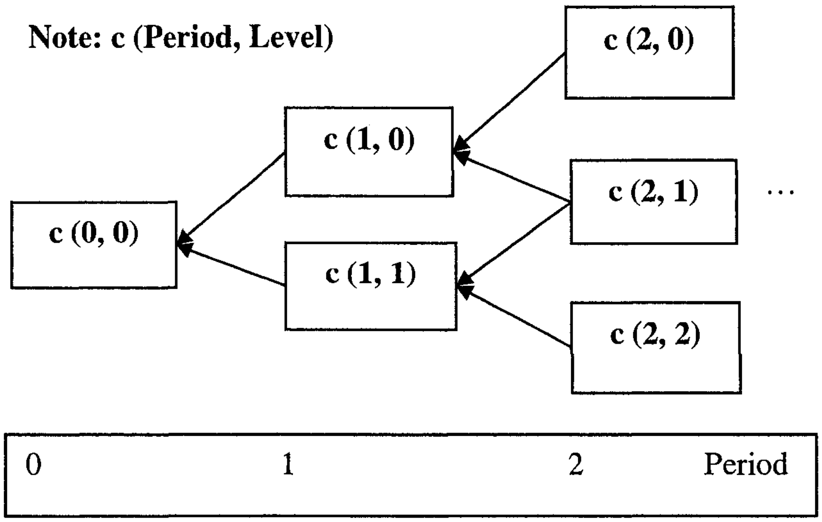


Figure 4.11 Example: 2-Step Binomial Option Valuation Lattice

The last step is to construct the option valuation lattice. The option value at each node can be obtained using the risk-neutral probabilities approach. Each option calculation follows a general formula (for example, in Fig. 4.11, the maturity date is the second period) as shown next page [Trigeorgis 1995], [Trigeorgis 1998], [Hull 2000], [Clemen 2001], [Copeland 2001], [Schwartz 2001], and [Teoh 2004].

- Option values at maturity, $c(2, x)$

  $$c(2, x) = \max(0, revenue - \cos t)$$

- Option values before maturity,

  For example, $c(1, x)$

  $$c(1, x) = \frac{p * c(2, x) + (1 - p) * c(2, x+1)}{e^{rf * \Delta t}}$$

  Where

  $$p = \frac{e^{(rf) * \Delta t - d}}{u - d} \quad \text{and} \quad \text{rf} = \textit{risk-free rate}$$

The option value calculation is based on a backward-flow tree approach: the option value at each step of the lattice is calculated backward from the expiration to the present as shown in Fig. 4.11 [Teoh 2004]. In general, there are four major steps in binomial lattice-value at risk, BL-VaR, model. Section 4.5 presents an example for this new efficient approach.

4.5 Example of Binomial Lattice-Value at Risk, BL-VaR, Model

Table 4.5 Elements of Binomial Lattice-Value at Risk, BL-VaR, Model

Elements	**Unit**	**Value**
Price of Electricity, S_h^e	\$/MWh	8.28
Output Level, Q	MWh	1000
Operation &Maintenance, $O\&M$	\$/MWh	0.69
Natural Gas Price, S_h^f	\$/MWh	Unknown
Volatility, σ	-	Calculate
Risk-Free Rate, rf	%	5
Period under consideration, n	Day	10

In this section, an example of binomial lattice–value at risk, BL-VaR, model is illustrated. There is only one uncertain element for the model presented in this section. The uncertain element is the daily price of natural gas. Thus, the daily natural gas price is treated as the underlying asset. Table 4.5 summarizes all the important elements (both known and unknown) for this model.

The price of natural gas is assumed to follow the same distribution as the past. The logarithmic asset price return approach is used to estimate the natural gas volatility used in Real Options Analysis, ROA, (lattice method). The critical calculated inputs for binomial underlying asset lattice construction are as follows:

- Volatility → 0.037
- Upward Movement → 1.038
- Downward Movement → 0.964
- Stepping Size → 1

Profit and Loss, P&L, calculation is then assigned to each node to obtain the decision analysis lattice:

- Revenue $= S_h^e * Q$
- Cost $= (S_h^f + O\&M) * Q$
- P&L Returns = Revenue – Cost

For this model, the historical return for the generation company is normally distributed as shown in Fig. 4.12. The returns (both profit and loss) are positioned in the order from worst at "left tail" to the best at "right tail".

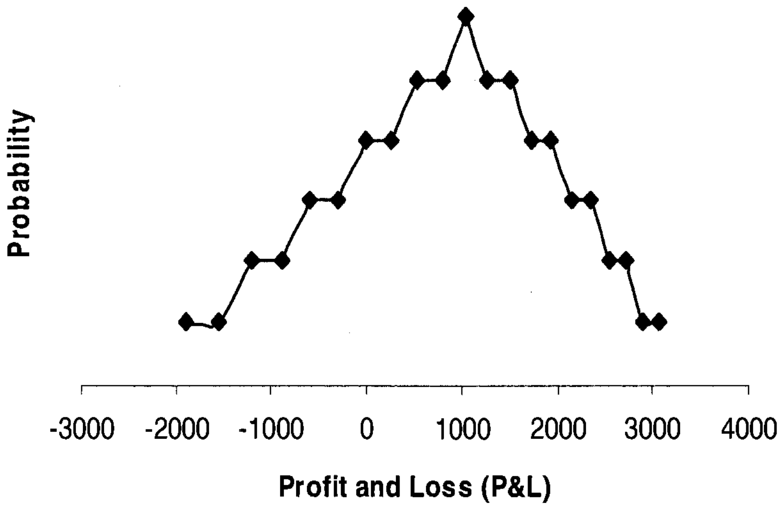


Figure 4.12 Daily VaR Distributions for BL-VaR Model

The value at risk, VaR, calculation is performed using the Historical VaR method.

Table 4.6 Evaluated and Eliminated Nodes for each Confidence Level

Confidence Level/Percentile	Evaluated Nodes	Eliminated Nodes
70% (or 0.30 percentile)	46	20
80% (or 0.20 percentile)	54	12
85% (or 0.15 percentile)	57	9
90% (or 0.10 percentile)	60	6
95% (or 0.05 percentile)	62	4

Assigning different confidence level will result in different VaR threshold level. A 95% confidence level is equivalent to the fifth percentile of any P&L returns. Table

4.6 summarizes the number of nodes that need to be evaluated (Evaluated Node) and the number of nodes that fall under the unacceptable region category (Eliminated Node) for each confidence level respectively. For this model, the total nodes of the binomial lattice without considering the implementation of value at risk, VaR, threshold level are sixty-six.

Therefore, by implementing the ideology of VaR threshold level, the degree of binomial lattice dimension can be reduced. The degrees of dimension reduction are dependable on the assigned confidence level. A 10-day 90% VaR results in a 9% lattice dimension reduction; a 10-day 80% VaR results in an 18% lattice dimension reduction, and so on. In terms of the option value, the calculated option value for this new method is the same as the one without the implementation of VaR threshold level. Thus, besides solving the curse of lattice dimensionality, this new efficient approach is also capable of maintaining high accuracy.

4.6 Conclusion

In conclusion, this new efficient binomial lattice-value at risk, BL-VaR, approach is capable of solving the curse of dimensionality for the binomial lattice method. The massive bush of lattice method can be reduced by analyzing the boundary of the lattice where the decision changes. This is achieved via the implementation of value at risk, VaR, into the lattice model. The VaR threshold level represents the decision decided by the owner after taking into account various considerations: financial, philosophy, budgeting, market risk, and others. The degree of dimension reduction is dependable on the degree of confidence level assigned. And the reduction of lattice dimension is critical in terms of timing issue. Besides reducing the degree of dimensionality, this new methodology also specifies "when" a decision changes. This is a very critical part in strategic budgeting planning. Timing and simplification yet maintaining high accuracy in analysis are essential in the new deregulated power economic uncertainties.

This chapter provides the basis for possible extensions. One interesting extension is the implementation of profit at risk, PaR, ideology, instead of VaR, into binomial lattice.

CHAPTER 5. REAL OPTIONS IMPACT ON CAPITAL BUDGETING

Chapter 5 enhances the binomial lattice-value at risk, BL-VaR, model introduced in Chapter 4. In a competitive deregulated energy industry, profit has become the center of attention. Any electric utility that does not produce any profit in a medium-to-long run is likely to be eliminated from the industry. Therefore, the implementation of profit at risk, PaR, ideology, instead of VaR, into binomial lattice is desirable.

5.1 Introduction

The United States deregulated energy market has only been operated for a short time: the US energy market is still characterized as immature. The market and regulatory frameworks are expected to continue to evolve in the future. Under the policy of a regulated monopoly, a utility has a guaranteed fair rate of return in exchange for an obligation to serve. However, in a deregulation market, there is no guarantee fair rate of return [Teoh 2004]. Therefore, the deregulation policy introduces uncertainties into the power market. Obliged to meet demand and maximize profit, generation companies seek to find the most economical and feasible way to perform their capital budgeting and operate their generation assets.

Due to deregulation, the realization of cash flow varies over time. When new information arrives, the market uncertainties become clearer. Electric utility needs to reevaluate the previous decision to maximize the utility's rate of return

[Teoh 2004]. Therefore, two decision analysis factors, financial risks and managerial flexibility, become significant under a deregulated energy market. Real Options Analysis, ROA, enables such flexibility for the management. As mentioned in Chapter 4, there are four major methods often used in ROA and this dissertation concentrates on the lattice method. To define a lattice model, the investment duration under consideration and the length of model period need to be established [Luenberger 1998]. The investment duration under consideration refers to the total investment time. The investment duration can be in terms of days, weeks, months, or years. The length of model period refers to the step size of each period. When the investment duration is small (or the length of model period is large), the lattice model is easy to appreciate and understand. However, when the investment duration is large (or the length of model period is small), the lattice model becomes a massive bush of lattice, which is known as the curse of dimensionality. This dissertation proposes a new, efficient methodology known as binomial lattice-profit at risk, BL-PaR. This proposed method of integrating profit at risk, PaR, into ROA achieves three critical goals:

(a) Simplicity as it reduces the dimensionality of binomial lattice method
(b) Timing as it reduces the computation time
(c) Reliability as it maintains the accuracy of the final result

PaR measures the minimum expected profit of a portfolio over a holding time. It sets the benchmark for future operations. Strategic planning committees, SPCs, designate a certain percentage of the portfolio profit requirements above the benchmark. This leads to achieving the target of performing a company's operations over a comfort zone. The ideology of comfort zone is derived from Capital Asset Pricing Model, CAPM. CAPM is an investment model used by investors to determine return and risk associated with an investment or portfolio. For example, in the stock market, stock market analysis generally set a price target for each stock based on the beta value of the stock. Beta value is a measure of a stock's volatility with respect to market volatility. The market volatility is taken as 1, and beta values of a stock are calculated as a measure of how much the stock price moved from this market volatility. As illustrated in Fig. 5.13, the solid node represents the price target expectation set by the stock market analysis. Due to the uncertainty of a competitive stock market, the fluctuations of stock price are unavoidable. Stock market analysis establishes the boundary of acceptable stock price ranges, which is known as the tolerance circle (the bigger circle). Therefore, in my research, the solid node represents PaR. The upper half of the tolerance circle represents the comfort zone. An electric utility first tries to meet the overall sector's expectation – the solid node. Then it tries to exceed the company's portfolio expectation set by strategic planning committees, SPCs (the upper half of the tolerance circle). Therefore, this method is also capable of entertaining risk management: it enables SPCs to set an electric utility's goals.

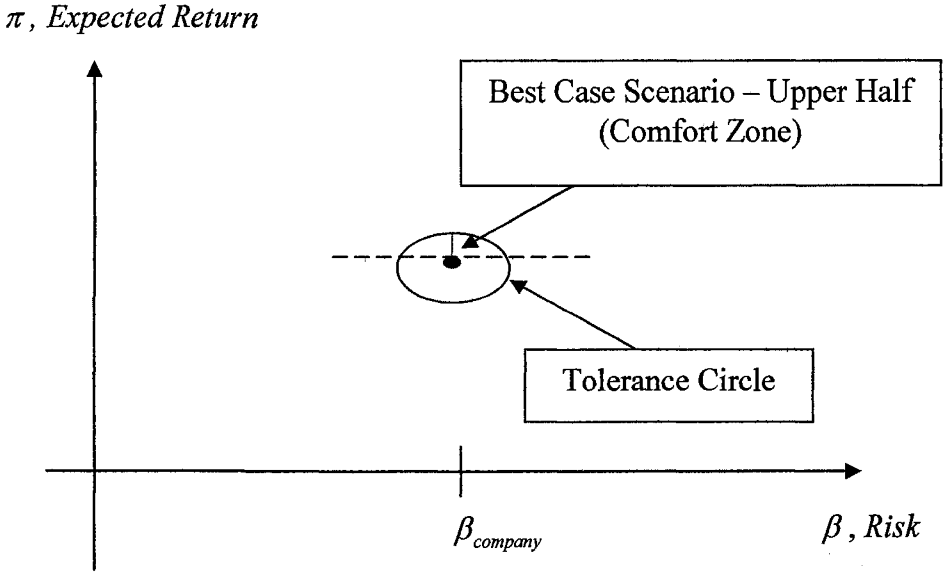


Figure 5.13 Comfort Zone Graphical Representation

Section 5.2 provides an introduction and comparison of PaR with VaR. An overview of the binomial lattice model is presented in Section 5.3 [Teoh 2007]. Section 5.4 introduces the new, efficient approach, which is known as the binomial lattice-profit at risk, BL-PaR, approach. The combination of lattice method with PaR simplifies the binomial lattice model, and thus solves the curse of lattice dimensionality. An example of BL-PaR calculation is performed in Section 5.5. Section 5.6 discusses the conclusions and the potential extension to this research.

5.2 Profit at Risk, PaR, versus Value at Risk, VaR

Before deregulation, many electric utilities set their own prices and the services they offered. Basically, the main purpose of all electric utilities is to provide electric service to energy consumers with a balance of cost and reliability appropriate to meet the requests of their customers [Willis 2004]. This fundamental purpose of planning has never changed. The main risk that any regulated electric utility faces is the change of tariff by the Public Utility Commissions, PUCs. PUCs are formed by state governments to protect the consumers. Thus, the risk that any electric utility faces is very low.

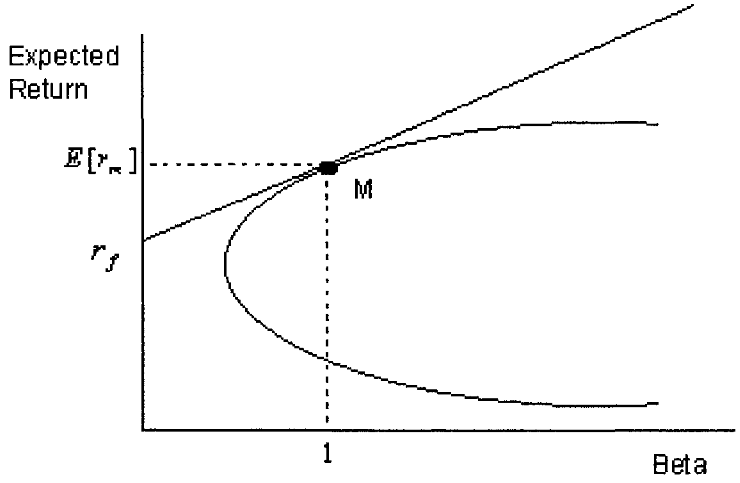


Figure 5.14 Capital Asset Pricing Model, CAPM

CAPM is an economic model that relates expected return with risk/beta. It is based on the idea that if investors shoulder additional risk, they demand additional expected return. Therefore, when the risk/beta is low, the expected return is low as shown in Fig. 5.14. The formula to calculate profit is as follows:

- $\pi = R - E$

  Where

  R = revenue (or expected return)

  E = expenses

With an almost fixed expected return, many electric utilities before deregulation focus on the term "loss," which is to minimize and control the operation's expenses as shown in equation above.

According to [Willis 2004],

> "Every electric utility represents some combination of three distinct 'cultures' or attitudes diffused throughout the organization, with more or less of a 'hold' on some portions than others."

The three "cultures" are equipment, stockholder, and customer as shown in Fig. 5.15 [Willis 2004]. Strategic utility planning can be demonstrated as a balance between these three cultures. The explanation of each culture is as follows [Willis 2004]:

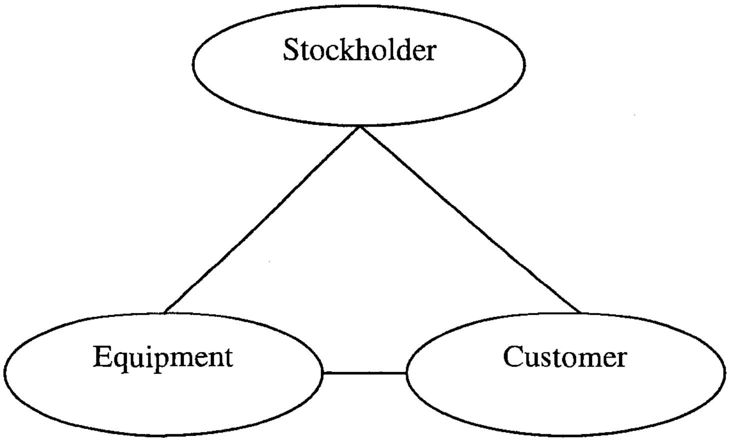


Figure 5.15 Three Major Cultures of Electric Utility

(a) Stockholder Steward

This culture considers that an electric utility is just another type of business. The main objective of operating a business is to make money for its investors and to meet its capital budget commitments. Members of the executive committee are always business-oriented, and thus always fall under this culture. The most important aspects in this culture are stock price, budget balance, and profitability [Willis 2004].

(b) Equipment Stewardship

For most traditional utilities, this culture emphasizes that "equipment and facilities must be cared for and preserved in good condition, simply because 'our job' is to do so" [Willis 2004]. Equipment lifetime expectation is infinite. Any major equipment failure is considered as a failure of the organization to carry its job.

(c) Customer, or Public, Steward

This culture considers that customers are always at the top of the priority lists. The utility's obligation is to do the right thing and satisfy the needs of customers.

Every electric utility is a mixture of these three cultures. Fig. 5.16 illustrates the general electric utility cultures' trend [Willis 2004]. Before deregulation, the stockholder stewardship culture was not as important. However, due to deregulation and an increasing emphasis on service reliability, these two major drives have changed the cultures in energy industry. Customer and stockholder issues become significant and equipment issues become less important. According to [Willis 2004], we can draw out a conclusion that the stockholder culture is gaining attention nowadays.

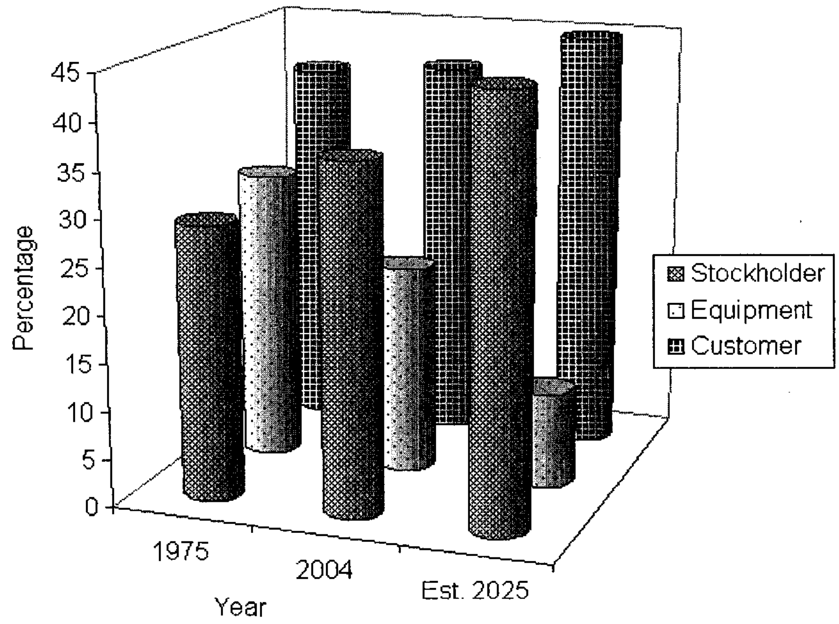


Figure 5.16 Electric Utility Cultures Trend [Willis 2004]

In general, the idea of deregulation is to cut consumers' costs by giving them a choice in selecting their supplier. Deregulation lowers costs, improves service, and opens the industries to more efficient competitors. Reliability reflects a change in customer needs from the utility. As illustrated in Fig. 5.16, the stockholder issue is gaining tremendous attention. In other words, the concept of profitability is becoming more significant. In a competitive industry, profit represents everything. Any electric utility that does not produce any profit in the medium-to-long run is likely to be eliminated from the industry. Profit has become the center of attention for the deregulated energy industry. Therefore, from here onwards, this dissertation will be focusing on profit instead of loss.

