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Investment planning applied to power systems using real options analysis

by

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Program of Study Committee:
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ABSTRACT

The electric industry has changed from a vertically integrated industry to a market based competitive industry. The incentives of market participants have changed and there is additional uncertainty since the industry is no longer vertically integrated. Traditional methods used in investment planning are no longer adequate; thus, improved methods are needed to provide a better valuation of investments. This research concentrates on transmission planning and real options analysis. The transmission planning research applies real options analysis and compares it to other approaches. Real options analysis is preferred as it can model the managerial flexibility that takes place in investment planning. In the process of researching real options analysis, wind energy planning was also studied and this topic is presented as well. The wind energy planning research applies real options analysis to the problem of wind energy being uncontrollable and examines other methods that are recommended to remedy this problem.

CHAPTER 1: INTRODUCTION

1.1 Motivation

The electric industry used to be vertically integrated. Market participants would share information and work together in order to better serve their customers. With deregulation, incentives have changed; market participants do not want to share information regarding their strategic plans, as that would tip off their competition. As a result, there is more uncertainty and volatility in the market. Traditional methods did not have to deal with such uncertainty. Likewise, market participants are now more concerned about their profit, as return on investments are no longer guaranteed. This has changed investment planning and the industry is searching for new methods to value investments. The concentration of this research is on transmission planning and real options analysis. In the process of researching real options analysis, the author used it to analyze wind energy planning and this topic is presented.

This thesis analyzes transmission expansion planning by providing a review of past methods and a discussion on why the proposed method, real options analysis (ROA), is a preferred method. One key difference is that real options analysis does not assume the decision making process is static like traditional methods do. Instead, it considers these managerial options, such as the option to expand, abandon, suspend, etc. Thus, it provides a better estimate of the investment's value.

Wind energy is also discussed in this research. It is a popular topic since it is a pollution free energy source so it has a large environmental benefit. Wind energy is also an alternative source of energy that helps decrease our dependency on foreign oil. Researchers are looking for ways to make wind energy a more desirable investment so that it can compete with fossil fuels. The main setback for wind energy is the uncertainty and uncontrollability of the energy source, wind. The currently proposed methods to handle this problem involve converting the electric energy to potential energy by using compressed air or pumped storage hydro facilities. This work analyzes the option of using a pumped storage hydro plant together with a wind farm from a financial viewpoint. In addition, this research analyzes whether such an option is truly best by comparing it to the case where the wind farm can purchase call/put options to protect against the uncertainty of the wind. Black-Scholes is used to determine the proper price of these options. The objective of this research is to analyze the effectiveness of these hedging methods and the financial implications.

1.2 Thesis Organization

This thesis consists of seven chapters. Chapter 2 presents the literature reviews on the main topics of the thesis. Chapter 3 provides a review of real options analysis and investment science techniques. Chapter 4 presents forecasting techniques that are used during this research. Chapter 5 presents a detailed discussion on transmission planning while chapter 6 entails wind energy planning. Chapter 7 provides a summary of this thesis.

1.3 Summary of Contents

The objective of this work is first to provide a review of traditional investment strategies for the two main research topics, which include transmission expansion planning and wind energy planning. Once the traditional investment strategies are covered, the main objective is to discuss how real options analysis can be used instead and how such a planning strategy compares to traditional methods.

Chapter 2 provides a literature review on the main topics of this thesis: transmission expansion planning and wind energy planning. This chapter discusses the current and traditional investment planning techniques for the topics at hand and it discusses how the proposed methods are state of the art.

Chapter 3 provides a thorough background of investment science techniques and real options analysis. The chapter discusses Net Present Value (NPV), Value at Risk (VaR), Return On Investment (ROI), Capital Asset Pricing Model (CAPM), Black-Scholes Options Pricing Method, Real Options Analysis (ROA), and a few other techniques.

Chapter 4 presents an introduction to the forecasting methods that have been used throughout this research. The focus of this research is not on the forecasting methods; thus, the chapter presents the methods only and does not provide a thorough proof of such methods. The presented methods are the Extended Kalman Filter (EKF) and Geometric Brownian Motion (GBM).

Chapter 5 first provides a review of traditional transmission planning approaches. It then continues by introducing real options analysis along with providing a review of a few case studies in order to provide a comparison of the different approaches. The purpose of chapter 5 is to apply real options analysis and model the uncertainties of transmission planning in order to provide a more rigorous valuation of the economic benefits than traditional methods. [47], [48], and [49] proposes a method to model the stochastic nature of Available Transfer Capability (ATC) as well as the stochastic nature of power flows. This research is in collaboration with [47], [48], and [49] and their data has been provided for use in this work.

Chapter 6 covers wind energy planning. The key issue for wind energy is the fact that it is an uncontrollable energy source. Thus, wind energy planning focuses on this concern. Current remedies for this issue propose using a pumped storage facility in cooperation with the wind farm. Whenever there is energy from the wind farm, it would replace the energy that the pumped storage is either buying or selling. Chapter 6 investigates whether such a large investment into a pumped storage facility is truly necessary by considering the use of call options to hedge the risk of whether or not there will be the wind to produce the energy needed.