PaR measures the minimum expected profit of an asset or portfolio over a specific holding time under normal circumstances. The main distinction between VaR and PaR is in terms of the perspective. Bottom-line profit is the center of attention for PaR. In general, PaR is a statistic that summarizes the profit exposure of an asset or portfolio to market risk. PaR has three critical parameters [Zask 1999], [Golub 2000], [Dempster 2002], and [Teoh 2007]:

(a) The portfolio holding time, which is the length of time to hold the assets in the portfolio
(b) The confidence level at which the estimate is made
(c) The expected portfolio profit amount, which can be expressed either in dollar or percentage terms

Looking from a different perspective, profit at risk, PaR, refers to the maximum profit amount at risk to be lost from an operation under normal conditions over a specific holding time at a specific confidence level. Fig. 5.17 shows the graphical representation of PaR. The order of asset price returns is arranged from the left to the right. The worst are always at the "left tail." Therefore, the unacceptable region for a given confidence level is always at the "left tail." The most important contribution of PaR is the improvement in the quality of the risk management. Note: PaR is only an estimate, not a uniquely defined value. For example, the owner of a generation portfolio only knows her portfolio market value for today. However, the holder does not know her portfolio market value after today. The holder of the portfolio may indicate her maximum expected profit portfolio loss amount (or maximum profit amount at risk to be lost from an operation) after today by observing and analyzing the portfolio returns data. A simple example is illustrated: the owner of a generation portfolio can be expected to state that her portfolio has a 5-day PaR of USD 50,000 at a 90% confidence level. The formula to calculate the PaR threshold level is listed in Section 5.4. Under normal conditions, the holder expects, with a probability of 90%, the maximum profit value of her portfolio at risk is USD 50,000, which is the threshold level [Zask 1999] and [Denton 2003]. Any amount that falls below the threshold level is considered as unacceptable for the portfolio holder.

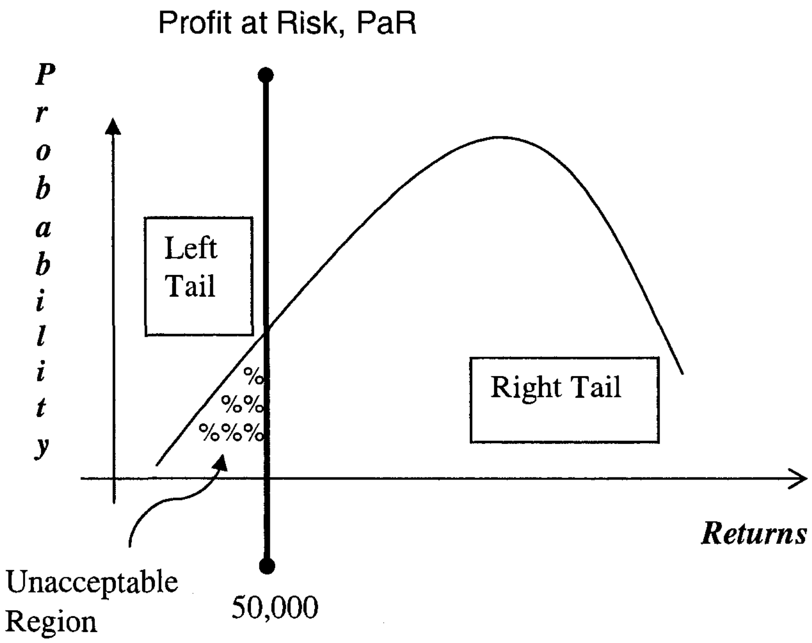


Figure 5.17 Profit at Risk, PaR, Graphical Representation

The shaded area represents the maximum expected portfolio losses. This area is based on market expectation instead of distribution. As mentioned in the previous chapter, several methods with their own set of assumptions exist for estimating PaR are illustrated in [Zask 1999], [Golub 2000], [Dempster 2002], and [Teoh 2007]. This chapter also mainly concentrates on the Historical PaR method. This method assumes that the asset/portfolio returns in the future follow the same distribution as the past. In general, PaR provides a useful summary measure of market risk due to [Zask 1999]:

(a) PaR provides the capability of examining the potential least profit over a specific holding time

(b) PaR consistency as a measure of financial risk by referring to risk as a possible least-dollar-profit

(c) Probability Theory - PaR allows a specific potential estimated least profit over the holding time period to be linked with that specific level of confidence

5.3 Binomial Lattice Model

The binomial lattice model is one of the major methods of Real Options Analysis, ROA. This model is based on the idea of a finite tree structure that branches out from the current asset price and from the current time until the expiration time [Hull 2000]. The entire possible path pursued by the asset price over the specific operating timeframe is represented by a decision tree. Every leaf of the tree represents each possible outcome. This model segments time to maturity into a number of time intervals or steps, which is known as the length of model period [Teoh 2007]. A tree of underlying asset prices is produced by working forward from valuation date to the maturity date. According to the binomial distribution process, the asset price is assumed to take on one of two possible values: one going up or one going down.

The assumptions of the binomial lattice model are as follows:

(a) No riskless arbitrage opportunity

(b) Asset price is represented by a binomial distribution

Normally, a binomial lattice model consists of two major lattices:

(a) Underlying Asset Lattice (Fig. 5.18)

(b) Option Valuation Lattice (Fig. 5.19)

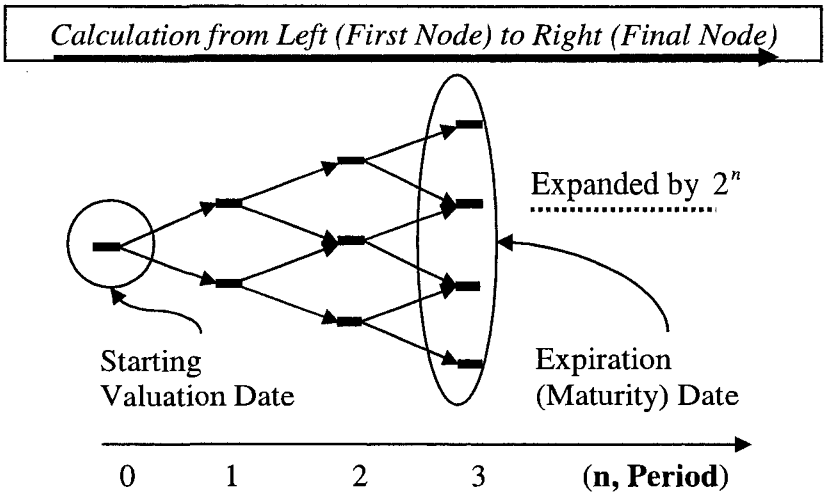


Figure 5.18 Binomial Underlying Asset Lattice for Simulation

As mentioned in [Teoh 2007], the option valuation lattice is a replication of the underlying asset lattice. The purpose of this lattice is to analyze the optimal decision for each node [Teoh 2007]. For example, if a generation company has the option to contract its generation output anytime during the operation time, then the option valuation lattice will evaluate each node whether it is more effective in terms of profitability to exercise the option, which is to contract its generation output, or to maintain current generation output.

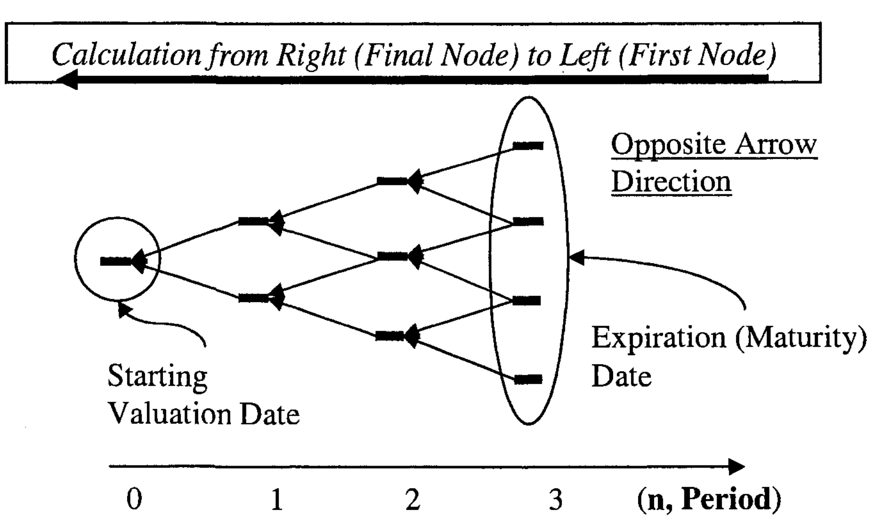


Figure 5.19 Binomial Option Valuation Lattice for Decision Analysis

The only difference between these two lattices is in terms of calculation [Teoh 2007]. The calculation for the underlying asset lattice is from left to right – starting from the first node to the final node as shown in Fig. 5.18. However, the calculation for option valuation lattice is from right to left – starting from the final node to the first node as shown in Fig. 5.19. This is due to the fact that a binomial lattice model values an option by backward-flow tree induction, which is extending the replicating and related portfolio values back one period at a time from the claim values to the starting time [Teoh 2004]. The option values at each step of the tree are calculated backwards from the expiration to the present. The main objective of a binomial lattice model is to calculate the option price at the initial node of the trees. Detailed explanations of the binomial lattice model are also illustrated in

[Trigeorgis 1995], [Luenberger 1998], [Trigeorgis 1998], [Hull 2000], [Clemen 2001], [Copeland 2001], [Schwartz 2001], and [Mun 2003], and [Teoh 2004].

5.4 Binomial Lattice-Profit at Risk, BL-PaR, Model

Fig. 5.20 shows the graphical representation of the binomial lattice-profit at risk, BL-PaR, model. This model has three main steps. The first step of the BL-PaR model is to construct the underlying asset binomial lattice. Fuel cost is one of the most critical cost components for a generation plant. Thus, the model in this chapter has natural gas cost (fuel cost) as the only uncertain element. Currently, the usage of natural gas to generate electricity is still increasing. Therefore, the price of natural gas is increasing. The selection is due to the fact that natural gas is the cleanest burning fossil fuel and it produces fewer emissions compared to other fuels. The rise of natural gas prices has been the major factor in increasing the electricity rate. All other elements are assumed to be known. Natural gas price is treated as the underlying asset price for the binomial lattice model. To estimate the natural gas volatility used in Real Options Analysis, ROA, this chapter focuses on the logarithmic asset price return approach. After obtaining the estimated natural gas price for each node, Profit and Loss, P&L, calculation is then performed on each node.

As mentioned in [Teoh 2007], a binomial lattice model has the flexibility of handling various conditions. It is easy to implement and understand. However, a binomial lattice model has a major disadvantage that is closely related to its lattice

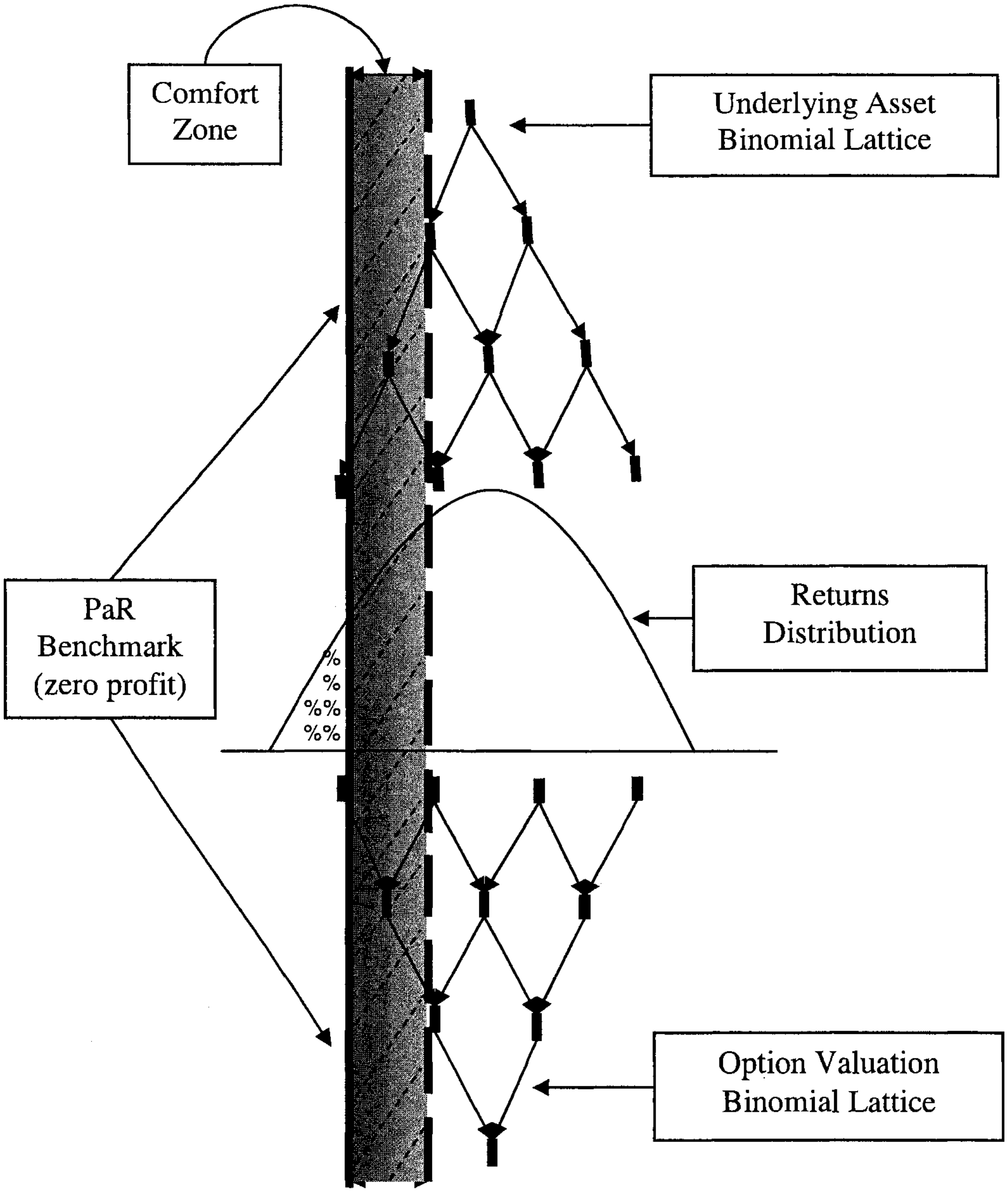


Figure 5.20 Graphical Representation of Binomial Lattice-Profit at Risk, BL-PaR, Model

dimension. To obtain a good approximation, this model requires significant length of model period (time-steps). Therefore, when the investment duration is large and the length of model period is small, the binomial model becomes a massive bush of lattice, which is referred to as the curse of dimensionality as shown in Fig. 5.18. The binomial lattice dimension expands by 2^n for each additional model period.

The next step is to reduce the massive bush of binomial lattice by analyzing the boundary of the lattice where the decision changes. The concept of implementing value at risk, VaR, into the lattice model is applied by [Teoh 2007]. However, as shown in Section 5.2, profit has become the center of attention for the deregulated energy industry. Therefore, this dissertation focuses on profit instead of loss and suggests that the curse of lattice dimensionality can be solved by integrating profit at risk, PaR, into the lattice model as shown in Fig. 5.20. PaR is the maximum profit amount at risk to be lost from an operation under normal conditions over a specific holding time at a specific confidence level. Fig. 5.17 shows the graphical representation of PaR. The PaR threshold level is calculated using the Historical PaR method. This method re-organizes the returns (both profit and loss), positioning them in the order from the worst to the best; the worst is located at the "left tail" and the best is located at the "right tail." The PaR threshold level stands for the boundary of a portfolio holder's decision: to commit or not to commit. For this model, the benchmark for the PaR threshold level is set to be exactly at zero profit (break-even point). Then, a minimum percentage profit above the PaR benchmark, known as a comfort zone, is established by the strategic planning committees, SPCs. The purpose of creating a comfort zone is to enable the SPCs to set the minimum profit requirement guideline.

Once the PaR threshold level and the comfort zone have been determined, both of the guidelines can be applied to the binomial lattice. This is similar to extending both of the lines, the PaR threshold line and the comfort zone line, vertically from the underlying asset lattice to the option valuation lattice as shown in Fig. 5.20. It can be observed that at the end of the operation time, all feasible outcomes/returns from the binomial underlying asset lattice form a normally distributed plot (probability/frequency versus returns) regardless of the time duration or the length of the model period.

As an example, let us look at Fig. 5.20. The underlying asset binomial lattice has ten nodes. With the implementation of the PaR, threshold level and a comfort zone, only eight nodes are being considered or evaluated. This is due to the fact that the remaining two nodes fall under the unacceptable region category. This example illustrates a twenty-percent binomial lattice dimension reduction.

The last step is related to the construction and calculation of the option valuation lattice. The option value at each node can be obtained using the risk-neutral probabilities approach. The option value calculation is based on a backward-flow tree approach. An example of the BL-PaR model is illustrated in the following section - Section 5.5.

5.5 Example of Binomial Lattice-Profit at Risk, BL-PaR, Model

As mentioned in Section 5.4, the first step of the BL-PaR model is to construct the underlying asset binomial lattice. The price of natural gas (fuel price) is treated as the underlying asset price because it is the only uncertain element in the model. The natural gas volatility, σ_{ng}, is calculated using the logarithmic asset price return approach. This approach utilizes all the individual forecasted asset price estimates and their corresponding logarithmic returns [Teoh 2007]. First, all the forecasted asset prices are converted into their relative returns. Then, each of these relative returns is converted into its natural logarithms. The standard deviation of these natural logarithm returns is the asset price volatility. The volatility estimation equation is as follows [Mun 2003]:

- $Volatility = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}(x_i - \bar{x})^2}$

Where

n = the number of returns

x = natural logarithm of cash flow returns

$\bar{x}$ = average of x value

After obtaining σ_{ng}, the next step is to construct the complete underlying asset binomial lattice by including the Profit and Loss, P&L, calculation. Fig. 5.21 shows the first few steps of the underlying asset lattice calculation. For the underlying asset lattice, every natural gas price has two possible movements for the following period: one goes up or one goes down. The total expenses of a generation company to generate electricity for a specific time period can be estimated using the forecasted natural gas price. Together with the P&L calculation at each node, the realization of a decision analysis lattice is achievable. The formula of P&L is as follows:

- Revenue $= S_h^e * Q$
- Cost $= (S_h^f + O\&M) * Q$
- P&L Returns = Revenue – Cost

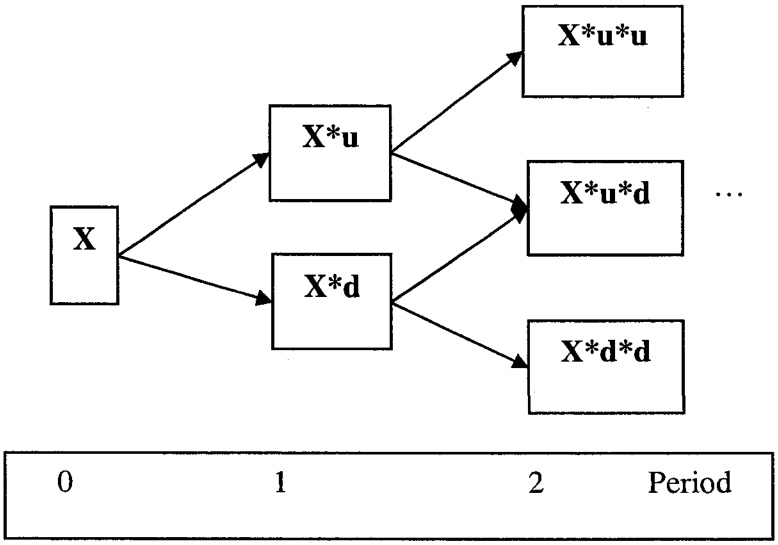


Figure 5.21 Example: 2-Step Binomial Underlying Asset Lattice

Where

- X = underlying asset → natural gas price
- u = upward movement → $e^{\sigma\sqrt{\Delta t}}$

- d = downward movement → $e^{-\sigma\sqrt{\Delta t}}$
- σ = volatility
- Δt = stepping time (the time scale between steps)

Table 5.7 Elements of Binomial Lattice-Profit at Risk, BL-PaR, Model

Elements	**Unit**	**Value**
Volatility, σ_{ng}	-	0.03585
Upward Movement	-	1.037
Downward Movement	-	0.965
Stepping Size	-	1
Risk-Free Rate, rf	%	5
Period under consideration, n	Day	20
Average Electricity Price, S_h^e	$/MW	7.82
Average Daily Electricity Output, Q	MW	10000
Operation &Maintenance, $O \& M$	$/MW	0.7
Average Natural Gas Price, S_h^f	$/MW	5.739

All the variables that are critical to construct the complete underlying asset lattice are summarized in Table 5.6. And the following step is to apply the Historical PaR method to calculate the PaR threshold level.