Chapter 7 provides an overview of the thesis and presents the key conclusions of this research.

1.4 Overview of Collaborative Work

This report is part of a multi-university project that was funded through PSERC, Power Systems Engineering Research Center. This joint project included a group from Arizona State University (ASU), the University of Illinois, Urbana-Champaign (UIUC), and Iowa State University (ISU). The publications from these three universities on this joint project include [21], [22], [47], [48], & [49]. This report represents the work to be completed by ISU for this project, which includes the financial valuation of transmission expansions. The other universities' role in the project was to develop new techniques to model and forecast the stochastic behavior of ATC & power flow data. This data was then to be provided to ISU to perform the financial valuations.

The author also worked jointly with other graduate students on some of the work presented in this report. The sections of the report that are based on joint work include section 4.2 on Extended Kalman Filtering [23], which was a course project that was jointly developed by Kory Hedman, Chin-Chuen Teoh, & Umar Butt. Sections 5.1 through 5.2, which discuss the problem formulation of transmission planning [21], was jointly developed by Kory Hedman and Feng Gao under Dr. Gerald Sheble for this report.

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

This thesis covers investment planning applied to power systems. Within this topic, this thesis focuses on transmission planning as well as wind energy planning. The main technique used is real options analysis. This chapter provides a thorough literature review for these main topics, which are the focus of this thesis.

2.2 Investment Science & Options Theory

When the energy industry was regulated, investment planning revolved more around reliability concerns than profitability and risk. Objectives were based on minimizing cost to the consumers while meeting reliability standards. The use of options theory and real options analysis in power system topics is a newer approach for the electrical industry since the industry is now deregulated. Companies' objectives have now changed to be profit oriented and they have to consider the risk associated with their investments, as they now have to deal with risk exposure.

Real options analysis is becoming more common as the industry is recognizing that applying the best method to value their assets is more important now since market participants have to deal with risk that did not exist in the regulated environment as well as the simple fact that they are now for profit. Research surrounding derivatives is particularly popular currently. Researchers are learning how derivatives can help reduce risk, increase profits, and even help with market stability. [12] determines the value of a tolling agreement by using real options analysis. A tolling agreement is like a call option since it gives the buyer the right 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 the electricity in the market and the heat rate adjusted fuel price. [40] discusses how Load Serving Entities (LSEs) could use call options for peak load hours in order to reduce the risk of being exposed to high-energy prices. [64] analyzes contingency services for wind energy. The contingency services are modeled as call options and prices are determined using option pricing theory. [65] applies real options analysis to determine the value of switchable tariffs for wind energy in the Spanish electricity markets.

2.3 Transmission Planning

2.3.1 Introduction to Transmission Planning

Deregulation of the electric industry has opened the doors for competition and this has caused a significant difference in what information is required to evaluate the value and risk associated with a transmission expansion investment. In the regulated, vertically integrated industry, the objective was to meet these standards while minimizing the cost for the ratepayers. Now, the deregulated industry has market participants that are profit-maximizing firms while the transmission stays regulated. Sharing of information is no longer beneficial as such information as revealing your strategic plans can decrease your profits by allowing your competition to know your plans. This adds additional uncertainty to transmission planning in the long run as predicting market behavior is difficult. Another difference is that the deregulated markets are a lot more volatile and thus, harder to predict. This further complicates transmission planning. These reasons are why new transmission planning methods are required. Many researchers are working on this problem and the proposed methods vary. The following paragraph provides an overview of proposed transmission planning methods while the following four sections, sections 2.3.2-2.3.5, provide a review on the papers that are discussed in more detail in Chapter 5.

[1] employs a benefits-to-costs ratio test to determine the appropriate transmission investment. The method uses a probabilistic analysis for the failures of the various transmission investments that are being considered and incorporates a cost for the failures. [7] provides an overview of traditional, cost minimization based transmission planning methods. The paper discusses why different transmission planning methods are needed for the competitive industry and presents a method where the objective is to maximize competition subject to a budget constraint on transmission investments. One issue with this approach is that they do not consider the benefits of such transmission investments and only look to increase competition. [43] analyzes the affect of not considering how the transmission

investment may alter generators' strategies. Most transmission planning methods consider only what is happening in the current market and do not consider how the investment will alter the strategies of the market participants. By not considering this, what was thought to be an optimal investment might become sub-optimal. [53] presents a method that analyzes the uncertainty based on not knowing future generation investments as independent power producers (IPPs) have an incentive not to share their strategic plans. They also include uncertainties involving fuel prices, load, etc. Their method is based on analyzing the regret that might occur based on different future events that might occur. They choose the project to invest in based on a risk preference model, which can be based on minimize regret, maximize profit, minimize average regret, etc.

2.3.2 Cost/Benefit Analysis Applied to Transmission Expansion Planning

[38], "Transmission Planning in the Presence of Uncertainties," develops a method to determine the proper transmission investment to make while dealing with the uncertainty of where the next generation plant would be built. This sort of uncertainty is a new problem in the deregulated market, as the industry is no longer vertically integrated. Thus, this research provides a method to account for this uncertainty. Their main method is to first analyze all of the different cases where generation might be built and to choose a transmission expansion project based on minimum cost for each case. Then, with one transmission project for each case, they evaluate the different transmission projects based on the cost-to-benefit ratio. Their method determined an acceptable expansion project with an internal rate of return of 12% above their case study.

2.3.3 Probabilistic LMPs Using Monte Carlo Simulations

The objective of [5], "Market-Based Transmission Expansion Planning," is to determine how much a certain transmission expansion project improves competition in the market. Their main method to evaluate this is based on congestion cost. Congestion cost is the difference between two buses' Locational Marginal Price (LMP) times the power flow across the line. As competition improves, this cost should decrease or essentially the difference in the LMPs should decrease. They use Monte-Carlo Simulations to determine the probabilistic

LMPs of the network. This includes having to determine the probability density function (PDF) to the random inputs involved throughout the planning horizon like change in load, generation, transmission lines, etc. Finally, they determine the transmission investment based on the improvement to competition relative to the cost of the transmission investment and the risk of the investment. [6] is an extension of this work where the authors focus more on the uncertainties associated with transmission planning.

2.3.4 CAISO's Transmission Economic Assessment Methodology (TEAM)

The objective of traditional planning methods would be to minimize the cost for the ratepayers. Since ISOs are suppose to be completely independent from both the supplier and the buyer side, many now support the approach of maximizing social welfare. The California Independent System Operator (CAISO) recently developed the Transmission Economic Assessment Methodology (TEAM), which they use to determine the economic value transmission investments [9]. TEAM determines the value of the transmission investment based on the societal benefit it provides to all market participants. This takes into account the benefit to ratepayers (lower costs), the benefit to suppliers (higher profits), and the benefit to transmission owners (higher congestion revenue). Thus, this considers congestion revenue as a benefit to society. TEAM also uses a novel approach to model the strategic behavior of the merchant suppliers by determining a price-cost markup. TEAM methodology uses an econometric approach and equates the price-cost markup, which is the Lerner Index, to the residual supply index, the percent of load unhedged, a dummy variable for the summer period, and a dummy variable for the peak hours. TEAM also employs a scenario-based analysis to capture the affect of certain uncertainties like high/low fuel prices, load growth, available generation, hydro resources, etc. This is a simplified approach as methods that are more complicated like Monte Carlo simulations take much more time. Further discussion on this topic is presented in Chapter 5 including a discussion on why such analysis is needed and why real options analysis would strengthen the TEAM methodology.

2.3.5 Proposed Transmission Planning Technique

This research discusses the method of real options analysis and how it can be used to value transmission expansion investments. The work also discusses the difference between this approach and other approaches presented in the previous three sections. One key difference is that real options analysis does not assume the decision making process is static like traditional methods do. Instead, it allows these managerial options to be considered. Thus, by doing so, it provides a better estimate of the investment's worth. Real options analysis also provides a robust method to analyze the risk. There are multiple real options methods from Black-Scholes to Monte-Carlo simulation to Trees/Lattices (Binomial, Trinomial, etc.) and more. In order to perform real options analysis, one needs stochastic, probabilistic data. This work is in cooperation with [47], [48], and [49]. These papers develop a stochastic Available Transfer Capability (ATC) method as well as a probabilistic power flow method. [21], written by the author of this research, provides an overview of transmission planning and discusses why real options analysis is an improvement over most transmission planning methods.

2.4 Wind Energy Planning

2.4.1 Introduction to Wind Energy Planning

Wind energy is different from most forms of energy as it is not controllable. There is no mechanism to say how much energy can be produced and at what time. The production of wind energy is uncertain and hard to predict. This is not the norm in power engineering so engineers look for ways to balance this aspect of wind energy and since wind energy is becoming more and more popular as renewable energy becomes more popular, this becomes a more important.

2.4.2 Current Wind Energy Planning Techniques

Current methods that address this issue propose converting the electrical energy to potential energy. One method that is not optimal is storing the energy in batteries as the costs and energy losses are too high. Two methods that are popular at this moment are using a pumped storage hydro facility that interacts with the wind farm to balance the fluctuations in energy production and uses the excess wind energy to pump water up to the upper reservoir so that water can be used to produce energy later. The other method is to use the energy with a compressed air facility that will later use the compressed air to decrease the required fuel for natural gas plants.

[10] presents a method to use a hydro plant and the wind farm together in order to meet a required supply level. The objective of the research is to model the wind speeds and determine a reliable forecast so that one can determine an optimal scheduling between the two facilities for the following 24 hours. [31] discusses the possibility of having a future energy supply based mainly on a “wind and water model,” where a large portion of the energy is produced by wind farms and pumped storage facilities that interact together. This study was conducted based on the network in Germany. For this to be implemented, a large number of pumped storage facilities would be needed, which is subject to topology and is costly. Thus, the authors conclude that it is improbable to have a system that is mainly wind energy driven and it is more likely to have a mix of thermal plants as well. [42] discusses the improvements in energy storage and mention that such improvements increase the value of renewable resources like wind energy. [44] provides an overview of the various 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 (CAES) facilities. [58] states that compressed air helps convert natural gas to energy more efficiently than natural gas alone. [59] discusses the current research on a project that plans to build a 200MW CAES plant in Fort Dodge, Iowa along with a 100MW wind farm. The CAES and the wind farm will work together by taking the extra wind energy and using it to store potential energy in the form of compressed air.