The general equation for the PaR calculation is as follows [Zask 1999]:

- PaR = CGPMV* R^p

  Where

  CGPMV = Current Generation Portfolio Market Value/Returns

  R^p = p percentile return

Table 5.8 Evaluated and Eliminated Nodes for each Confidence Level

Confidence Level with 18% Comfort Zone	**Evaluated Nodes**	**Eliminated Nodes**
99% (or 0.01 percentile)	227	4
95% (or 0.05 percentile)	215	16
90% (or 0.10 percentile)	206	25
85% (or 0.15 percentile)	195	36
80% (or 0.20 percentile)	182	49
75% (or 0.25 percentile)	167	64

Assigning a different confidence level will result in a different PaR threshold level. The confidence level is the interval estimate in which the PaR would not be expected to exceed the maximum profit amount at risk to be lost from an operation. Confidence levels are not indications of probabilities. A 90% confidence level is equivalent to the tenth percentile of any P&L returns. For this example, the benchmark for the PaR threshold level is set to be at zero profit (break-even point), which is at 75% confidence level. The minimum percentage profit above the PaR benchmark, known as a comfort zone, is then established by the SPCs. An 18% comfort zone (or 18% minimum profit requirement - USD 2506, above the PaR benchmark), has been established. Table 5.8 summarizes the number of nodes that need to be evaluated and the number of nodes that fall under the unacceptable region category for each confidence level respectively. The total nodes of the binomial lattice without considering the implementation of the PaR threshold level and the comfort zone are 231.

The degree of binomial lattice dimension reduction depends on the assigned confidence level and comfort zone. A one-month PaR at a 90% confidence level, together with an 18% comfort zone results in an 11% lattice dimension reduction; a one-month PaR of zero profit at a 75% confidence level, together with an 18% comfort zone results in a 28% lattice dimension reduction, etc.

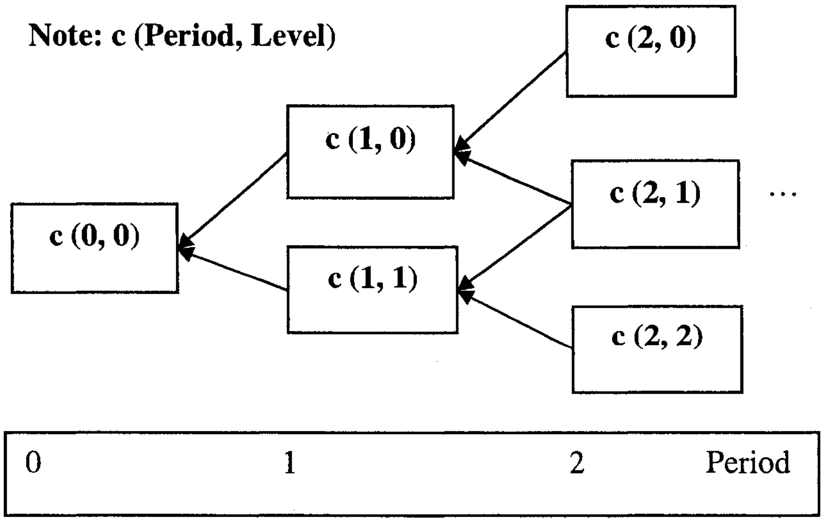


Figure 5.22 Example: 2-Step Binomial Option Valuation Lattice

The last step is the construction and calculation of the option valuation lattice. The option value at each node is calculated using the risk-neutral probabilities approach. The option value calculation is based on a backward-flow tree approach: the option value at each step of the lattice is calculated backward from the expiration to the present as shown in Fig. 5.22 [Teoh 2004].

Any node that falls to the left of the comfort zone is ignored. Each option calculation follows a general formula (for example, in Fig. 5.22, the maturity date is the second period) [Trigeorgis 1995], [Trigeorgis 1998], [Hull 2000], [Clemen 2001], [Copeland 2001], [Schwartz 2001], and [Teoh 2004]:

- Option values at maturity, $c(2,x)$

  $$c(2,x) = \max(0, revenue - \cos t)$$

- Option values before maturity,

  For example, $c(1,x)$

  $$c(1,x) = \frac{p * c(2,x) + (1-p) * c(2,x+1)}{e^{rf * \Delta t}}$$

With the integration of both the PaR threshold level at zero profit and a comfort zone, the calculated option value is USD 13,773.50, which is same as the calculated option value without considering the integration of the PaR threshold level and a comfort zone. Do keep in mind: we are calculating the value of option flexibility. According to [Mun 2002], "the traditional NPV analysis can be seen as a special case of ROA when there is negligible uncertainty. That is, when the underlying asset's volatility approaches zero, the real options value approaches zero, and the value of the project is exactly as defined in a discounted cash flow model. It is only when uncertainty exists, and management has the flexibility to defer making mid-course corrections until uncertainty becomes resolved through time, that a project has option value." Therefore, the calculated option value using the traditional NPV analysis is equal to zero. Besides reducing the binomial lattice dimension and overall computation time, this new approach is still capable of maintaining the same accuracy as the old approach (without the inclusion of the PaR threshold level and a comfort zone).

5.6 Conclusion

In conclusion, the overall significances of this new, efficient binomial lattice-profit at risk, BL-PaR, approach are as follows:

(a) Flexibility - Decision and Risk Management

- Provides flexibility of decision and risk management to SPCs
- Enable SPCs to set a company's goals

(b) Simplicity

- Solve and reduce the curse of binomial lattice dimensionality

(c) Timing

- Reduce the overall computation time due to the simplification of binomial lattice dimension

(d) Reliability

- Maintaining the same accuracy as the old approach (without the inclusion of the PaR threshold level and a comfort zone)

This chapter provides the basis for possible extensions. One of the interesting extensions will be the integration of the BL-PaR model with both physical asset hedging and financial contract hedging, which will be introduced in Chapter 7.

CHAPTER 6. INTEGRATION OF PUMP STORAGE HYDRO, PSH, WITH WIND ENERGY

Chapter 6 provides the knowledge required to fully understand the new efficient approach introduced in Chapter 7. A decision analysis based solution of incorporating wind energy with either pump storage hydro system or financial contract hedging is presented. This energy technology integration increases the available-capability of wind energy to be as effective as thermal unit.

6.1 Introduction

According to the Annual Energy Outlook 2007, AEO2007, renewable energy sources continue to experience rapid growth. With the prices of fuels soaring and environmental concerns growing larger, the demand for renewable energy sources continues to increase. Fossil fuels are only an intermission between pre- and post-industrial eras dominated by the application of renewable energy. Renewable energy has significant advantages as it does not contribute to the greenhouse gases, GHG. Wind energy is a renewable energy alternative that is being installed throughout the world.

> "Wind power generating capacity increased by 27% in 2006 and is expected to increase an additional 26% in 2007, proving wind is now a mainstream option for new power generation. Wind's exponential growth reflects the nation's increasing demand for clean, safe, and domestic energy." [AWEA 2007]

6.2 Wind Characteristics

Wind is air in motion relative to the surface of the earth. It is produced by the differences in air pressure within the atmosphere. In general, wind is defined as air from the areas of high pressure moves towards areas of low pressure. The greater the difference in pressure, the faster the air flows. The sun causes the wind to blow.

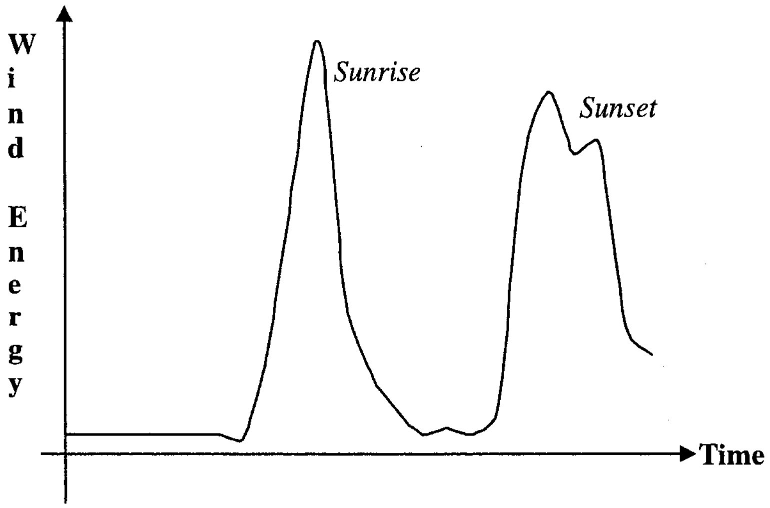


Figure 6.23 General Wind Energy Curve

When the sun shines during the day, it heats the earth. The air over the land becomes hot faster as compare to the air over water. Therefore, the hot air over the land rises and the cooler air over water moves in to take its place. This moving air is known as wind. The general curve for wind energy is shown in Fig. 6.23.

6.2.1 Advantages and Disadvantages of Wind Energy

Wind energy is one of the fastest growing energy sources. It offers many advantages. First, wind energy is produced by wind, a renewable energy, which will never run out. As long as the sun shines, there will be wind.

> "Wind energy does not pollute the air like power plants that rely on combustion of fossil fuels, such as coal or natural gas. Wind turbines do not produce atmospheric emissions that cause acid rain or greenhouse gases." [DOE 2005]

Secondly, wind energy is a clean fuel source as its production only depends on the availability of the wind. Thirdly, the cost of producing electricity from the wind is very low. The cost is about 4 cents per kilowatt-hour [General 2006]. On top of that, the cost of building a wind plant is also less expensive than a conventional energy plant.

The major disadvantage of using wind as a source of power is that wind is unpredictable. It does not always blow when electricity is needed. According to Fig. 6.23, the capability of producing wind energy is at its highest during sunrise and sunset. However, in general, the highest need of electricity happens from 11 am to 2 pm. Another disadvantage is good wind sites are always located in remote location, which is far from the cities where the electricity is needed [DOE 2005].

6.3 Availability versus Reliability

Wind energy is an unpredictable and uncontrollable energy source, and thus, less available as compared to conventional power plants. The availability of wind compared to conventional power plants is a cause of contention.

> "Availability refers to the value of being at hand when needed. Reliability deals with the performance of the system under stress." [EIA 2007]

Currently, the wind availability rate is approximately 50% and the thermal unit reliability rate is about 90%. Fig. 6.24 shows the reliability of thermal, "T", and the availability of wind "W".

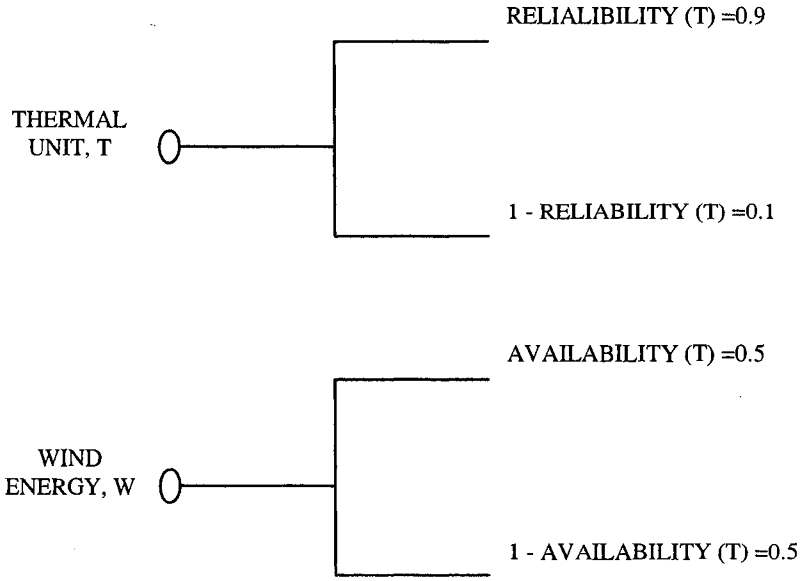


Figure 6.24 Availability Rate of Wind and Reliability Rate of Thermal

For the purpose of comparison, it is necessary to express and standardize the availability of wind energy and the reliability of thermal unit in an equivalent term. In general, one of the most important aspects in energy industry is the capability of delivering energy. Capability is defined as the talent that has potential for development. To a certain extent, capability, availability, and reliability, all these three expressions, are interrelated in one way or another. For instance, a thermal unit might have 100% resources available. However, due to the reliability of a thermal plant, which is approximately 90%, the capability of thermal unit to develop or deliver energy is 90%. As for the wind energy, the reliability of wind unit is almost 100%. Yet, the availability of wind is only 50%. Thus, the capability of the wind unit to develop or deliver energy is 50%. On the whole, the primary attention focuses on the final output from each unit respectively. Therefore, by concentrating on the final output of each unit taking into consideration the availability of resources, the procedure of combining the terms, availability and reliability, can be achieved. This standardization term is known as available-capability.

6.4 Methodologies: Increment of the Wind Available-Capability via Hedging

It is highly desirable to construct the available-capability of wind energy to be equivalent with the thermal unit. In general, thermal unit has the following distribution in terms of operation as shown in Fig. 6.25:

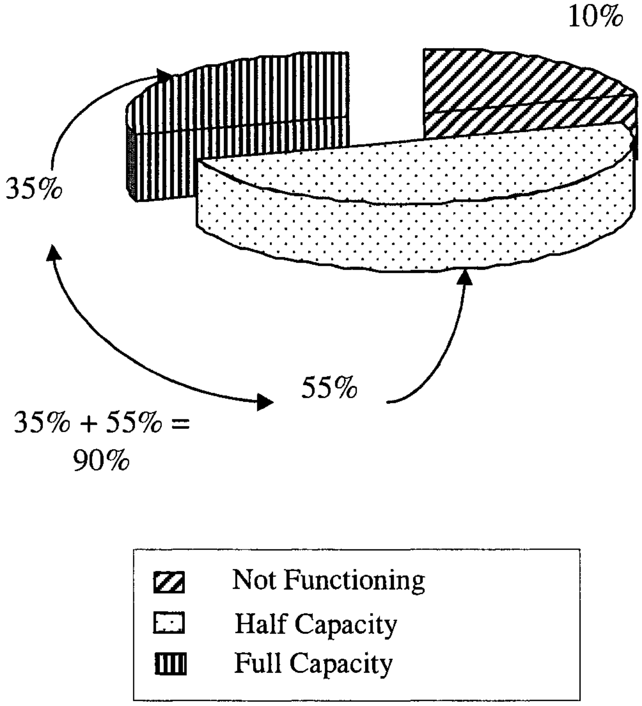


Figure 6.25 Probability Distribution of Thermal Unit Operation

(a) 90% - Functioning

- 35% - Full capacity
- 55% - Half capacity

(b) 10% - Not functioning

The increment of wind available-capability can be done via hedging. Hedging describes the action of entering a transaction with the purpose of offsetting or reducing risk from another related transaction.

Hedging can be executed in two ways: financial contract hedging and physical asset hedging. Financial contracts are obtainable from spot and secondary (futures, options, and forward) markets. Physical asset refers to the pump storage hydro, PSH, system - for this chapter. There are three possible ways of increasing the available-capability of wind energy as shown in Fig. 6.26.

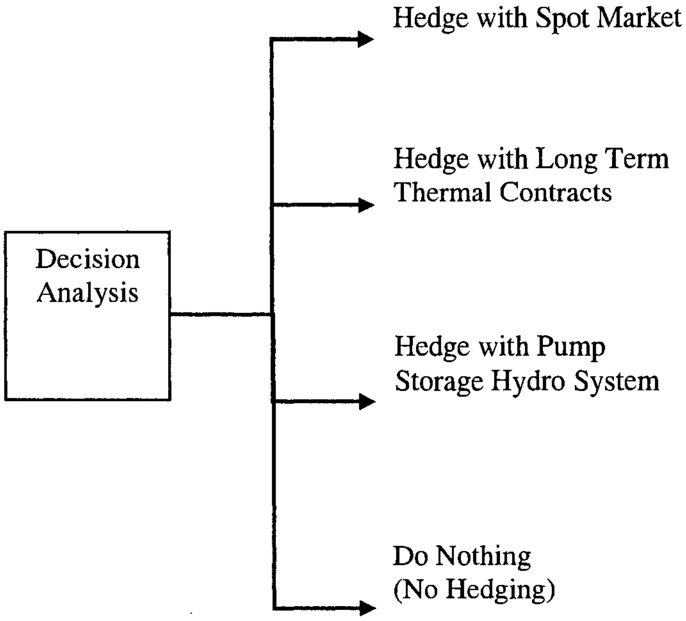


Figure 6.26 Possible Methods (Hedging) for Incrementing Wind Available-Capability

Both hedging with long term thermal contracts and spot market require the involvement of financial contracts. Therefore, it is known as financial contract hedging. As for hedging with pump storage hydro, PSH, system, it requires the involvement of physical asset. Hence, it is known as physical asset hedging.

6.4.1 Spot Market

> "The spot market is a real-time commodity market for instant sale and delivery of energy." [Energy 2007]

Contracts bought and sold on spot markets are immediately effective. Therefore, the advantage of spot market is immediate delivery. Spot market prices are very unpredictable and volatile. It depends on the demand and supply of the commodities as well as the anticipated future forecasting value [Kirschen 2005]. Currently, spot markets for most securities are operated over the Internet.

6.4.2 Long Term Contracts with Thermal Units

The second method is through the collaboration of wind generations and thermal units. The available-capability rate of wind energy can be increased through long term contracts with thermal units. This method is known as self-hedging. In general, self-hedging is defined as matching the purchase with sales. The term "sales" refers to the available-capability rate of thermal unit, and the term "purchase" represents the availability rate of wind plus the long term contracts with thermal units. Before engaging in any contracts, the procedure of forecasting expected average future electricity price needs to be performed. The main purpose is to gain an insight regarding the distribution of expected average future electricity price. It makes no sense to engage into any contract that has higher contract price than the expected average future electricity price. With such hedging, the construction of the available-capability of wind energy to be equivalent with the thermal unit is achievable.

6.4.3 Pump Storage Hydro, PSH

The third method is via the integration of pump storage hydro, PSH, system with wind generation. PSH system is used to store and produce energy. During low energy demand, water is pumped into the higher reservoir using energy produced either by the wind energy or excess energy capacity from the energy market. In other words, the electrical energy produced by the wind is converted into a different form of energy that can be stored for future use. When the demand is high, water is released back into the lower reservoir. Pumping water into the reservoir means storing energy, while releasing water from the reservoir means generating energy. PSH system follows the ideology of "buy low, sell high". One of the advantages of PSH system is it increases the available-capability of wind energy to be as effective as the thermal unit. In order to successfully implement this energy technology integration, we need to assume that the wind energy can only be sold to the energy market when the total wind energy exceeds the total amount of energy needed to fully fill the reservoir. The sales of wind energy to the energy market can only be executed via PSH system.

6.5 Example

Wind generator owners do notice that wind is unpredictable. It does not always blow when electricity is needed and wind energy cannot be stored.

Table 6.9 Wind Sample Data

Date	Time	Generation (MWh)	Simple Average LMP ($/MWh)
1/20/2015	12:00 AM	0.00	73.77
1/20/2015	1:00 AM	0.00	73.53
1/20/2015	2:00 AM	0.00	72.17
1/20/2015	3:00 AM	0.00	71.1
1/20/2015	4:00 AM	0.00	69.69
1/20/2015	5:00 AM	0.00	69.62
1/20/2015	6:00 AM	0.00	67.9
1/20/2015	7:00 AM	0.00	72.27
1/20/2015	8:00 AM	56.54	71.94
1/20/2015	9:00 AM	157.55	72.01
1/20/2015	10:00 AM	231.99	71.74
1/20/2015	11:00 AM	79.99	71.94
1/20/2015	12:00 PM	35.05	72.31
1/20/2015	1:00 PM	14.26	72.85
1/20/2015	2:00 PM	0.00	74.57
1/20/2015	3:00 PM	1.45	73.73
1/20/2015	4:00 PM	0.00	73.15
1/20/2015	5:00 PM	10.63	71.26
1/20/2015	6:00 PM	161.65	71.2
1/20/2015	7:00 PM	203.47	71.06
1/20/2015	8:00 PM	166.74	72.16
1/20/2015	9:00 PM	172.80	73.52
1/20/2015	10:00 PM	62.60	73.3
1/20/2015	11:00 PM	45.28	73.64
	SUM	**1400.00**	**1730.43**

Besides that, wind generator owners always have the desired to increase the available-capability of their wind energy to be equivalent with any thermal unit. As mentioned in section 6.4, there are three major methodologies to increase the available-capability of wind energy:

(a) Via spot market

(b) Via long term contracts with thermal units

(c) Via pump storage hydro, PSH, system.

This chapter introduces a decision analysis based solution of incorporating the integrating of wind energy with PSH system, and the collaboration of wind energy with options or long term thermal contracts. An example is demonstrated. Table 6.9 shows the wind sample data for some calculation purposes. Note: this wind sample data is extracted from Dr. Sheblé's class note.

6.5.1 Via Spot Market

The first method of increasing the available-capability of wind energy is via the spot market. Spot market prices change quickly, unpredictable, and volatile as they are affected by the demand and supply factor as well as the anticipated future forecasting value. Therefore, to reduce price risk exposure, a secondary market is created. Futures, forwards, and options are traded under the secondary market. An option gives the holder the right to buy or sell the underlying asset by a certain date for a certain price. The holder does not have to exercise this right: exercise the right when profitable, and vice-versa. To acquire an option, an up-front fee is needed. Basically, option is a hedging tool. Options contracts provide insurance [Luenberger 1998] and [Hull 2000]. The value of options can be evaluated using Real Options Analysis, ROA [Trigeorgis 1995], [Sturm 1997], [Hull 2000], [Chavas 2004], and [Teoh 2004]. The owner of the wind generation will only engage into options contracts if the options are justified financially and economically. Detailed explanations regarding options as a hedging tool are covered in [Trigeorgis 1995], [Sturm 1997], [Hull 1999], [Chavas 2004] and [Dahl 2004].