2.4.3 Assessment of Wind Energy Planning Techniques

Wind power is increasing in popularity and production since it is a renewable energy source and it is an environmentally friendly way to produce electricity. The problem with wind power is that the energy source, wind, is not controllable. Since electric energy is unlike any other good since it cannot be stored, this is a crucial problem for wind energy if it is to be competitive with other methods such as coal or natural gas. Thus, current researchers are trying to develop ways to mitigate this problem by using compressed air facilities or pumped storage hydro units that would take the wind energy (electric energy) and convert it into potential energy. Many papers cite that wind energy combined with a pumped storage facility or a compressed air facility is an effective way to overcome the problems with the uncertainty of wind energy. However, this takes a large investment into a secondary plant just to be able to store the electric energy in a different form. Thus, the question to be answered is whether this is the most effective way.

[22], the author's published paper on this work, analyzes the tradeoffs for a single owner that has two main assets: a wind farm and a pumped storage facility. The owner can either have the two facilities work together to optimize profit or can have them work separately. If they operate separately, the owner will purchase call options in order to guarantee that the energy the owner sells on the market will be provided. The fair values of the options are determined by using Black-Scholes Options Pricing theory [2]. The two cases are evaluated based on expected return and variance in order to determine whether a pumped storage facility is necessary to offset the uncontrollable nature of wind energy. This research points out that financial derivatives can be used to mitigate the uncertainty of wind, which is a financially competitive investment as compared to these other proposed methods.

CHAPTER 3: INVESTMENT SCIENCE & OPTIONS THEORY

3.1 Basic Valuation Techniques

3.1.1 Net Present Value (NPV)

Net Present Value (NPV) is a method used to discount future cash flows in order to have them in present value terms so that one can sum up all cash flows to get a net present value. This method is used since a dollar today is worth more than a dollar a year from now, unless there is deflation. Thus, future cash flows must be discounted into present value terms. The equation below, (3-1), shows how to calculate the NPV of a cash flow.

$$NPV = \frac{A}{r-g} * \left(1 - \left(\frac{1+\frac{g}{n}}{1+\frac{r}{n}} \right)^{n*yr} \right) \qquad (3\text{-}1)$$

- NPV: Net Present Value
- A: yearly cash flow
- r: yearly interest rate to discount future cash flows
- g: yearly growth rate reflecting the growth of cash flows over time
- n: number of periods in a year the interest is applied
- yr: total years of the cash flow

3.1.2 Return on Investment (ROI)

Return On Investment (ROI) is used to determine how much profit is made relative to the invested amount for that asset. Since different investments have different costs associated with them, comparing profit only is not sufficient to determine the right project. It is a reflection of how much bang for the buck you will receive.

$$r = \frac{NPV}{I} - 1 \qquad (3\text{-}2)$$

NPV: Net Present Value of all cash flows (includes cost)

- I: Invested amount
- r: rate of return or ROI

3.1.3 Value-At-Risk (VaR)

Value at Risk defines a worst-case loss level given a certain confidence interval for a given time horizon. It seeks to establish how bad it can get in the short term. Banks use VaR to determine how much cash on hand they are required given the risks that they are taking. To calculate the VaR, one chooses a confidence interval, typically 95%. If the CDF is known, then the VaR is just μ - X and X is the value where 1-CDF(X) = 0.95 or the chosen confidence interval. For Normal distributions, one first determines the value that sets the lower tail CDF to 1-0.95. For a Normal distribution, that is -1.65. This value is then multiplied by the standard deviation to get the VaR. Then, the worst-case outcome for this chosen confidence interval is the expected value minus the VaR. The VaR equation is shown below as (3-3).

$$VaR = 1.65 * \sigma \tag{3-3}$$

When you have standard deviations that are not for the time horizon that you wish to have for your VaR, then you must do a conversion. For instance, if you want a 5-year VaR when your standard deviation is for a one-year period, you can calculate the 5-year VaR based on the 1-year VaR. This is shown below as (3-4).

$$\text{5-Year VaR} = \sqrt{5} * \text{1-Year VaR} \tag{3-4}$$

3.1.4 Payback Period

At times, the length of time that it will take to pay off an investment can be very important. This length of time is referred to as the payback period. Typically, it is assumed that the real interest rate does not change over time. For long-term investments, this can be a very critical assumption. Thus, determining the payback period can be helpful in deciding which investment to take if one does not want to be exposed to such risk. The payback period is determined by solving (3-1) for yr with everything else known.

3.2 Minimum Variance Portfolios

Those that are risk averse at times just wish to determine how much to invest in different assets such that they achieve their desired expected return but with the minimum possible variance. Let w_i reflect the weight given to asset i. Then, the Markowitz problem to achieve the minimum variance for a specified expected return is shown below as (3-5).

$$\text{Minimize}: \sigma^2 = \sum_{i,j=1}^{n} \omega_i \omega_j \sigma_{ij} \tag{3-5}$$

$$\text{Subject to}: \sum_{i=1}^{n} \omega_i \bar{r}_i = \bar{r} \tag{3-6}$$

$$\sum_{i=1}^{n} \omega_i = 1 \tag{3-7}$$

3.3 Capital Asset Pricing Model (CAPM)

The CAPM model assumes that only mean and variance are important to the consumer. Expected value is treated as a good while variance is considered a bad. For any given desired expected return, the efficient portfolio provides such at the lowest possible variance level. This is known as mean-variance efficiency. To determine the optimal portfolio, one must consider the person's utility function in order to incorporate risk preferences.

The expected return of the portfolio is the sum of weight$_i$*expected_return$_i$ for all i as shown by (3-6). The portfolio variance is calculated by the sum of weight i times weight j times covariance(i,j) over all i, over all j as shown by (3-5). There is no restriction on the sign of the weights, just that they have to sum to one. This is to reflect the possibility of both long and short positions.

CAPM states that an asset (portfolio) is efficient if (3-8) holds. For real assets, (3-8) reflects the required rate of return. (3-8) states that the expected return of the asset (portfolio) is equal to the risk free rate plus the beta of the asset (portfolio) multiplied by the difference between the expected market portfolio return and the risk free rate. The beta of the asset is equal to the covariance of the asset with the market portfolio divided by the market portfolio variance. These equations are listed below.

$$\overline{r_i} = r_f + \beta_i * (\overline{r_m} - r_f) \tag{3-8}$$

$$\beta_i = \frac{\sigma_{im}}{\sigma_{mm}} \tag{3-9}$$

The equations above reflect the rate of return and not the price of an asset while CAPM is a pricing model. With little manipulation, CAPM is a pricing model. The reason the above equations are used instead is that people typically focus on the rate of return instead. According to CAPM, the price I of an investment with a random payoff of S should follow:

$$I = \frac{\bar{S}}{1 + r_f + \beta_i * (\bar{r}_m - r_f)} \tag{3-10}$$

$$\bar{r}_i = \frac{\bar{S} - I}{I}$$

There are many different assets (portfolios) that satisfy this relationship and these portfolios make up the portfolio frontier. The portfolio frontier is shaped like a C. There is a point on the portfolio frontier known as the minimum variance point. This minimum risk point is the lowest variance one can achieve while having an efficient portfolio. Since this is an efficient portfolio, this point must have an expected return higher than that of the risk free rate. This point and all other points on the portfolio frontier that are above the minimum variance point make up the efficient frontier. This region of the portfolio frontier is known as the efficient frontier because even though the other portfolios satisfy the CAPM equation, there are always better portfolios on the upper half of the curve. These other portfolios are said to be better (efficient) because they have the same risk as do the portfolios on the lower half of the portfolio frontier but they have a higher expected return as well. Therefore, the portfolios below the minimum variance point are not efficient since you can always get a higher expected return for the same risk.

Given the efficient frontier, one can determine the market portfolio by finding the linear line that is tangent to the efficient frontier and intersects the axis at the risk free rate. Given this market portfolio and the risk free asset, one can obtain any portfolio that rests on the efficient frontier given some combination of these two assets. This can be seen again by referring to the earlier equation (3-8) that represents any expected return for an asset by the risk free rate, the asset's beta times the difference between the expected market portfolio return and the risk free rate. Figure 3-1 below shows all portfolios that rest on the frontier, the section that represents the efficient frontier, the minimum variance point, the risk free rate (Rf), the market's rate (Rm), and the market portfolio point on the efficient frontier.

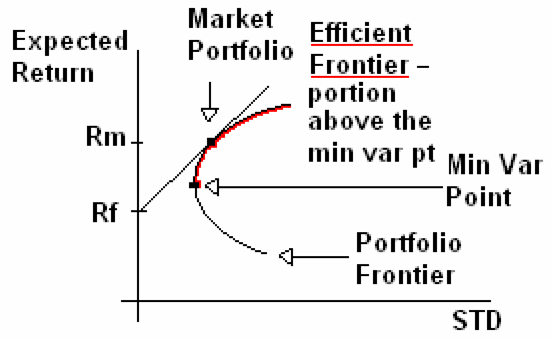


Figure 3-1. Portfolio Frontier, Market Portfolio, & Min Variance Point

For real assets, it typically is not possible to determine the portfolio frontier so the process of project selection is not straightforward. It is evident that all points to the northwest are preferred as you receive a higher return with less variance. One can look for the most northwestern point and choose that asset. However, such an approach does not guarantee optimality. This point is the optimal only if it is to the northwest of all other points. Any point that is directly east of another is inferior as it has the same return but a higher variance. Any point that is directly south of another is inferior as it has the same variance but a lower return. The difficulty arises when you have two points and one is to the northeast (southwest) of the other; it provides a higher (lower) return but also a higher (lower) variance. At this time, one would not be able to determine which real asset is preferred without modeling risk preferences or one of the points is inferior to some other point in which case such a point would be disregarded.

3.4 Arbitrage Pricing Theory (APT)

CAPM relies on the mean-variance framework and assumes that everyone applies this technique in order for it to be valid. Arbitrage pricing theory (APT) is more generic since it does not rely on these specific assumptions. The only key assumptions that APT relies on is that there needs to be a large number of assets that differ from one another in nontrivial ways; specifically, there should be an infinite number of these assets for the assumption to be satisfied.