6.5.2 Via Long Term Contracts with Thermal Units

The collaboration of wind generations and thermal units to increase the wind energy available-capability rate is known as self-hedging. Basically, self-hedging is defined as matching the purchase with sales as explained in section 6.4.2. In order to increase the available-capability rate to 90%, first the calculation of expected average future electricity price needs to be performed. With the simple average locational marginal price values from Table 6.9, the calculation for the expected average future electricity price is as follows:

Expected Average Future Electricity Price

$$= \frac{1730.43}{24}$$

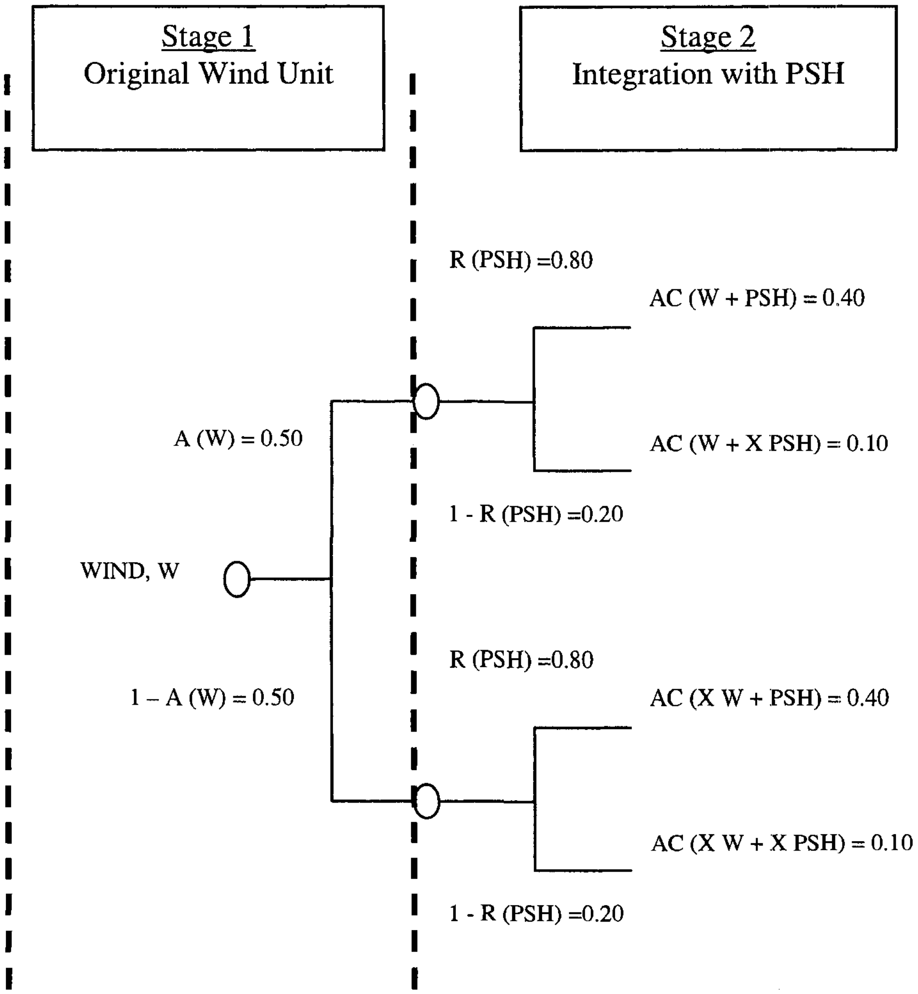
$$= 72.10 \text{ \$/MWh}$$

Therefore, wind generator owners should always engage in contacts where the contract price is within acceptable range, which is approximately 72.10 $/MWh. The long term contracts with any thermal units basically are bilateral contracts. A bilateral contract is a direct contract between the energy producers [EIA 2007]. Under bilateral contracts, information such as quantity, price, and specific time of delivery are negotiated and included. The contracts price and the number of contracts involve have to be financially and economically justified.

6.5.3 Via Pump Storage Hydro, PSH, System

The collaboration of wind generations and PSH system to increase the wind energy available-capability rate is known as physical asset hedging. The physical assets refer to wind generations and PSH system. Fig. 6.27 illustrates every feasible combination of wind generations with PSH system, together with each related probability respectively. From Fig. 6.27, the integration of PSH system with wind generation increases the available-capability rate for wind energy. The calculation for overall available-capability rate of wind energy is as follows:

$$\begin{aligned} & = 0.40 + 0.10 + 0.40 \\ \text{Wind Energy Available-Capability} \quad & = 0.90 \\ & = 90\% \end{aligned}$$



Note:

W = 'Wind'
PSH = 'Pump Storage Hydro'
A = 'Availability'
R = 'Reliability'
AC = 'Available-Capability'
X = 'Without'

Figure 6.27 Integration of Pump Storage Hydro, PSH, with Wind Energy

6.6 Conclusion

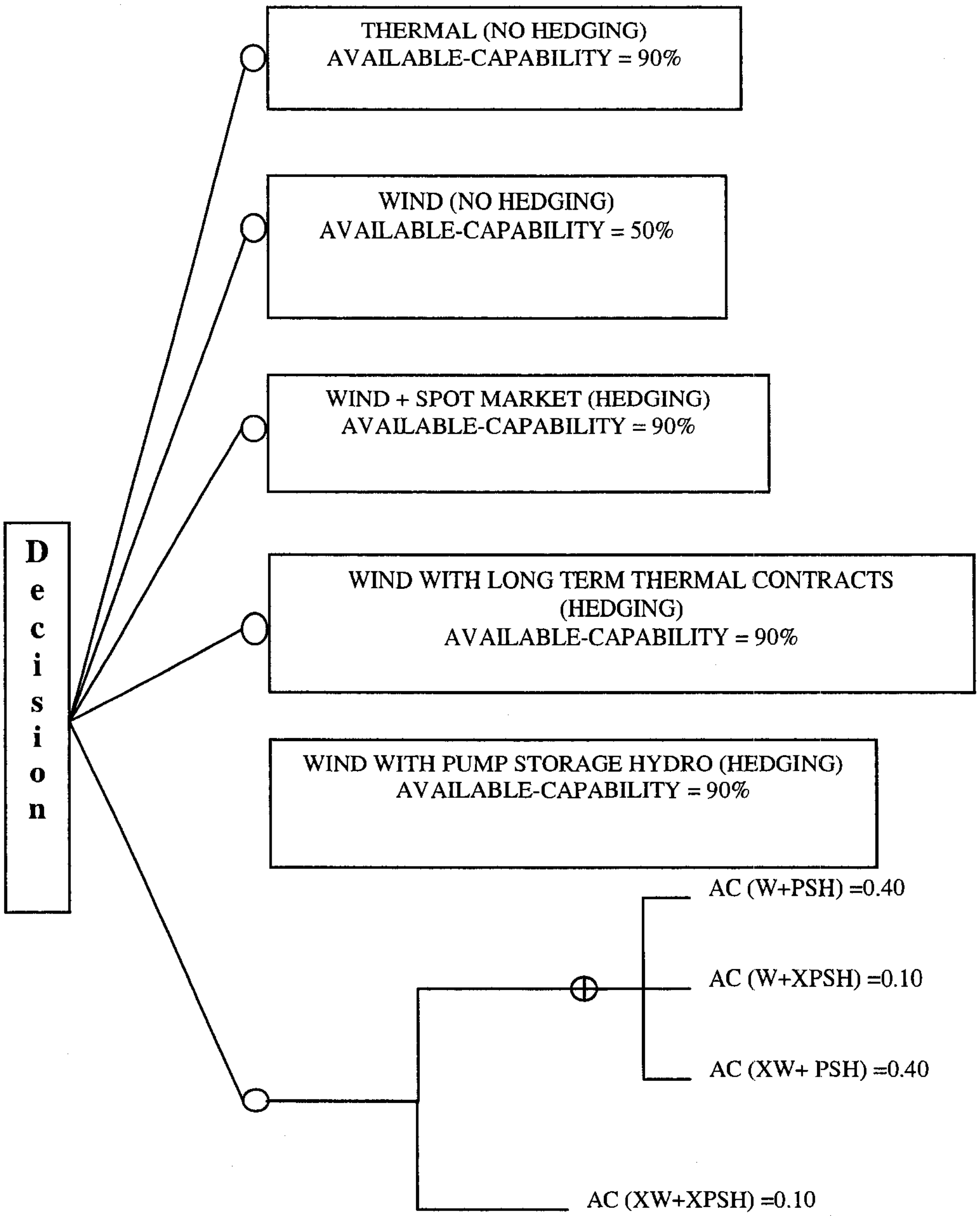


Figure 6.28 Decision Analysis Diagram

The main purpose of hedging is to protect the value of a commodity from unfavorable conditions. Generally, the strategy of asset hedging is the same. The most critical factor is to properly define the model. It is necessary to separate the equipment reliability, fuel availability, and transmission capability. This chapter standardizes the availability of wind and the reliability of thermal unit into an equivalent term, the available-capability. Available-capability refers to the final output from each unit respectively, taking into consideration the fuel resources availability and equipments reliability. Obtaining an equivalent asset characteristic is critical for proper modeling. Fig. 6.28 shows the decision analysis diagram of all feasible options. The decision of determining the best option depends on the justification in terms of financial and economic perspective.

This chapter provides the basis for possible extensions. One of the extensions is the implementation of Real Options Analysis, ROA, into the model. Another interesting extension is the collaboration of profit at risk ideology, PaR, into the model.

CHAPTER 7. INTEGRATION OF PHYSICAL ASSET HEDGING WITH BINOMIAL LATTICE-PROFIT AT RISK, BL-PaR

Chapter 7 develops a new efficient methodology of integrating physical asset hedging with binomial lattice-profit at risk, BL-PaR, which is the combination of different approaches introduced in previous chapters.

7.1 Introduction of Energy Industry

The United States energy industry has been going through major changes since the mid-1990s. The energy industry has been a monopoly for more than a century and has been moving toward an open retail market. When the energy industry was regulated, the energy systems in most of the United States were vertically integrated. In a vertically integrated energy system, one large utility owns and operates all three major aspects (generation, transmission, and distribution) of energy operations, and the utility has a guaranteed fair rate of return in exchange for an obligation to serve in a given service territory.

Due to deregulation policies, a number of state proposals mandate the dissolution of vertically integrated energy systems. The utilities must dispossess one or more of the energy operations. Restructuring the energy industry is a complicated process, as delivering the energy product to the market in an efficient, reliable, and well-timed manner involves establishing a complex set of procedures. The deregulation policies introduce uncertainties into the energy market. Within this new environment, there are two factors that play significant roles in decision analysis: managerial flexibility and financial risks [Trigeorgis 1995], [Trigeorgis 1996], and [Teoh 2004]. Due to uncertainties, the realization of cash flow of a utility can change at any time and can be significantly different from what is initially expected. When new information arrives, and uncertainties about the market conditions become clearer, the utility needs to reevaluate the previous decision in order to maximize the utility's rate of return. Under uncertain market conditions, expected values such as expected profit or expected rate of return have become less meaningful without the corresponding financial risks. Therefore, in the deregulated market, there is no guarantee of a fair rate of return. Utilities seek the most economical feasible way to operate their assets, as they are obliged to meet demand and maximize profit. Real Options Analysis, ROA, enables such flexibility for the management.

7.2 Renewable Energy

According to the Annual Energy Outlook 2007, AEO2007, renewable energy sources continue to experience rapid growth.

> "Wind power generating capacity increased by 27% in 2006 and is expected to increase an additional 26% in 2007, proving wind is now a mainstream option for new power generation … The nation's increasing demand for clean, safe, and domestic energy is reflected by the wind's exponential growth." [The Washington, D.C.-based American Wind Energy Association – AWEA 2007]

With the prices of fuels rise and environmental concerns grow larger, the demand for renewable energy sources continues to increase. Many energy experts believe that fossil fuels are only an intermission between pre- and post-industrial eras dominated by the use of renewable energy. Renewable energy has significant advantages since it does not contribute to greenhouse gases, GHG. Wind energy, a renewable energy alternative, is being installed throughout the world. However, wind energy is an uncertain and uncontrollable energy source. Thus, it is highly desirable to convert the electrical energy produced by the wind into a different form of energy that can be stored for future use. A decision analysis based solution of integrating pump storage hydro, PSH, system with wind energy has emerged. A physical asset hedging approach known as the look ahead optimization, LAO, method is applied to both the wind farm facilities and PSH system. The PSH unit is used to deal with the uncertain and uncontrollable nature of wind energy. The main purpose of the LAO method is to obtain optimal energy storage and to minimize the size of hedging. By combining the LAO method and the BL-PaR model, several important goals can be achieved:

(a) An increase in the availability and reliability rate of wind energy
(b) A reduction in the computation time
(c) A reduction in lattice dimension
(d) An allowance for managerial flexibility and risk management.

7.3 Model Description

In general, there are three major energy suppliers for my model: wind farm facilities (wind energy), pump storage hydro, PSH, system, and equivalent thermal unit as shown in Fig. 7.29. All these three energy suppliers provide the necessary services to satisfy the overall energy market demand. The integration of wind energy with PSH system is one of the two major focuses in this chapter. The purpose of using PSH system is to store and produce energy.

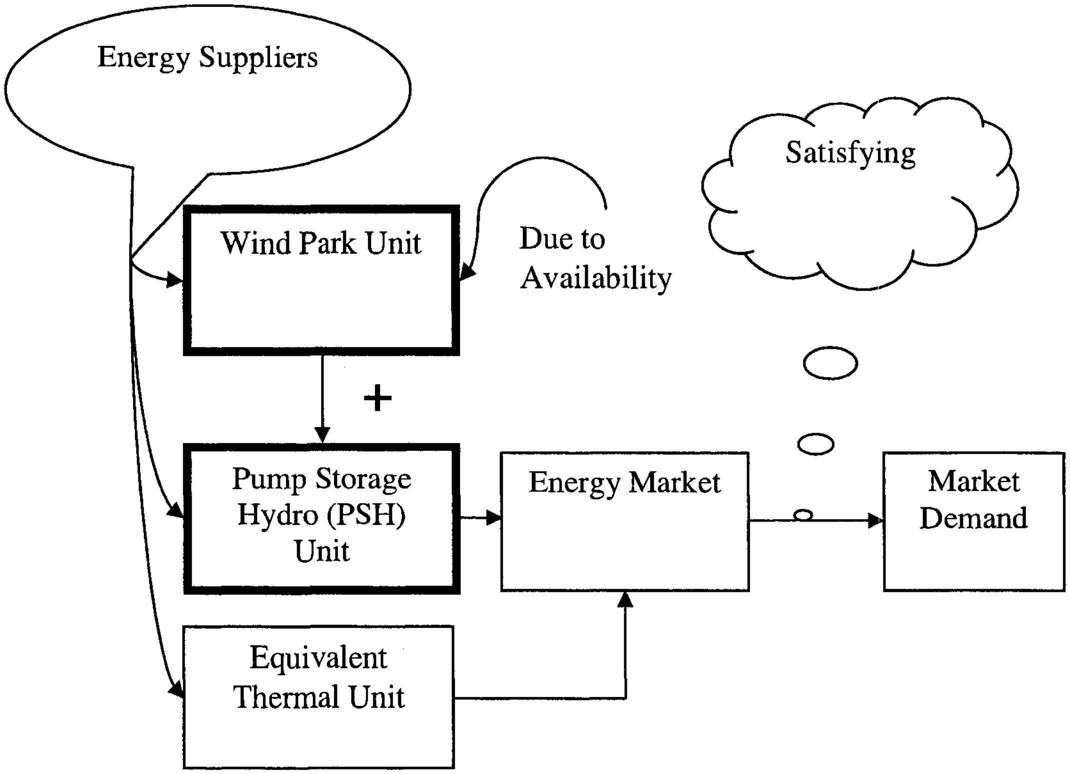


Figure 7.29 Energy Market Relationships

In order to obtain the optimal energy storage and to minimize the size of hedging, a physical asset hedging approach known as the look ahead optimization, LAO, method is applied to both wind energy and PSH system. The procedure of the LAO method is as follows: When the energy demand is low (or the electric price is low), water is pumped into the higher reservoir using the energy produced either by wind energy or the excess energy capacity from the energy market. The electrical energy produced by the wind is converted into a different form of energy that can be stored for future use. When the energy demand is high (or the electric price is high), water is released back into the lower reservoir. Pumping water into the reservoir means storing energy, while releasing water from the reservoir means generating energy. PSH system follows the ideology of "buy low, sell high". One of the advantages of PSH system is it increases the available-capability of wind energy, making it as effective as the thermal unit [Teoh 2008].

In order to successfully implement this energy technology integration, we need to assume that wind energy can only be sold to the energy market when the total wind energy exceeds the total amount of energy needed to fully fill the reservoir. The sale of wind energy to the energy market can only be executed via pump storage hydro, PSH, system as shown in Fig. 7.30.

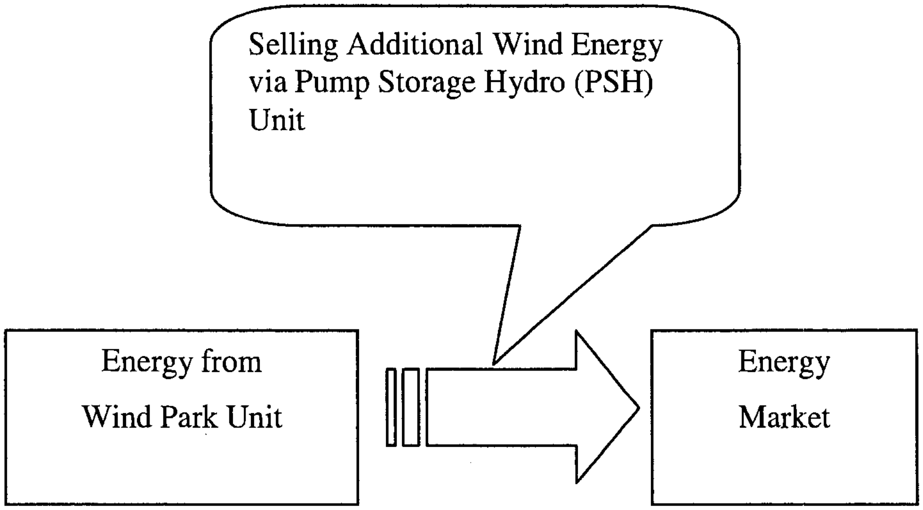


Figure 7.30 Co-operation between PSH system and Wind Farm Facilities

7.3.1 Look Ahead Optimization, LAO, Method

The procedure of the LAO method is as follows: First, PSH system pumps the water into the reservoir by either using the energy from wind farm facilities or the energy market (by paying the locational marginal price, LMP, to the energy market). PSH system will pump the water using the energy generated by the wind farm facilities when it is available. If the wind energy is not available, and the full reservoir capacity has not yet been reached, PSH system will then pump the water using the energy from the energy market. This is performed until the cost of pumping water into the reservoir is equal or higher than the price of releasing water from the reservoir. Pumping water into the reservoir means storing energy, while releasing water from the reservoir means generating energy.