APT assumes that the rate of return for any asset is related to factors, which are random quantities, and the relationship is linear as shown in (3-11) with f being the only uncertain term. Linear regression is used to obtain the a & b parameters. For the single factor model, the expected rate of return is shown by (3-12).

$$r_i = a_i + b_i * f \tag{3-11}$$

$$\bar{r}_i = a_i + b_i * \bar{f} \tag{3-12}$$

APT says that if an asset (portfolio) is well diversified, then the expected return follows (3-13).

$$\bar{r}_i = r_f + b_i * \lambda \tag{3-13}$$

$$\lambda = \frac{a_i - r_f}{b_i} + \bar{f} \tag{3-14}$$

For the single asset, multi-factor model, the expected return is listed as (3-15). For well-diversified assets (portfolios), there exist lambdas such that (3-16) holds for all well-diversified assets (portfolios).

$$\bar{r}_i = a_i + \sum_{j=1}^{n} b_{i,j} \overline{f_j} \tag{3-15}$$

$$\bar{r}_i = r_f + \sum_{j=1}^{n} b_{i,j} \lambda_j \tag{3-16}$$

$$\lambda_j = \frac{a_i - r_f}{b_i} + \overline{f_j} \tag{3-17}$$

3.5 Options Theory

3.5.1 Black-Scholes Options Pricing Model

The Black-Scholes Options Pricing Model can be used to determine the fair price for a European call or put option. By saying fair, it means that there is no possibility for arbitrage with this pricing system. Essentially, it prevents the "free lunch," the ability to make a sure profit without any investment or cost. The Black-Scholes model assumes that, for short time periods, the percentage changes in stock prices are normal distributed and Black-Scholes assumes that the returns are lognormal [26]. This implies that the lognormal of the stock price at time T divided by the current stock price, $\ln(S_T/S_0)$, is normally distributed. The Black-Scholes pricing model also assumes a constant interest rate over the period as well as continuous compounding. It also assumes that only European exercise terms can be used, i.e. the option can only be exercised on the expiration date. The assumption that is considered incorrect typically is the first one that states that the probability density function (PDF) of the lognormal of the variable represents a normal distribution. The Black-Scholes options pricing equations are listed below along with the terminology.

$$C(S,t) = S * N(d1) - K * e^{(-rt)} * N(d2) \tag{3-18}$$

$$P(S,t) = K * e^{(-rt)} * N(-d2) - S * N(-d1) \tag{3-19}$$

$$d_1 = \frac{\ln(S/K) + \left(r + \frac{\sigma^2}{2}\right)t}{\sigma * t^{1/2}} \tag{3-20}$$

$$d_2 = d_1 - \sigma * t^{1/2} \tag{3-21}$$

C : call premium
P : put premium
S : current stock price
t : time until option expiration
K : strike price
r : interest rate
N(x) : Prob. that a N(0,1) variable is less than x
e : exponential
σ : standard deviation of stock returns

3.5.2 Call & Put Options

A European call option gives the holder (long position) the right to purchase the stock or commodity for a specific price at a future time. There is no obligation to exercise the option, i.e. if it is not profitable to exercise the option you do nothing. Essentially, you purchase a call option if you believe that the commodity's price will be higher than the strike price at the expiration date but you want to avoid the risk of being wrong and losing money. Firms that purchase a specific commodity and wish to hedge risk associated with the price increasing can use call options to create a perfect hedge so that there is no risk exposure as well. Those selling call options (short position) are paid a premium, the sale price, for assuming the risk that the buyer wishes to hedge.

A diagram for the call option is shown in Figure 3-2. The figure displays long positions only. A short position is just a direct reflection of the long position about the x-axis since a short and a long position must always sum to zero. The payoff for exercising one call option is shown below by (3-22). The spot price is the current price of the stock or commodity. The strike price is the agreed upon price that the holder pays for the commodity when the holder exercises the option on the maturity date.

$$Payoff\_call = \max[S - K, 0] \tag{3-22}$$

S : Stock Price
K : Strike Price

A European put option gives the buyer of the option (long position) the right to sell a certain commodity to the seller of the put option (short position) at a strike price and at a certain time. Essentially, if you believe that the price of a commodity will drop below the strike price but wish to avoid the risk, you want to purchase a put option such that you can sell your commodity to someone at a price that is higher than the market price. Like the call option, there is no obligation for the holder to exercise the option. The payoff for the put option is shown below. A diagram for a put option is shown in Figure 3-2.