The LAO method has two stacking algorithms: the pumping stacking algorithm and the generating stacking algorithm. There are five steps in the pumping stacking algorithm (Note: lambda means cost):

i. As the energy generated from wind farm facilities is assumed to be zero, the lambda wind values ("zero") always occupy the lower stack positions (Step 1 - Fig. 7.31)

ii. If the new lambda pump value (for example "1") is lower than any of the previous lambda pump value (for example "4"), the new lambda pump value will occupy the third lambda pump stack position and move all the other lambda pump values up a position in the stack (Step 2 – Fig. 7.31)

iii. If the new lambda pump value (for example "6") is between two lambda pump values (for example "4" and "8"), then the new lambda pump value will occupy the position in between lambda pump value "4" and lambda pump value "8" (Step 3 – Fig. 7.31)

iv. If the new lambda pump value (for example "12") is higher than all the other lambda pump values, the new lambda pump value will occupy the highest stack position (Step 4 – Fig. 7.31)

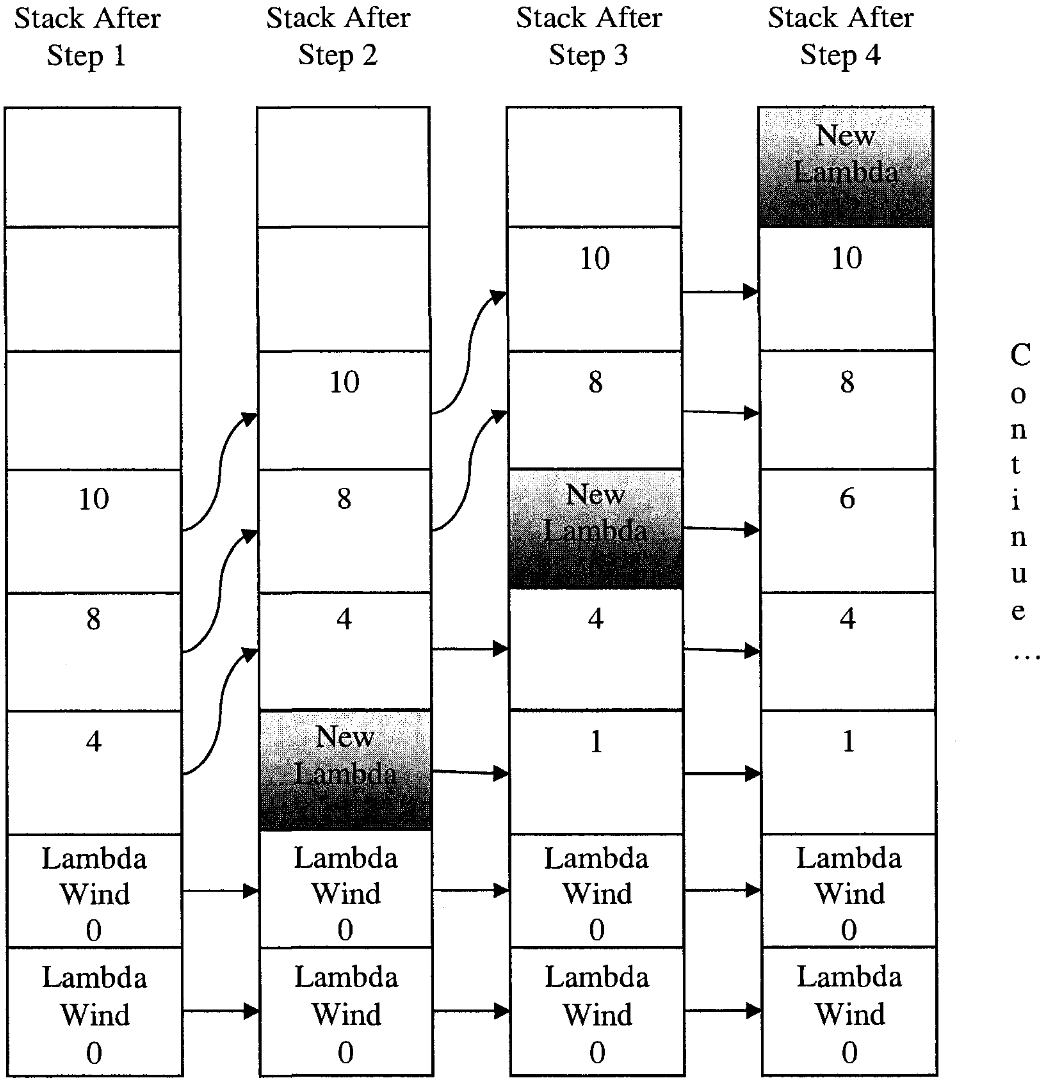


Figure 7.31 Pumping Stacking Algorithm

v. When the Maximum Storage Reservoir Level has been reached:

If the new lambda pump value (for example “3”) is lower than any of the previous lambda pump values, the highest old lambda pump value will be eliminated and the new lambda pump value will be placed according to the pumping stacking algorithm (Step 5 – Fig. 7.32)

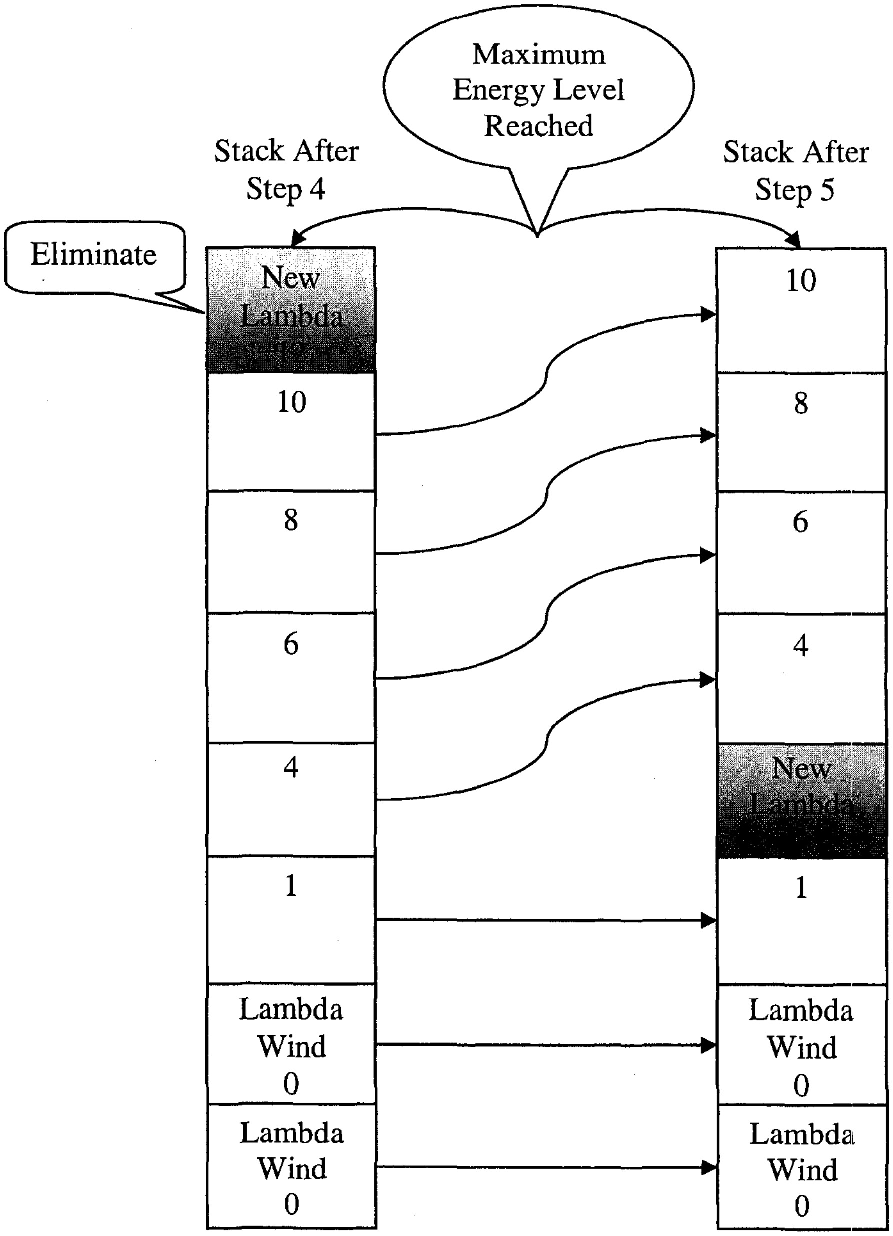


Figure 7.32 Pumping Stacking Algorithm when Maximum Energy Level Reached

The procedure of the generating stacking algorithm is same as the procedure of the pumping stacking algorithm. The main difference is the order of stacking. The pumping stacking algorithm arranges the lambda pump values from the cheapest to the most expensive (from the bottom to the top), while the generating stacking algorithm arranges the lambda generate value from the most expensive to the cheapest (from the bottom to the top).

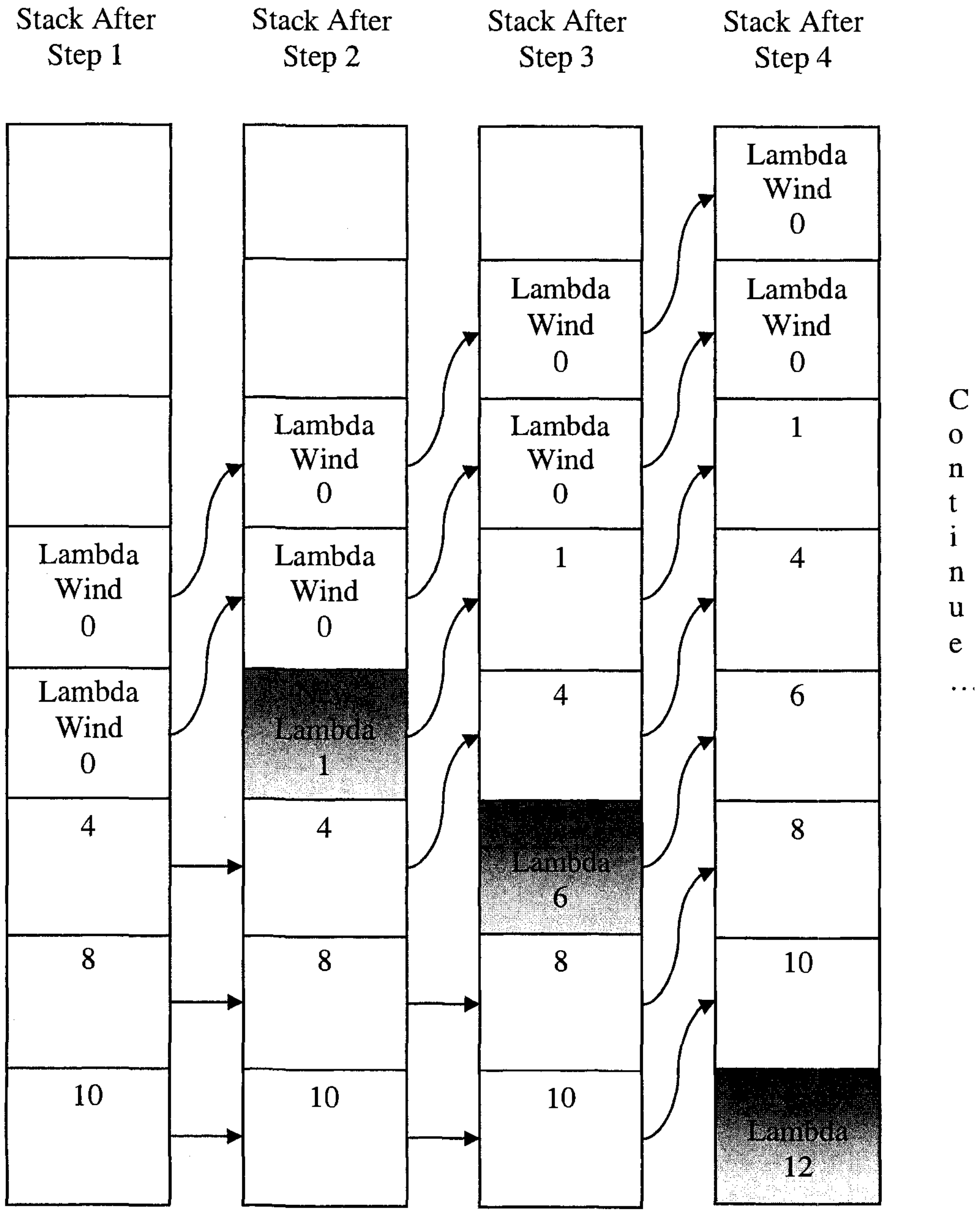


Figure 7.33 Generating Stacking Algorithm

There are five steps in the generating stacking algorithm:

i. As the energy generated from wind farm facilities is assumed to be zero, the lambda wind values ("zero") always occupy the higher stack positions (Step 1 - Fig. 7.33)

ii. If the new lambda generate value (for example "1") is higher than the previous cheapest lambda generate value (for example "4"), the new lambda generate value will occupy the fourth lambda generate stack position (Step 2 – Fig. 7.33)

iii. If the new lambda generate value (for example "6") is between two lambda generate values (for example "8" and "4"), then the new lambda generate value will occupy the position in between lambda generate value "8" and lambda generate value "4" (Step 3 – Fig. 7.33)

iv. If the new lambda generate value (for example "12") is higher than all the other lambda generate values, the new lambda generate value will occupy the lowest stack position (Step 4 – Fig. 7.33)

v. When the Minimum Storage Reservoir Capacity has been reached:

   If the new lambda generate value (for example "3") is higher than any of the previous lambda generate values, the lowest old lambda generate (or wind) value will be eliminated and the new lambda generate value will be placed according to the generating stacking algorithm (Step 5 – Fig. 7.34)

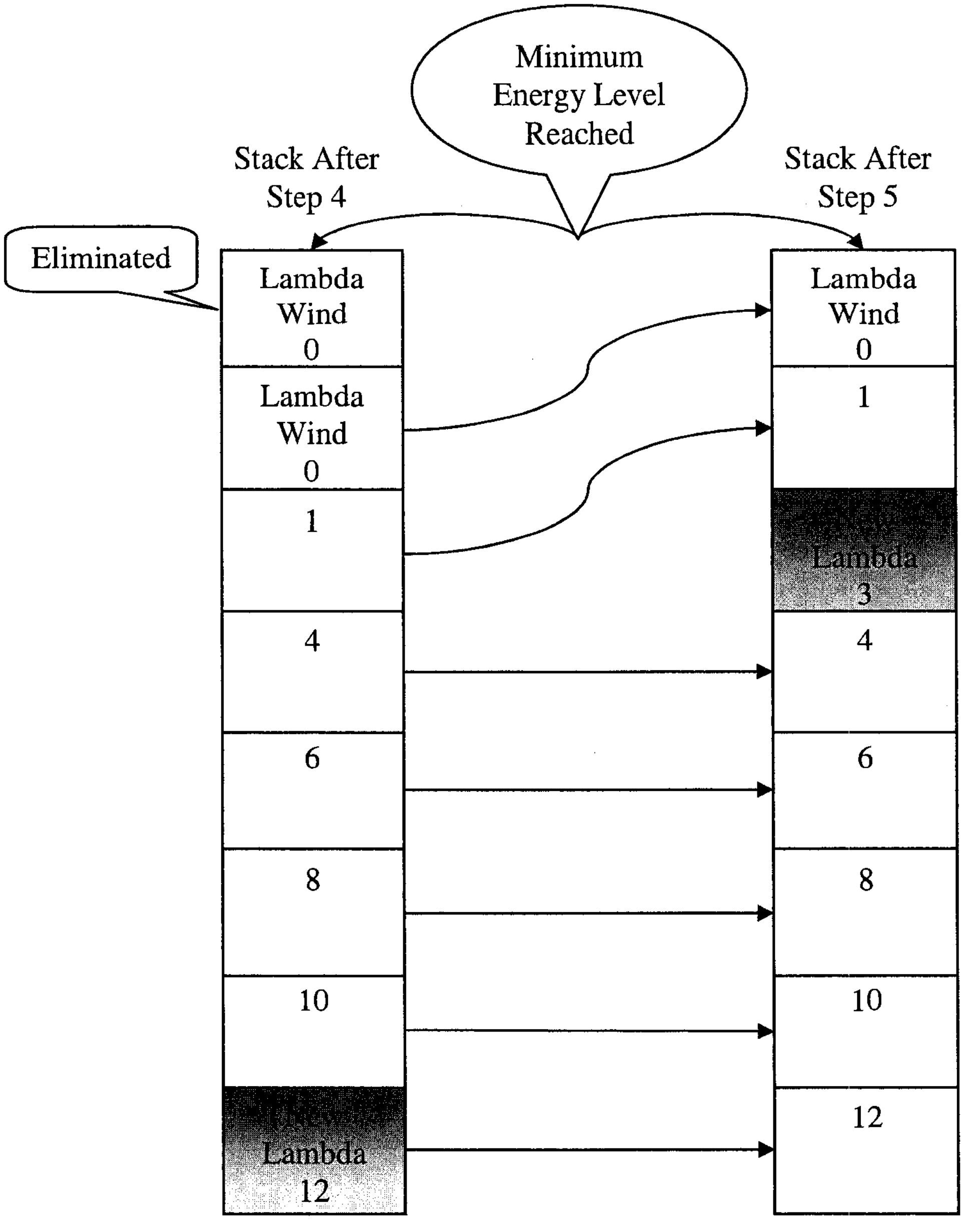


Figure 7.34 Generating Stacking Algorithm when Minimum Energy Level Reached

The procedure of achieving profit maximization with LAO method is by matching the lowest lambda pump value with the highest lambda generate value as shown in Fig. 7.35. For this example, there are four matching pairs. Transaction will only occur when the matching pair value is higher than zero. Therefore, there are four transactions in this example as there are four positive matching pair values. No transaction will occur if the matching pair value is equal or less than zero.

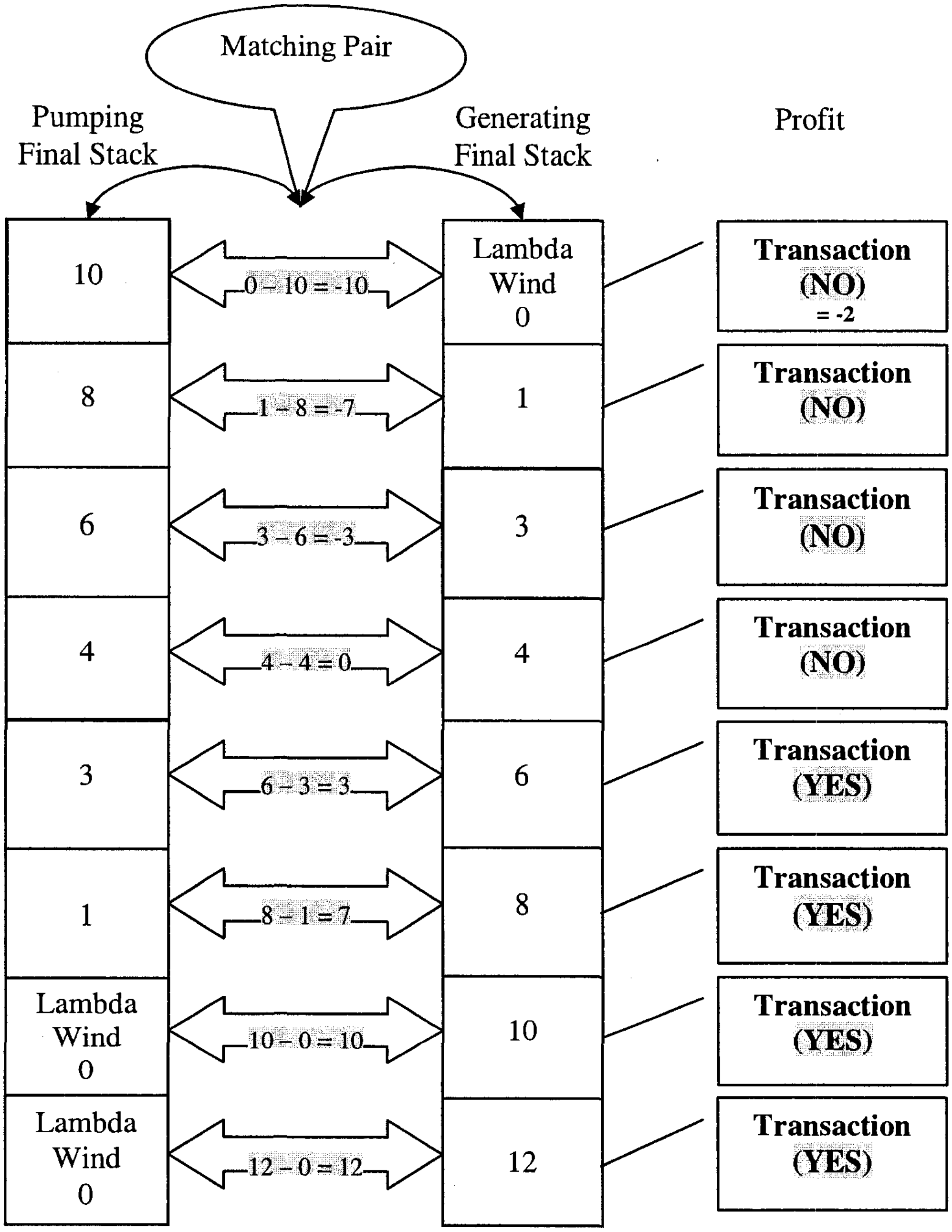


Figure 7.35 Profit Maximization with the LAO Method

The main purpose of LAO method is to achieve profit maximization and obtain the optimal energy storage. For this chapter, both weekly and monthly operations are evaluated. Wind energy is the only uncertain element. Assuming every operation runs optimally, data for the daily, monthly or even yearly profits (or losses) are obtainable by applying Profit and Loss, P&L, calculation into the model. This method can also be viewed as “smoothing out the 24 hours wind curve”.

7.3.2 Binomial Lattice–Profit at Risk, BL-PaR, Method

Due to the uncontrolled and unpredictable nature of wind energy, the combination of physical asset hedging with BL-PaR is highly desirable. Even with the best forecasting technique for the wind energy, it is still a forecast value. Deviations from the forecasted value are unavoidable. Thus, profit at risk, PaR, is implemented into the binomial lattice model by the strategic planning committees, SPCs, to set the threshold level and the comfort zone. PaR is the maximum profit amount at risk to be lost from an operation under normal conditions over a specific holding time at a specific confidence level [Zask 1999], [Golub 2000], [Dempster 2002], and [Teoh 2007]. Due to deregulation, the concept of profitability is becoming more significant. In a competitive deregulated energy industry, the ultimate goal of every electric utility is to make profit. Any electric utility that does not produce profit in a medium-to-long run is likely to go out of business or be forced to leave the industry. Therefore, profit represents everything. Fig. 7.36 illustrates the graphical representation of the three procedures BL-PaR model:

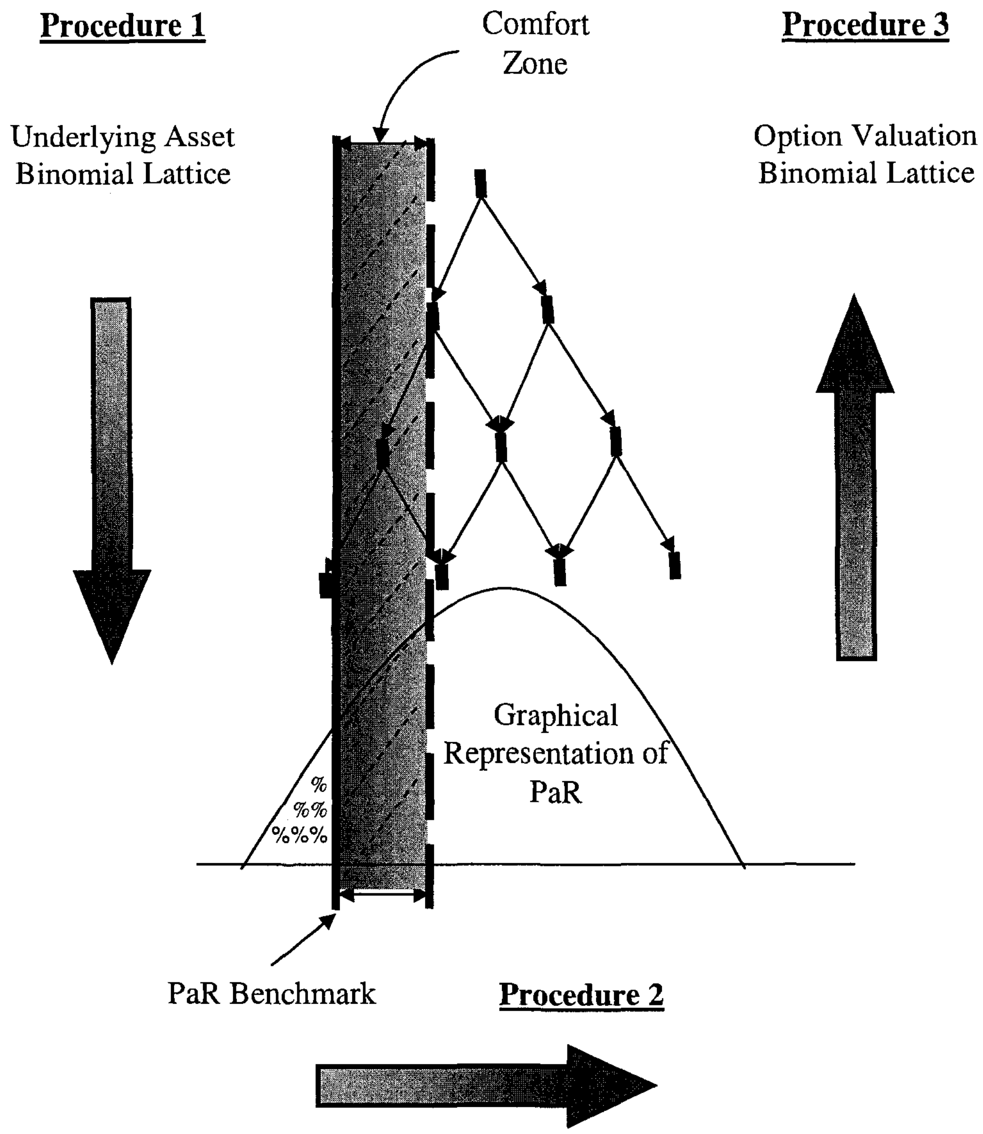


Figure 7.36 Graphical Representation of Three Procedures BL-PaR Model

i. The construction and calculation of the underlying asset binomial lattice

Profit is one of the most critical components for any electric utility and it is directly affected by the electric price. Thus, the model in this chapter has electric price as the uncertain element. Profit is treated as the underlying asset price for the binomial lattice model. To estimate the electric price volatility used in Real Options Analysis, ROA, this chapter focuses on the logarithmic asset price return approach. The underlying asset lattice is created using the first month (or week) Profit and Loss, P&L, data and the implied volatility of forecasted electric price.

ii. The construction and calculation of profit at risk, PaR

The binomial lattice model is relatively easy to implement and has the flexibility of handling various conditions. To obtain a good approximation, this model requires significant length of model period (time-steps). Here comes the major disadvantage of the binomial lattice model: lattice dimension! When the investment duration is large and the length of model period is small, the binomial model becomes a massive bush of lattice, which is referred to as the curse of dimensionality as explained in Chapter 4 and Chapter 5. The binomial lattice dimension expands by 2^n for each additional model period. Detailed explanations regarding the binomial lattice model are illustrated in [Trigeorgis 1995], [Trigeorgis 1998], [Luenberger 1998], [Hull 2000], [Clemen 2001], [Copeland 2001], [Schwartz 2001], [Mun 2003], [Teoh 2004], and [Teoh 2007]. The reduction of the massive bush of binomial lattice by analyzing the boundary of the lattice where the decision changes is highly desirable. The ideology of implementing value at risk, VaR, into the lattice model is applied by [Teoh 2007]. However, since profit has become the center of attention for the deregulated energy industry, this chapter focuses on profit instead of loss. The graphical representation of PaR is shown in Fig. 7.36. Basically, the PaR threshold level is calculated using the Historical PaR method. This method rearranges the returns (both profit and loss) from the worst to the best; the worst is located at the "left tail" and the best is located at the "right tail." The PaR threshold level represents the boundary of a portfolio holder's decision: to commit or not to commit. A minimum profit percentage above the PaR benchmark is then established by the strategic planning committees, SPCs. This zone is known as the comfort zone, which enables the SPCs to set a stricter profit requirement guideline. From Fig. 7.36, it can be shown that the application of the PaR threshold level and the comfort zone to the binomial lattice is similar to extending both of the lines vertically from the underlying and option asset lattices to the graphical representation of PaR. As mentioned in Chapter 4 and Chapter 5, an example of a twenty percent binomial lattice dimension reduction is explained. There are ten underlying asset binomial lattice nodes. With the implementation of the PaR threshold level and a comfort zone, only eight nodes are evaluated because the remaining two nodes fall under the unacceptable region category.

iii. The construction and calculation of the option valuation binomial lattice
The option value at each node is calculated using the risk-neutral probabilities approach. The option value calculation is based on a backward-flow tree approach. Detailed explanations regarding the binomial lattice model are illustrated in Chapter 3, Chapter 4, [Trigeorgis 1995], [Trigeorgis 1998], [Luenberger 1998], [Hull 2000], [Clemen 2001], [Copeland 2001], [Schwartz 2001], [Mun 2003], [Teoh 2004], and [Teoh 2007].

An example of the Look Ahead Optimization-Binomial Lattice-Profit at Risk, LAO-BL-PaR, model is illustrated in Section 7.4. (Note: Both the weekly and monthly P&L data from LAO method represents only one of the feasible paths under the binomial lattice.)

7.4 Example of Physical Asset Hedging with BL-PaR Model (LAO-BL-PaR Model)

The combination of the integration of 'PSH system and wind energy' with the binomial lattice-profit at risk, BL-PaR, model (LAO-BL-PaR Model) not only increases the available-capability rate of wind energy and reduces the computation time and lattice dimension, it also allows managerial flexibility and risk management to the SPCs. Available-capability rate refers to the final output from each unit respectively, taking into consideration the fuel resources availability and equipment reliability [Teoh 2008].

The first step of look ahead optimization-binomial lattice-profit at risk, LAO-BL-PaR, model is to apply the physical asset hedging method (LAO method) to both wind energy and PSH system. Several critical constraints to consider when performing the LAO method are shown in Table 7.10.

Table 7.10 LAO Method Constraints

Constraints	**Data/Information**
Maximum Reservoir Energy Level	6,000 (MW)
Minimum Reservoir Energy Level	0 (MW)
Maximum Pumping Capacity	600 (MW)
Maximum Generating Capacity	500 (MW)
Energy Efficiency	67%

Note: This data is extracted from Dr. Sheblé's class note.

One of the most critical observations that need to be reflected in the model is the energy efficiency rate. The formula for energy efficiency is as follows:

$$\text{Energy Efficiency} = \frac{P_{GENERATED}}{P_{PUMPED}} = \frac{P_{OUT}}{P_{IN}}$$

Due to evaporation losses from the exposed water surface, mechanical efficiency losses during conversion, and leakage, not all water pumps into the reservoir can be regained as shown in Fig. 7.37. Normally, the energy efficiency rate for PSH system is between 67% and 85%.

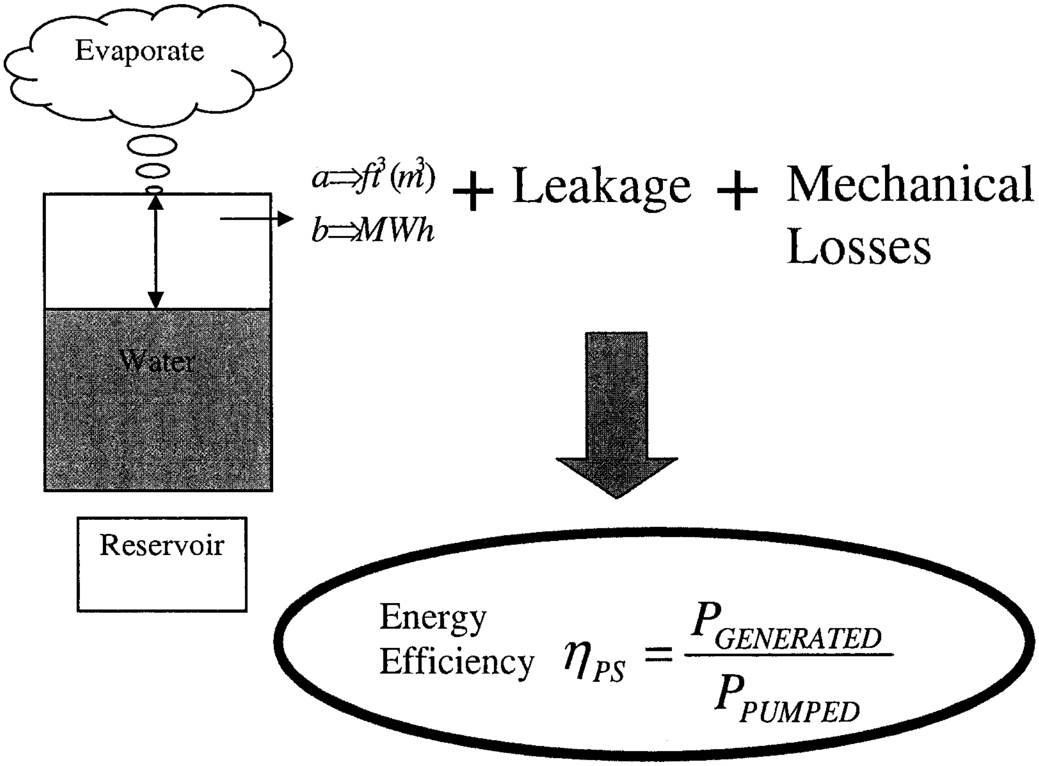


Figure 7.37 Graphical Explanations of PSH Energy Efficiency

As mentioned in section 7.2, when the amount of energy exceeds the total amount of energy needed to pump water into the reservoir, the wind energy can be sold directly to the market at locational marginal price, LMP, via pump storage hydro, PSH, system. When the amount of wind energy does not exceed the total amount of energy needed to pump water into the reservoir, PSH system has the option to buy energy from the market at low cost to pump water (store energy) into the reservoir and discharge the water (generate energy) at higher cost. For this chapter, two scenarios have been evaluated:

(a) Scenario 1: Monthly 'PSH and Wind Energy' Profit

(b) Scenario 2: Weekly 'PSH and Wind Energy' Profit

7.4.1 Scenario 1: Monthly 'PSH and Wind Energy' Profit

Table 7.11 below demonstrates the monthly 'PSH and Wind Energy' profit obtained from the look ahead optimization, LAO, method:

Table 7.11 Monthly 'PSH and Wind Energy' Profit

Month	**Wind Profit**		**Pump Profit**	**Total Profit**
	Wind LMP	**Wind Pump**		
January	830237.6399	790715.8267	0	1620953.467
February	15897438.04	956784.2752	0	16854222.32
March	16042186.98	1766253.332	0	17808440.31
April	27134004.55	1571760	0	28705764.55
May	4407151.191	1301635.098	0	5708786.289
June	27543284.97	1616204	0	29159488.97
July	12032084.52	1725505.705	0	13757590.22
August	11150437.01	1895968	0	13046405.01
September	773276.1361	705218.0597	0	1478494.196
October	14645997.06	850496.0313	0	15496493.09
November	14843922.99	1644587.348	0	16488510.34
December	15553550.73	1717484.74	0	17271035.47

After obtaining the monthly 'PSH and Wind Energy' profit, the second step of LAO-BL-PaR model is the construction of the BL-PaR model. There are three procedures involved:

i. The construction of the underlying asset binomial lattice

The monthly 'PSH and Wind Energy' profit is treated as the underlying asset price because it is one of the most critical uncertain elements in the model. The profit volatility, σ_{PROFIT}, is calculated using the logarithmic asset price return approach. This approach utilizes all the individual forecasted asset price estimates and their corresponding logarithmic return [Teoh 2007]. First, all the forecasted asset prices are converted into their relative returns. Then, each of these relative returns is converted into its natural logarithms. The standard deviation of these natural logarithm returns is the asset price volatility. The volatility estimation equation is as follows [Mun 2003]:

- $Volatility = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}(x_i - \bar{x})^2}$

Where

n = the number of returns

x = natural logarithm of cash flow returns

$\bar{x}$ = average of x value

After obtaining σ_{PROFIT}, the next process is to construct the complete underlying asset binomial lattice. Fig. 7.38 shows the first few steps of the underlying asset lattice calculation. For the underlying asset lattice, each monthly 'PSH and Wind Energy' profit has two possible movements for the following period: one goes up and one goes down. With such, all possible profit paths can be constructed.

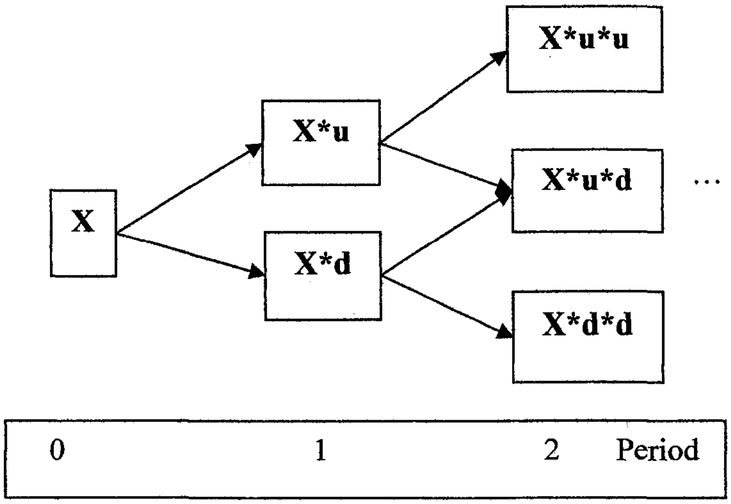


Figure 7.38 Example: 2-Step Binomial Underlying Asset Lattice

Where

- X = underlying asset → monthly 'PSH and Wind Energy' Profit
- u = upward movement → $e^{\sigma_{PROFIT}\sqrt{\Delta t}}$
- d = downward movement → $e^{-\sigma_{PROFIT}\sqrt{\Delta t}}$
- Δt = stepping time (the time scale between steps)
- σ = volatility

All the variables that are critical to construct the complete underlying asset lattice are summarized in Table 7.12: (Note: the implied volatility is very high, ~ 45%, which is unusual for this model of calculation.)

Table 7.12 Elements of the LAO-BL-PaR Model for Monthly 'PSH and Wind Energy' Profit

Elements	**Unit**	**Value**
Volatility, σ_{PROFIT}	-	1.45985
Upward Movement	-	4.305
Downward Movement	-	0.232
Stepping Size	-	1
Risk-Free Rate, *rf*	%	5
Period under consideration, *n*	Month	12
First Month Profit, S^{profit}_{month}	$	1620964.467

ii. The construction of PaR

The following procedure is to apply the Historical PaR method to calculate the profit at risk, PaR, threshold level. The general equation for the PaR calculation is as follows [Zask 1999]:

- PaR = MPs* R^p

Where

MPs = Monthly 'PSH and Wind Energy' Profits

R^p = *p* percentile return

Assigning a different confidence level will result in a different profit at risk, PaR, threshold level. A 90% confidence level is equivalent to the tenth percentile of any profit. For this scenario, the benchmark for the PaR threshold is set to be at USD 64,832, which is at 90% confidence level. The minimum percentage profit above the PaR benchmark, known as a comfort zone, is then established by the strategic planning committees, SPCs. A 25% comfort zone (or 25% minimum profit requirement - USD 407,977, above the PaR benchmark), has been established. The total nodes of the binomial lattice without considering the implementation of the PaR threshold level and the comfort zone are 78. The degree of binomial lattice dimension reduction depends upon the assigned confidence level and comfort zone. A one-year PaR at a 90% confidence level, together with a 25% comfort zone, results in a 46% lattice dimension reduction.

iii. The construction of option valuation binomial lattice

The option value at each node is calculated using the risk-neutral probabilities approach. The option value calculation is based on a backward-flow tree approach: the option value at each step of the lattice is calculated backward from the expiration to the present as shown in Fig.7.39 [Teoh 2004].

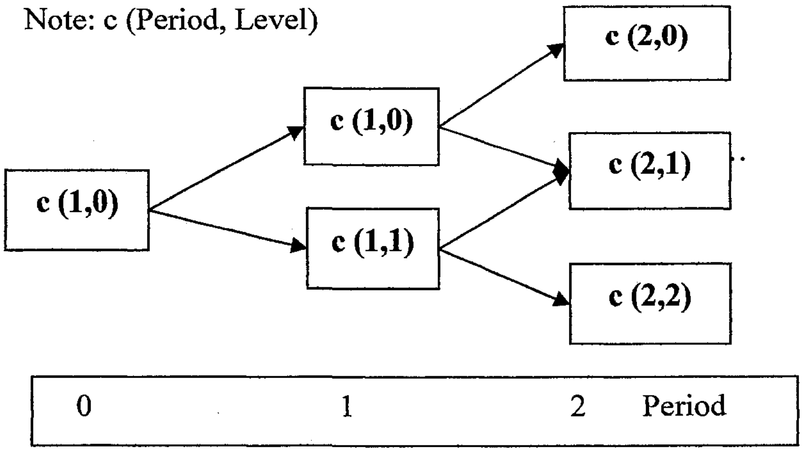


Figure 7.39 Example: 2-Step Binomial Option Valuation Lattice

Any node that falls to the left of the comfort zone is ignored as shown in Fig. 7.36. Each option calculation follows a general formula (for example, in Fig. 7.39, the maturity date is the second period) [Trigeorgis 1998], [Luenberger 1998], [Hull 2000], [Clemen 2001], [Copeland 2001], [Schwartz 2001], [Mun 2003], [Teoh 2004], and [Teoh 2007]:

- Option values at maturity, $c(2,x)$

$$c(2,x) = \max(0, \text{Monthly 'PSH and Wind Energy' Profit - 472809})$$

(Note: USD 472,809 is the summation of the PaR Threshold Level – USD 64,832 + the comfort zone – USD 407,979)

- Option values before maturity (same calculation as before),

For example, $c(1,x)$

$$c(1,x) = \frac{p*c(2,x) + (1-p)*c(2,x+1)}{e^{r_f * \Delta t}}$$

With the integration of both the PaR threshold level and a comfort zone, the calculated option value is USD 1620,953. In other words, besides reducing the binomial lattice dimension and overall computation time, this new approach is still capable of maintaining the same accuracy as the old approach (without the inclusion of the PaR threshold level and a comfort zone).

7.4.2 Scenario 2: Weekly 'PSH and Wind Energy' Profit

The weekly 'PSH and Wind Energy' profit analysis follows the same procedure as the monthly profit analysis. All variables that are critical to perform the weekly 'PSH and Wind Energy' profit analysis are illustrated in Table 7.13:

Table 7.13 Elements of the LAO-BL-PaR Model for Weekly 'PSH and Wind Energy' Profit

Elements	**Unit**	**Value**
Volatility, σ_{PROFIT}	-	0.6872096
Upward Movement	-	1.988
Downward Movement	-	0.503
Stepping Size	-	1
Risk-Free Rate, rf	%	5
Period under consideration, n	Week	52
First Month Profit, S^{profit}_{month}	$	376965.9226

The benchmark for the profit at risk, PaR, threshold is set to be at zero profit (break-even point), which is at 88% confidence level. A 12.72% comfort zone (or 12.72% minimum profit requirement - USD 47,967.61, above the PaR benchmark), has been established. The total nodes of the binomial lattice without considering the implementation of the PaR threshold level and the comfort zone are 1378. The degree of binomial lattice dimension reduction depends upon the assigned confidence level and comfort zone. A one-year PaR at an 88% confidence level, together with a 12.72% comfort zone results in a 45.36% lattice dimension reduction. With the integration of both the PaR threshold level and a comfort zone, the calculated option value is USD 376,965.92, which is same as the calculated option value without considering the integration of the PaR threshold level and a comfort zone. Do keep in mind: we are calculating the value of option flexibility. According to [Mun 2002], "the traditional NPV analysis can be seen as a special case of ROA when there is negligible uncertainty. That is, when the underlying asset's volatility approaches zero, the real options value approaches zero, and the value of the project is exactly as defined in a discounted cash flow model. It is only when uncertainty exists, and management has the flexibility to defer making mid-course corrections until uncertainty becomes resolved through time, that a project has option value." Therefore, the calculated option value using the traditional NPV analysis is equal to zero. For both scenarios, this new LAO-BL-PaR approach is capable of maintaining the same accuracy as the old approach (without the inclusion of the PaR threshold level and a comfort zone), while reducing the binomial lattice dimension and overall computation time.