$$Payoff\_put = \max[K - S, 0] \tag{3-23}$$

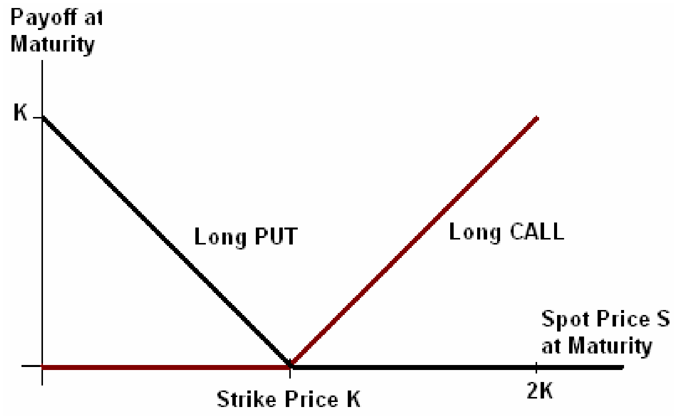


Figure 3-2. Call & Put Payoff Curves

European options can only be exercised at maturity while American options can be exercised at any time. This research uses European options for simplicity. For European options, there is the put-call parity that describes how the price of a call option & a put option are related. Remember that S stands for the current stock price, P for the put price, C for the call price, K for the strike price, and r for the interest rate. Then, the put-call parity equation is provided below. If the two sides are not equal, then there is an arbitrage opportunity. An arbitrage opportunity refers to when there is an opportunity to obtain a guaranteed profit without any investment or cost, i.e. a free lunch.

$$S + P - C = Ke^{-rt} \tag{3-24}$$

3.6 Real Options Analysis

In the past, decisions to invest or not in an asset were simplified. Whether or not this investment option is worthwhile would be determined if the project would make a profit. This would be determined by the net present value (NPV) of the profit. However, real life investment decisions are more complicated. There is uncertainty involved with the cash flow, proper assessment of the risk is necessary, future managerial decisions should be considered, etc. Real Options Analysis (ROA) accounts for these various options and uncertainties. Real options analysis is more realistic because it formulates the problem according to the real world better than traditional methods and thus, provides a better valuation of the investment option.

Various managerial options must be considered in real life business conditions. Traditional methods ignore these future strategies because there is too much uncertainty or the uncertainties are too complex. However, these uncertainties are likely to become resolved as time progresses. The managerial decisions may change and thus, including these possibilities in the valuation of the investment is important. Real options analysis is a technique that allows one to include such managerial flexibility, essentially a strategic road map, while more traditional methods do not consider such options; thus, the project is undervalued. Real options analysis provides such guidance by providing the investor ways to analyze the various strategic paths that can be taken throughout the entire life of the project and to be able to decide which path is the most promising given the current status & future outlook. Real options analysis does this in three main ways.

a.) By being able to analyze when it is the appropriate time to exercise an option. This can vary from when to abandon the investment project, when to expand the project, when to suspend the project until a further time, when to hire more workers, produce more, etc.

b.) As more information is known, you are able to adjust your investment strategies by re-analyzing various options. For instance, options that were too risky might now be worthwhile given the new information. This has a lot to do with the electricity markets, the actions of your competitors, etc. In the electric industry, at times, the risk is too high and thus, special contracts are used to share this risk with the ISO. In transmission expansion planning, a grandfathering contract is used for such cases.

c.) Last, it allows the investor to continually consider and include the valuation of new options throughout the planning horizon. This allows the investor to consider a completely new strategic path to be considered. Real options analysis looks at what the best decision is now given all of the options and risk involved while considering future options as well. Thus, the problem formulation is always going to be updated accordingly throughout the planning horizon, as is the case in real life.

3.6.1 Monte-Carlo Simulations

Monte Carlo simulation is useful for large problems that are difficult to solve. Its purpose is to provide information on the distribution of the variables in question by knowing the distribution and relationships of the input variables involved. Then, by providing information on the distribution, one is provided with the expected value of the investment and one can ascertain the risk involved with such an investment by considering the overall variance of the distribution. Essentially, one needs to identify the distribution of the input variables, variance, etc. and once the relationship between the inputs & outputs is formulated, you run the simulation many times and are provided with the resulting distribution for analysis. Monte Carlo simulation relies on the following requirements:

- The input variables' probability distributions are properly represented by the chosen distributions. This is not only important for the expected value but also variance. It is also very important with regard to the tails of the distribution. The tails of the distribution provide a lot of information on risk involved and confidence intervals so to have inaccurate tail representation can cause the valuation of the option to be off even if the mean is the same. Any correlation between variables must be determined as well.
- The assumption that the resulting simulated distribution will be close enough to the actual distribution by running a large number of simulations, i.e. the theory of large numbers applies once there are adequate simulations. If there are enough simulations for this to hold, the result will match or be very close to the option price obtained by the Black-Scholes Option Pricing Method.

3.6.2 Binomial & Multinomial Trees

Binomial trees are used to represent all of the possible paths that an investment can take. The trees are constructed like decision tress and the different paths represent different managerial decisions that should be considered as well as different possible outcomes that are not controllable such as demand fluctuations, new competition, a change in the network, etc. An important aspect of real options analysis is that new branches can be added to accommodate for new strategies that were not thought to be possible in the past. The trees can be expanded or completely new branches added when some option seems to be more promising and thus, more analysis is needed. They can also be shortened or cut-off completely when an option is no longer possible or there is too much uncertainty involved so that the investment is not worth considering.

Binomial trees have just two path options at each node while multinomial trees have multiple paths. The trees are analyzed by backward induction so that the value at the initial time, the initial node, can be determined. Each path would have a probability assigned to it and an expected value of the investment at that node. If one is interested in the distribution of outcomes, this could be defined at the node as well to provide a range of possible outcomes. The other possibility is to represent the distribution by additional branches.