7.5 Conclusion

In conclusion, the overall significance of this new efficient look ahead optimization-binomial lattice-profit at risk, LAO-BL-PaR, approach is as follows:

(a) Flexibility - Decision and Risk Management

- This new approach provides flexibility to decision and risk management for SPCs. It enables SPCs to set company's goal.

(b) Simplicity

- BL-PaR approach solves and reduces the curse of binomial lattice dimensionality. In other words, it simplifies the lattice dimension.

(c) Timing

- The simplification of binomial lattice dimension indirectly reduces the overall computation time.

(d) Reliability

- Even though the dimension of binomial lattice has been reduced, this new approach still capable of maintaining the model's accuracy as the old approach (without the inclusion of the PaR threshold level and a comfort zone).

(e) Protection

- Physical asset hedging (the integration of PSH with wind energy) protects the value of a commodity from unfavorable conditions.

For Operation1, the value of implied volatility is high due to insufficient information. There are many uncertainties that can happen within a month. Due to the lack of market transparency, many uncertainties are not taken into consideration when performing the implied volatility calculation. To properly calculate the implied volatility, a shorter evaluation time is considered: Operation2 – the Weekly 'PSH and Wind Energy' Profit. The probability of capturing all the weekly uncertainties is reasonablely encouraging. Therefore, the calculated option value is favorably acceptable. The LAO-BL-PaR approach is practical to implement for traders as it provides response in a timely fashion.

CHAPTER 8. RISK MANAGEMENT: FINANCIAL TRANSMISSION RIGHTS', FTRs', PORTFOLIO CORRESPONDING TO ENERGY CONTRACTS TERMINATION

Chapter 8 provides an extension and enhancement of look ahead optimization-binomial lattice-profit at risk, LAO-BL-PaR, analysis. The inclusion of financial contract hedging via financial transmission rights, FTRs, provides a double-protections mechanism. Besides that, the evaluation of FTRs' portfolio using Real Options Analysis, ROA, enables the risk management process to run smoothly and efficiently.

8.1 Introduction

As mentioned before, the deregulation policies introduce uncertainties into the energy market. Within this new environment, there are two factors that play significant roles in decision analysis: managerial flexibility and financial risks [Trigeorgis 1995], [Trigeorgis 1996], and [Teoh 2004]. Due to uncertainties, the realization of cash flow of a utility can change at any time and can be significantly different from what is initially expected. When new information arrives, and uncertainties about the market conditions become clearer, the utility needs to reevaluate the previous decision to maximize the utility's rate of return. Under uncertain market conditions, expected values such as expected profit or expected rate of return have become less meaningful without the corresponding financial risks. Thus, in the deregulated market, there is no guarantee of a fair rate of return.

The energy market becomes increasingly competitive and transactions are based more on prices set by market forces instead of regulation [EEI 2001]. Due to the competitiveness and rising volatility of a deregulated energy market, risk management plays an important part in analyzing and recognizing all possible risks, and developing strategies to respond appropriately should any of those risks occur. The allocation of risk capital is critical for risk management and financial decision making. The capital allocation for risk management is often related to hedging.

Whenever generation companies, GENCOs, engage in any energy bilateral contracts, they face various types of risks that can lead to adverse impact. Currently, one of the most critical risks is the transmission congestion risk. With the help of probability theory and historical data, the probability distribution of potential transmission congestion is predictable to some extent. GENCOs hedge against the transmission congestion risk via financial transmission rights, FTRs. The total worth of FTRs' portfolio is evaluated using Real Options Analysis, ROA, which has the capability and flexibility of incorporating various future uncertainties into the model. Of the four major methods of ROA, this chapter concentrates on the lattice method.

8.2 Risk Management

The framework of risk management process is as follows [Harrington 2004]:

(a) Identification of all important risks

(b) Evaluation of the possible frequency and severity of losses

(c) Management of risk development

(d) Implementation of risk management method

(e) Evaluation of performance

With the new deregulated energy market structures, GENCOs, who engage in bilateral energy contracts, always face the risk of not fulfilling their energy contracts obligations (or delivering the electric) due to transmission congestion. Transmission congestion risk, which is beyond GENCOs' control, can be transferred through the use of insurance mechanism or derivatives such as FTRs. Thus, GENCOs have the tendency to hedge against transmission congestion risk for the purpose of protection. Whenever any energy contract is terminated, GENCOs usually have three options to satisfy their supply obligations:

(a) Purchase electric from another party at higher price

(b) Reimburse the total amount owed to the customers

(c) Purchase electric via spot market

Contracts bought and sold on spot markets are immediately effective. Therefore, the advantage of spot market is immediate delivery.

> "The electric energy spot market is a real-time commodity market for instant sale and delivery of energy." [Energy 2007]

However, spot market prices change quickly, and are unpredictable and volatile. It depends on the demand and supply of the commodities as well as the anticipated future forecasting value [Kirschen 2005]. Transmission congestion, which causes the unexpected interruptions in normal supply condition, causes the spot market to spike. To minimize losses, GENCOs hedge against congestion transmission risk via financial transmission rights, FTRs. Hedging describes the action of entering a transaction with the purpose of offsetting or reducing risk from another related transaction [Teoh 2008].

8.3 Financial Transmission Rights, FTRs, Overview

"Financial Transmission Right, FTR, is a financial instrument that entitles the holder to receive compensation or be charged (depending on the instrument) for Transmission Congestion Charges that arise when the transmission grid is congested in the Day-Ahead Market and differences in Day-Ahead Locational Marginal Prices, LMPs, which result from the dispatch of generators out of merit order to relieve the congestion" [PJM 2006]. Each FTR is defined in megawatts, MWs, from a point of receipt (where the power is injected onto the grid) to a point of delivery (where the power is withdrawn from the grid) [PJM 2006]. For each hour in which congestion exists on the Transmission System between the receipt and delivery points specified in the FTR, the holder of the FTR is awarded a share of the congestion obligations collected from the Market Participants for that hour [PJM 2006]. The purpose of FTRs is to provide a mechanism to deal with transmission congestion risk.

8.3.1 Types of FTR

Generation companies, GENCOs, who are also market participants, are able to acquire FTRs in the form of options or obligations [PJM 2006]:

(a) Financial Transmission Right, FTR, Obligations

- The hourly economic value of an FTR Obligation is based on three aspects:
    i. The MWs amount of FTR
    ii. The difference between Day-Ahead LMPs
    iii. The sink point (point of delivery) and the source point (point of receipt)
- The hourly economic value of an FTR Obligation is positive (a benefit) when the Day-Ahead LMP at the point of delivery (sink point) is higher than the Day-Ahead LMP at the point of receipt (source point). The direction of congested flow is same as the direction designated in the FTR.
- The hourly economic value of an FTR Obligation is negative (a liability) when the Day-Ahead LMP at the point of delivery (sink point) is lower than the Day-Ahead LMP at the point of receipt

(source point). The direction of congested flow is opposite the direction designated in the FTR. "However, if the holder were to actually deliver energy along the designated path, they would receive a congestion credit that would offset the FTR charge" [PJM 2006].

(b) Financial Transmission Right, FTR, Options

- The hourly economic value of an FTR Option is based on three aspects:
  i. The MWs amount of FTR
  ii. The difference between Day-Ahead LMPs when the difference is positive
  iii. The sink point (point of delivery) and the source point (point of receipt)
- The hourly economic value of an FTR Option is positive (a benefit) when the Day-Ahead LMP at the point of delivery (sink point) is higher than the Day-Ahead LMP at the point of receipt (source point). The direction of congested flow is same as the direction designated in the FTR.
- The hourly economic value of an FTR Option is zero (neither a benefit nor a liability) when the Day-Ahead LMP at the point of delivery (sink point) is lower than the Day-Ahead LMP at the point

of receipt (source point). The direction of congested flow is opposite the direction designated in the FTR.

Therefore depending upon the type, financial transmission rights, FTRs, can offer financial benefit as well as financial liability due to additional charges to the holder. In general, FTRs (FTR Obligation and FTR Option) are financial instruments only and do not represent a right for physical delivery of power. FTRs protect generation companies, GENCOs, in two different ways [PJM 2006]:

(a) FTRs protect generation companies, GENCOs, from increased cost due to Transmission Congestion when their energy deliveries are consistent with energy contract obligations.

(b) The holder of the FTR is not required to deliver energy in order to receive a congestion credit. If a constraint exists on the Transmission System in the Day-Ahead Market, the holders of FTRs receive a credit based on the MWs amount of FTR and the LMP difference between point of delivery and point of receipt. This credit is paid to the holder regardless of who delivered energy or the amount delivered across the path designated in the FTR [PJM 2006].

8.4 Capital Allocation and FTRs' Portfolio Valuation

8.4.1 Capital Allocation

Depending upon the company's risk characteristic, the risk capital allocation (or distribution) for each generation company, GENCO, is different. One of the major factors to take into consideration is the cash flow stream. Cash flow refers to the movement of cash flows into and out of a business. The inflow of cash refers to the cash received from investments while the outflow of cash refers to the money spent on investments. From a financial perspective, positive cash flow is always a good sign and encouraging. Therefore, it is critical for GENCOs to identify when, where, and how to handle the company's cash needs. Generally, GENCOs develop both short-term cash flow projection to manage daily cash, which is to allocate the amount of cash needed for short-term investment, and long-term cash flow projection to help developing the necessary capital strategy to meet business needs [DOT 2008]. The payback period of investment, which focuses on recovering the cost of investment, is important in determining the risk capital allocation. Payback period refers to the length of time required to recover the cost of investment.

Before engaging in any financial transmission right, FTR, contract agreement, the allocation of risk capital by GENCOs depends on:

(a) Payback period

(b) The penalty of contracts termination (the losses due to contracts termination)

(c) Company's cash flow stream

All these factors dictate the risk capital GENCOs are willing to commit. Basically, the size and bid price of FTRs by GENCOs indicate:

(a) The potential losses that arise from the energy contracts termination due to transmission congestion.

(b) The maximum risk GENCOs are willing to shoulder.

8.4.2 FTRs' Portfolio Valuation

Performance evaluation is an important process to define the success of risk management. A 24-hour FTRs' portfolio valuation has been carried out .The procedure is as follows:

(a) Forecast the financial transmission right, FTR, values for the next 24 hours.

(b) Calculate the implied volatility by using the forecasted 24-hours FTR values.

(c) Construct the underlying FTRs' portfolio binomial lattice.

(d) Construct the FTRs' portfolio option valuation binomial lattice.

- Assumption:

  If the predicted probability of transmission congestion occurring is higher than 70%, GENCOs hedge against the transmission congestion risk and vice-versa.

The total worth of FTRs' portfolio is evaluated using Real Options Analysis, ROA, which has the capability and flexibility of incorporating various future uncertainties into the model. The binomial lattice model is one of the major methods of ROA. This model is based on the idea of a finite tree structure that branches out from the current asset price and from the current time until the expiration time [Hull 2000]. The entire possible path pursued by the asset price over the specific operating timeframe is represented by a decision tree. Every leaf of the tree represents each possible outcome. This model segments time to maturity into a number of time intervals or steps, which is known as the length of model period [Teoh 2007]. A tree of underlying asset prices is produced by working forward from valuation date to the maturity date. According to the binomial distribution process, the asset price is assumed to take on one of two possible values:

(a) One going up
(b) One going down

The assumptions of the binomial lattice model are as follows:

(a) No riskless arbitrage opportunity
(b) Asset price is represented by a binomial distribution

Normally, a binomial lattice model consists of two major lattices:

(a) Underlying FTRs' Portfolio Binomial Lattice (Fig. 8.40)
(b) FTRs' Portfolio Option Valuation Binomial Lattice (Fig. 8.41)

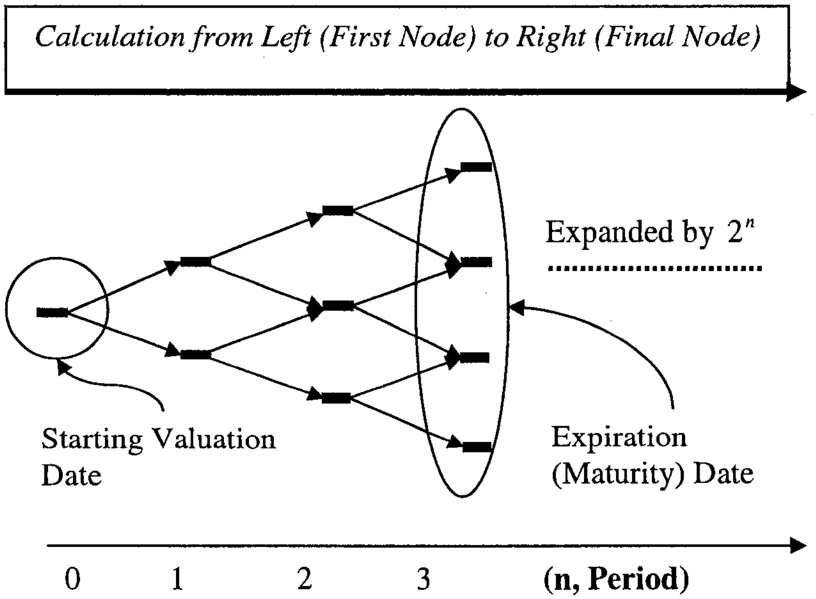


Figure 8.40 Underlying FTRs' Portfolio Binomial Lattice for Simulation

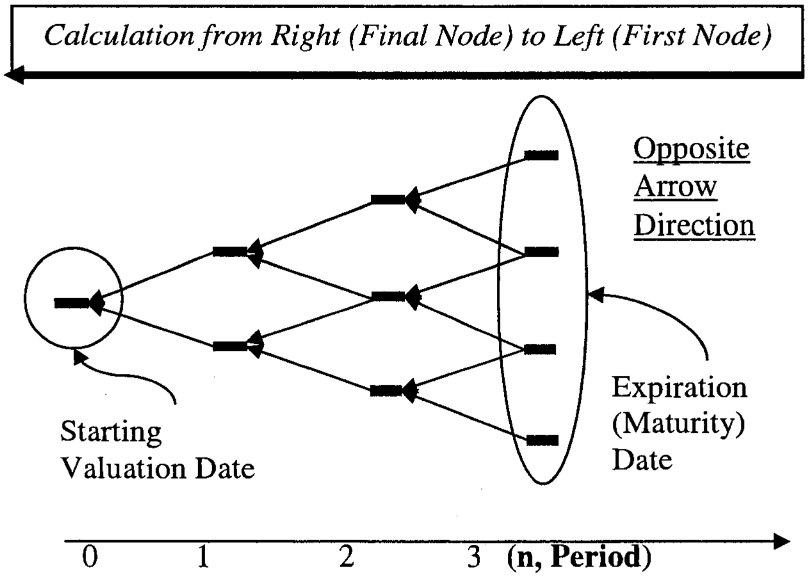


Figure 8.41 FTRs' Portfolio Option Valuation Binomial Lattice for Decision Analysis

This model has three main steps. The first step of the binomial lattice model is to construct the underlying FTRs' portfolio binomial lattice. To estimate the FTRs' portfolio volatility used in ROA, this chapter focuses on the logarithmic asset price return approach. As mentioned in chapter 4, chapter 5, and [Teoh 2007], the FTRs' portfolio option valuation binomial lattice is a replication of the underlying FTRs' portfolio binomial lattice. The purpose of this lattice is to analyze the optimal decision for each node [Teoh 2007].

For example, a generation company, GENCO, has the option to reduce losses by hedging against the transmission congestion risk via financial transmission rights, FTRs. The option valuation lattice will evaluate each node whether it is more effective in terms of profitability to exercise the option, which is to purchase FTRs, or not to purchase FTRs. The only difference between these two lattices is in terms of calculation [Teoh 2007]. The calculation for the underlying FTRs' portfolio binomial lattice is from left to right – starting from the first node to the final node as shown in Fig. 8.40. However, the calculation for FTRs' portfolio option valuation binomial lattice is from right to left – starting from the final node to the first node as shown in Fig. 8.41. This is due to the fact that a binomial lattice model values an option by backward-flow tree induction, which is extending the replicating and related portfolio values, back one period at a time from the claim values to the starting time [Teoh 2004]. The option values at each step of the tree are calculated backwards from the expiration to the present. The main objective of a binomial lattice model is to calculate the option price at the initial node of the trees. Detailed explanations of the binomial lattice model are also illustrated in

[Luenberger 1998], [Hull 2000], [Trigeorgis 1998], [Clemen 2001], [Copeland 2001], [Schwartz 2001], [Trigeorgis 1995], [Mun 2003], and [Teoh 2004].

8.5 Example of FTRs' Portfolio Valuation

Table 8.14 Data for FTRs' Portfolio Binomial Lattice Construction

Elements	Unit	Value
Volatility, σ_{PROFIT}	-	0.18025
Upward Movement	-	1.198
Downward Movement	-	0.835
Stepping Size	-	1
Risk-Free Rate, rf	%	5
Period under consideration, n	Hour	7
Initial FTRs Portfolio value,	$	48,000.00

GENCOs have the option of purchasing FTRs to hedge against transmission congestion risk. The size and bid price of FTRs that GENCOs decide depend upon the company's risk characteristics and the forecasted losses that arise from the energy contracts termination due to transmission congestion. This chapter demonstrates an example of FTRs' portfolio valuation. Data that are critical to construct the underlying FTRs' portfolio binomial lattice are shown in Table 8.14.

Fig. 8.42 illustrates the construction of the underlying FTRs' portfolio binomial lattice from Hour 9 to Hour 15 (peak hours). GENCOs are assumed to suffer losses during peak hours due to transmission congestion and at the same time, receive compensation (or profit) from FTRs contracts because of transmission congestion as well. Table 8.15 shows the losses and compensations GENCOs experienced for each hour respectively.

							169522
						141560	
					118211		118211
				98713		98713	
			82431		82431		82431
		68835		68835		68835	
	57481		57481		57481		57481
48000		48000		48000		48000	
	40083		40083		40083		40083
		33471		33471		33471	
			27951		27951		27951
				23340		23340	
					19491		19491
						16276	
							13591

Figure 8.42 Underlying FTRs' Portfolio Binomial Lattice

Table 8.15 Losses from Energy Contracts Termination and Compensations from FTRs

Hours	Compensation FTRs ($)	Losses ($)	Total Losses ($)
9	- 5,000	0	- 5,000
10	- 5,000	0	- 5,000
11	- 5,000	0	- 5,000
12	+ 61,090	- 51,090	+ 10,000
13	+ 44,090	- 41,090	+ 3,000
14	+ 34,500	- 33,500	+ 1,000
15	- 5,000	0	- 5,000

For Hours 9, 10, 11, and 15, there are no transmission congestions. GENCO suffers losses which consist of the options premium. For Hours 12, 13, and 14, GENCO receives compensation from other market participants.

After obtaining all the required information, the FTRs' Portfolio Option Valuation Binomial Lattice is constructed using backward-flow tree induction. Losses suffered due to energy contracts termination and compensations from FTRs for each peak hour are taken into consideration when performing the P&L calculation. Fig. 8.43 illustrates the option valuation lattice.

							164522
						137804	
					117638		113211
				108168		94957	
			86425		81858		77431
		67634		78290		65079	
	51339		61474		56908		52481
42157		46799		57455		44244	
	33940		44077		39510		35083
		32271		42926		29715	
			31944		27378		22951
				32795		19584	
					18918		14491
						12520	
							8591

Figure 8.43 FTRs' Portfolio Option Valuation Binomial Lattice

Therefore, with the inclusion of total losses suffered due to transmission congestion and total profits (or compensations) from financial transmission rights, FTRs, contracts, the calculated option value of the FTRs' portfolio is USD 42,157.21.

Even though the calculated option value of FTRs portfolio is lower than the initial investment, USD 48,000, the losses are still less compared to the losses suffered solely from the energy contracts termination.

8.6 Conclusion

Whenever generation companies, GENCOs, engage in any energy bilateral contracts, they face transmission congestion risk that may lead to adverse impact. Therefore, GENCOs hedge against transmission congestion risk via financial transmission rights, FTRs. The main purpose of hedging is to transfer risk and minimize losses. With the introduction of FTRs, even though GENCOs suffer losses from energy contracts termination, at the same time, they receive compensation via FTRs. Besides that, the inclusions of financial contract hedging also provide double-protection (together with physical asset hedging from look ahead optimization-binomial lattice-profit at risk, LAO-BL-PaR, approach) mechanism. The evaluation of FTRs portfolio using Real Options Analysis, ROA, enables the risk management process to run efficiently.

By observing the size and bid price of FTRs, the anticipation of any particular GENCO regarding transmission congestion occurring is predictable to a certain extent. This is due to the fact that the size and bid price of FTRs by any GENCO indicate the potential losses that arise from the energy contracts termination due to transmission congestion and the maximum risk any particular generation company, GENCO, is willing to shoulder can be predictable.

CHAPTER 9. CONCLUSIONS

The goal of this research is closely linked to my interest: financial engineering for energy system capital budgeting. The United State deregulated energy market has only been operated for a short time frame: the US energy market is still characterized as immature. The market and regulatory frameworks are expected to continue to evolve in the future. There are still many uncertainties surrounding the current energy market. Therefore, risk management and capital budgeting play very critical roles in energy system planning. Planning, especially long term planning, always involves uncertainties. When there are uncertainties, there are risks involve. The application of financial engineering methodologies-Real Options Analysis, ROA, especially binomial lattice method, to the energy system planning has since then become my interest.

Binomial lattice method has one major disadvantage: massive bush of lattice. The new binomial lattice-value at risk, BL-VaR, approach solves the curse of dimensionality for the binomial lattice method. Besides, that, deregulation has also changed the objectives for different market participants. The objective of generation companies, GENCOs, has switched from minimizing cost to maximizing profit. The GENCOs are no longer willing to release their cost information or their strategic plans. Bottom-line profit has become the center of attention for GENCOs. Thus, the implementation of profit at risk, PaR, ideology has created a new efficient binomial lattice-profit at risk, BL-PaR, approach.

The expansion of ROA into renewable energy sector is highly desirable. Renewable energy sources have been experiencing rapid growth. With the price of fuels soaring and environmental concerns growing larger, the demand for renewable energy sources continue to increase. Many energy experts believe that fossil fuels are only an intermission between pre- and post-industrial eras dominated by the use of renewable energy. Renewable energy has significant advantages as it does not contribute to greenhouse gases, GHG. Wind energy is the center of attention for this research. However, wind energy is uncontrollable and unpredictable. A decision based solution of incorporating the integrating either pump storage hydro, PSH, system or fossil plants with the wind energy, and financial contract hedging is introduced. This energy technology integration is to increase the availability and reliability of wind energy to be as effective as any thermal unit. A physical asset hedging known as the look ahead optimization, LAO, method is applied to both wind farm facilities and PSH system. This new LAO method is capable of obtaining the optimal energy storage and minimizing the size of hedging. The combination of the LAO method with BL-PaR approach achieves several critical goals. And together with the inclusion of financial contract hedging via financial transmission rights, FTRs, a double-protections mechanism is established. The evaluation of FTRs portfolio using ROA enables the risk management process to run smoothly and efficiently.

The overall significance of my research is as follows:

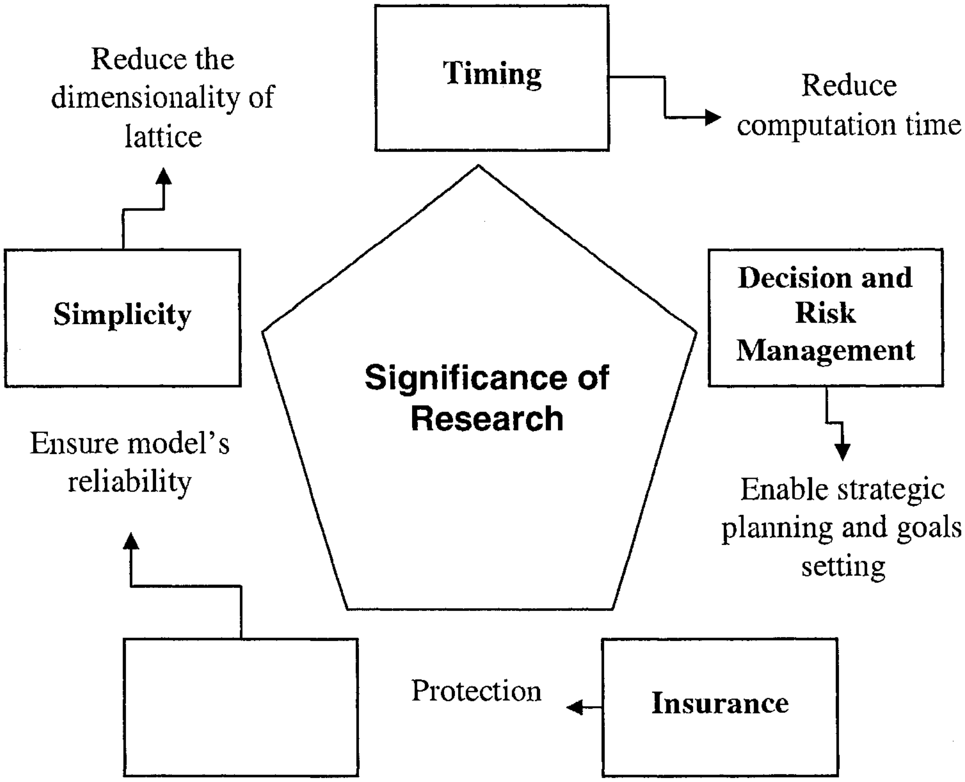


Figure 9.44 The Significance of My Research

(a) Decision and Risk Management

- Provides flexibility to decision and risk management
- Enable strategic planning committees, SPCs, to set reasonable company's (utility) goals

(b) Simplicity

- Reduce the dimensionality of binomial lattice method
- Simplifies the binomial lattice dimension or lattice tree

(c) Timing

- Reduce overall computation time due to the simplification of binomial lattice dimension

(d) Reliability

- Increase model's reliability by providing additional insurance with the combination of physical asset hedging and financial contract hedging approaches

(e) Insurance

- Hedges to protect the value of a commodity from unfavorable condition
- Physical asset hedging and financial asset hedging provide necessary insurance or protection

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APPENDIX: VIRTUAL WORLD CREATION, VWC

In the real world, anything can happen. An efficient and responsible decision-maker has to prepare to face various types of possible outcomes under one's management. One needs to implement the flexibility of one's management when encountering various unexpected cases. This is critical as economy nowadays is very volatile. Real Options Analysis, ROA, has become a key management tool for many managers to use for investment decision. Three simple cases are presented. All these cases are solved using ROA approaches.

Case #1 (The Basic Model)

All cases (Case #1, Case #2, and Case #3) refer to the California Electricity Market. Therefore, the data are obtained from the California Electricity Market Data on Energy Schedules (System-Wide Data). Our region of observation is considerably smaller than California, as the viewpoint is of a single company as an example. The actual and forecast load is reduced by about 90%.

There are 10 generator units in this case. Three of the generator units play important role in delivering electricity to the market. These three units, known as GU1, GU2 and GU3, are the main suppliers of electricity. As a self-owner of two smaller generator units, OGU1 and OGU2, my objective is to maximize the return of investment using Real Options Analysis, ROA. The maximum return of investment can be achieved by taking advantages when there are differences between actual load, sector-forecast load, and myself-forecast load. I assume that whenever there is a lack of power supply, the price of electricity will spike. Therefore, my job is to decide when I should exercise my option, which is to switch on my generator units.

Some facts and requirements to consider during decision making:

1. Large Generator Units:
    - (a) Fixed Cost High
    - (b) Variable Cost Low
    - (c) More Efficient
2. Small Generator Units:
    - (a) Fixed Cost Low
    - (b) Variable Cost High
    - (c) Less Efficient
3. Start Up Time:
    - (a) Large Generator Units (Longer Period of Time): 2-hours
    - (b) Small Generator Units (Shorter Period of Time): 1-hour
4. Reserve Requirement: 80%

These are the rules that I follow:

1. When the differences (Self-Forecast Load – Sector-Forecast Load) are negative, both OGU1 and OGU2 remain idle (off status).
2. When the differences are positive but do not meet the minimum power switch-on requirement, which is 50MW, both OGU1 and OGU2 remain idle (off status).

Table 1 Actual, Forecast, and Self-Forecast Power Load Data for Case #1

Operation Hours	**Actual Load (MW)**	**Forecast Load (MW)**	**Self-Forecast Load (MW)**
1:00 AM	2123	2134	2128
2:00 AM	2072	2058	2055
3:00 AM	2008	1984	1965
4:00 AM	1984	1956	1980
5:00 AM	2027	1977	2022
6:00 AM	2085	2019	2069
7:00 AM	2109	2053	2130
8:00 AM	2124	2102	2181
9:00 AM	2193	2183	2190
10:00 AM	2229	2313	2172
11:00 AM	2231	2373	2210
12:00 PM	2223	2405	2222
1:00 PM	2163	2378	2249
2:00 PM	2131	2358	2273
3:00 PM	2110	2312	2265
4:00 PM	2131	2271	2231
5:00 PM	2352	2500	2294
6:00 PM	2628	2701	2589
7:00 PM	2624	2675	2625
8:00 PM	2575	2629	2591
9:00 PM	2500	2559	2534
10:00 PM	2346	2393	2385
11:00 PM	2157	2174	2155
12:00 AM	2031	2042	2025

3. When the differences are more than 50 MW and less than 160 MW, OGU1 is switched on but OGU2 remain idle (off status).
4. When the differences are more than 1600 MW, both OGU1 and OGU2 are switched on.

Note: Table 1 shows the actual, sector-forecast, and self-forecast power load data for Case #1.

Case # 2 (Power Outage)

Table 2 illustrates some of the electrical outage events that happened in California during 2001. This data is obtained from the California Electricity Market Energy Schedules (System-Wide Data).

Table 2 History of Electrical Outages in California, 2001

History of Electrical Outages in California, 2001

Date	Start Time	Outage (MW)	Area Affected
5/8	3:12 pm	400	Statewide
5/7	4:45 pm	300	Statewide
3/20	9:20 am	500	Statewide
1/21	20 minute disruption due to transmission line failure		Northern California
1/18	9:50 am	1,000	Northern California
1/17	11:40 am	500	Northern California

Table 3 Actual, Forecast, Self-Forecast Power Load and Power Outage Data for Case #2

Operation Hours	**Actual Load (MW)**	**Forecast Load (MW)**	**Self-Forecast Load (MW)**	**Power Outages (MW)**
1:00 AM	2123	2134	2128	0
2:00 AM	2072	2058	2055	0
3:00 AM	2008	1984	1965	0
4:00 AM	1984	1956	1980	0
5:00 AM	2027	1977	2022	0
6:00 AM	2085	2019	2069	0
7:00 AM	2109	2053	2130	0
8:00 AM	2124	2102	2181	0
9:00 AM	2193	2183	2190	0
10:00 AM	2229	2313	2172	0
11:00 AM	2231	2373	2210	0
12:00 PM	2223	2405	2222	0
1:00 PM	2163	2378	2249	0
2:00 PM	2131	2358	2273	0
3:00 PM	2110	2312	2265	400
4:00 PM	2131	2271	2231	0
5:00 PM	2352	2500	2294	0
6:00 PM	2628	2701	2589	0
7:00 PM	2624	2675	2625	0
8:00 PM	2575	2629	2591	0
9:00 PM	2500	2559	2534	0
10:00 PM	2346	2393	2385	0
11:00 PM	2157	2174	2155	0
12:00 AM				

2031 2042 2025 0

For case #2, the power outage of 400 MW that occurred on the 8th of May 2001 is assumed to repeat again on the 1st of January 2006 (at 3.12 pm) as shown in Table 3. Power shortage causes the price of electricity to spike. Both of the generators are not switched on at that particular hour. Therefore, what should I do?

Case # 3 (Transmission Line Effect)

Forced outages can happen anytime and anywhere. Forced outage refers to the shutdown of a generating unit, transmission line, or other facility for emergency reasons or a condition in which the generating equipment is unavailable for load due to unanticipated breakdown. For example, on November 6th, 1998, a Cessna TR182, N756YE, operated by Kennewick Aircraft Services Inc. of Kennewick, Washington, struck power lines across the Columbia River near Desert Aires, Washington, at approximately 1225 Pacific Standard Time. The airplane crashed and sank into the river. Another example is as follows: the Blackout of August 14, 2003, which affected 50 million people in the Northeast, Midwest, and parts of Canada, was said to be partly caused by the interaction between a transmission line and a tree. What should I do if such unfortunate incident happens? Table 4 illustrated the total power shortage in MW due to forced outage.

Table 4 Actual, Forecast, Self-Forecast Power Load and Transmission Line Effect Data for Case #3

Operation Hours	**Actual Load (MW)**	**Forecast Load (MW)**	**Self-Forecast Load (MW)**	**Power Outages (MW)**
1:00 AM	2123	2134	2128	0
2:00 AM	2072	2058	2055	0
3:00 AM	2008	1984	1965	0
4:00 AM	1984	1956	1980	0
5:00 AM	2027	1977	2022	0
6:00 AM	2085	2019	2069	0
7:00 AM	2109	2053	2130	0
8:00 AM	2124	2102	2181	0
9:00 AM	2193	2183	2190	0
10:00 AM	2229	2313	2172	0
11:00 AM	2231	2373	2210	0
12:00 PM	2223	2405	2222	0
1:00 PM	2163	2378	2249	0
2:00 PM	2131	2358	2273	0
3:00 PM	2110	2312	2265	0
4:00 PM	2131	2271	2231	0
5:00 PM	2352	2500	2294	0
6:00 PM	2628	2701	2589	0
7:00 PM	2624	2675	2625	0
8:00 PM	2575	2629	2591	240
9:00 PM	2500	2559	2534	0
10:00 PM	2346	2393	2385	0
11:00 PM	2157	2174	2155	0
12:00 AM	2031	2042	2025	0

For case #3, I assume that a transmission line is tripped off around 8 pm on the 1st of January, 2006. GU2, which operates at its full capacity, loses half of its power transmission ability. The total power shortage due to transmission line effect is assumed to be 240 MW. Taking into consideration the differences between Self-Forecast Load and Sector-Forecast Load, the total power shortage is 451 MW. Should I (owner of two small generators) switch on my generators, OGU1 and OGU2?

Application of Real Options Analysis, ROA, Methods to Virtual World Cases

Different methods of Real Options Analysis, ROA, require different kinds of inputs. Table 5 shows the various inputs for each method (for detailed explanation regarding each input, please refer to [Teoh 2004]):

S = Current value of my portfolio

K = Strike Price, the value of my portfolio when exercising my option. (The strike price for Case #1 is lower compared to Case #2 and Case #3. This is due to the fact that both electrical outage and forced outage are unexpected events. Therefore, they will cause the electricity price to spike or increase even more)

r = Interest Rate

sig = Volatility

div = Dividend

T = Duration under considerations

N = Time Steps

dx = Space Steps

M = Number of Simulations

Table 5 Inputs of All Cases for Every Approach of ROA

Cases		Inputs								
		S	**K**	**r**	**sig**	**div**	**T**	**N**	**dx**	**M**
#1	**Black-Scholes**	100	120	0.06	0.2	NA	1	NA	NA	NA
	Lattice	100	120	0.06	0.2	0	1	7	0.2	NA
	Finite Element	100	120	0.06	0.2	0	1	7	0.2	NA
	Monte Carlo	100	120	0.06	0.2	0	1	7	NA	10000
#2	**Black-Scholes**	100	190	0.06	0.5	NA	1	NA	NA	NA
	Lattice	100	190	0.06	0.5	0	1	15	0.2	NA
	Finite Element	100	190	0.06	0.5	0	1	15	0.2	NA
	Monte Carlo	100	190	0.06	0.5	0	1	15	NA	10000
#3	**Black-Scholes**	100	180	0.06	0.4	NA	1	NA	NA	NA
	Lattice	100	180	0.06	0.4	0	1	20	0.2	NA
	Finite Element	100	180	0.06	0.4	0	1	20	0.2	NA
	Monte Carlo	100	180	0.06	0.4	0	1	20	NA	10000

Table 6 Results of all Cases for every Approach of ROA

	Traditional Method	Lattice Method		Finite Element Method			Simulation Method
Cases	Black-Scholes Option-Pricing	Binomial Tree	Trinomial Tree	Explicit	Implicit	Crank Nicolson	Monte Carlo
1	2.022	3.585	3.436	3.456	3.605	3.532	3.552
2	2.994	3.621	3.9	3.9	4.1	4	3.92
3	1.565	2.199	2.2	2.2	2.4	2.3	2.27

As shown in Table 6, the calculated option value for each case using the lattice method, the finite element method, and the Monte Carlo simulation method are rather close. The Black-Scholes option-pricing method generally has a lower calculated option value for every case compared to other methods. This is due to the fact that this method does not have the flexibility to take into account many aspects (flexibilities) when calculating the option value. Therefore, the traditional Black-Scholes option-pricing method is used as a benchmark.

Generally, when the calculated option value is positive, OGUs owner will operate his generators and vice-versa. The positive calculated option value indicates higher positive rate of return compared to normal operation rate of return. Since the calculated option values for all cases are positive, OGUs owner switches on his generator(s). The procedures of operating his generators are as follows: First, OGU1 will be switched on. If the supply from OGU1 is insufficient, OGU2 will then be switched on. Detailed operations of OGU1 and OGU2 with respect to each case are illustrated in Table 7, Table 8, and Table 9.

Table 7 Operation Decision for Case #1

Operation Hour	Differences (MW)	Decision (OGU1)	OGU1 Output (MW)	Decision (OGU2)	OGU2 Output (MW)
1:00 AM	-6	off	0	off	0
2:00 AM	-3	off	0	off	0
3:00 AM	-19	off	0	off	0
4:00 AM	24	off	0	off	0
5:00 AM	45	off	0	off	0
6:00 AM	50	ON	50	off	0
7:00 AM	77	ON	77	off	0
8:00 AM	79	ON	79	off	0
9:00 AM	7	off	0	off	0
10:00 AM	-141	off	0	off	0
11:00 AM	-163	off	0	off	0
12:00 PM	-183	off	0	off	0
1:00 PM	-129	off	0	off	0
2:00 PM	-85	off	0	off	0
3:00 PM	-47	off	0	off	0
4:00 PM	-40	off	0	off	0
5:00 PM	-206	off	0	off	0
6:00 PM	-112	off	0	off	0
7:00 PM	-50	off	0	off	0
8:00 PM	-38	off	0	off	0
9:00 PM	-25	off	0	off	0
10:00 PM	-8	off	0	off	0
11:00 PM	-19	off	0	off	0
12:00 AM	-17	off	0	off	0

Table 8 Operation Decision for Case #2

Operation Hour	Difference (MW)	Decision (OGU1)	OGU1 Output (MW)	Decision (OGU2)	OGU2 Output (MW)
1:00 AM	-6	off	0	off	0
2:00 AM	-3	off	0	off	0
3:00 AM	-19	off	0	off	0
4:00 AM	24	off	0	off	0
5:00 AM	45	off	0	off	0
6:00 AM	50	ON	50	off	0
7:00 AM	77	ON	77	off	0
8:00 AM	79	ON	79	off	0
9:00 AM	7	Off	0	off	0
10:00 AM	-141	off	0	off	0
11:00 AM	-163	off	0	off	0
12:00 PM	-183	off	0	off	0
1:00 PM	-129	off	0	off	0
2:00 PM	-85	off	0	off	0
3:00 PM	753	ON	160	ON	160
4:00 PM	-40	off	0	off	0
5:00 PM	-206	off	0	off	0
6:00 PM	-112	off	0	off	0
7:00 PM	-50	off	0	off	0
8:00 PM	-38	off	0	off	0
9:00 PM	-25	off	0	off	0
10:00 PM	-8	off	0	off	0
11:00 PM	-19	off	0	off	0
12:00 AM	-17	off	0	off	0

Table 9 Operation Decision for Case #4

Operation Hour	Difference (MW)	Decision (OGU1)	OGU1 Output (MW)	Decision (OGU2)	OGU2 Output (MW)
1:00 AM	-6	off	0	off	0
2:00 AM	-3	off	0	off	0
3:00 AM	-19	off	0	off	0
4:00 AM	24	off	0	off	0
5:00 AM	45	off	0	off	0
6:00 AM	50	ON	50	off	0
7:00 AM	77	ON	77	off	0
8:00 AM	79	ON	79	off	0
9:00 AM	7	off	0	off	0
10:00 AM	-141	off	0	off	0
11:00 AM	-163	off	0	off	0
12:00 PM	-183	off	0	off	0
1:00 PM	-129	off	0	off	0
2:00 PM	-85	off	0	off	0
3:00 PM	-47	off	0	off	0
4:00 PM	-40	off	0	off	0
5:00 PM	-206	off	0	off	0
6:00 PM	-112	off	0	off	0
7:00 PM	-50	off	0	off	0
8:00 PM	451	ON	160	ON	160
9:00 PM	-25	off	0	off	0
10:00 PM	-8	off	0	off	0
11:00 PM	-19	off	0	off	0
12:00 AM	-17	off	0	off	0