Figure 3-3 shows the general setup of a binomial lattice for 2 periods when one wants to determine the fair price of a call option. A binomial lattice is a simplified version of a binomial tree as it has the same node whether there is a move up and then down or down and then up and so on whereas a binomial tree has independent nodes for every possible path. The final values of the options are determined by the difference between the assumed stock price for that node minus the strike price. If the strike price is higher, the value of the call option is zero. Then, the tree is solved by backward induction to get the initial value of the call option.

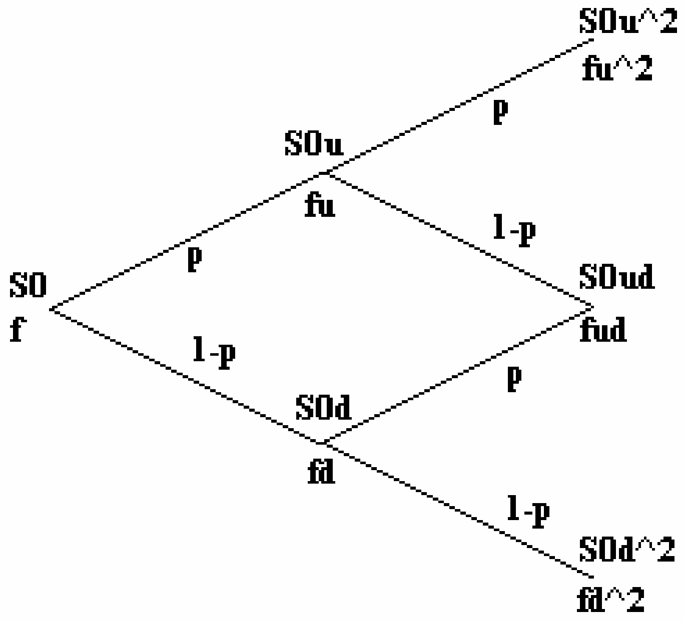


Figure 3-3: Binomial Lattice

- p is the probability of the stock price increasing
- f stands for the current option price
- S_0 stands for the initial stock price
- $u = e^{\sigma\sqrt{\Delta t}}$ (3-25)
- $d = \frac{1}{u}$ (3-26)
- $a = e^{r*\Delta t}$ (3-27)
- $p = \frac{a-d}{u-d}$ (3-28)

The following example illustrates the process to determine a call option's price:

- S_0 = \$20 K = \$15
- r = 0.05 σ = 0.4
- T = 1 year Δt = 0.5
- u = 1.3269 d = 0.75364
- a = 1.0253 p = 0.47389

- S_0 * u = 26.538 S_0 * u^2 = 35.21
- S_0 * d = 15.07 S_0 * d^2 = 11.36
- f_u^2 = max(35.21-15,0) = $20.21 f_d^2 = max(11.36-15,0)= $0.00
- S_0 * u * d = $20.00 f_ud = max(20.0-15,0) = $5.00
- f_u = p * f_u^2 + (1-p) * f_ud = $12.208
- f_d = p * f_ud + (1-p) * f_d^2 = $2.370
- **f = p * f_u + (1-p) * f_d = $7.032**

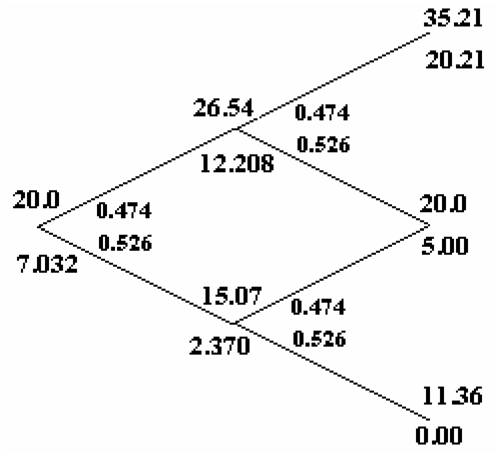


Figure 3-4: Binomial Lattice Example for Determining Call Option Price

CHAPTER 4: FORECASTING

4.1 Introduction

First, the focus of this research is not on forecasting techniques. This chapter will cover the various forecasting techniques researched by the author for various courses or published papers. The choice of the techniques discuss are therefore limited by these topics. The chapter will present and discuss the techniques and how they are used but the chapter will not cover the derivation of the methods and it will not go through a rigorous analysis of the method. The chapter presents two techniques: the Extended Kalman Filter (EKF) and Geometric Brownian Motion (GBM).

4.2 Extended Kalman Filter (EKF)

The basic Kalman filter is limited to a linear assumption. However, the fluctuations of electricity prices over time are non-linear. The non-linearity can be associated with the process model, with the observation model, or with both.

The purpose of the Extended Kalman filter is to linearize about a trajectory that is continually updated with the state estimates resulting from the measurements. In the EKF, the state transition and observation models need not be linear functions of the state but may instead be (differentiable) functions.

$$\text{State Equation}: x_{k+1} = \phi x_k + w_k \tag{4-1}$$

$$\text{Measurement Equation}: z_k = H_k x_k + v_k \tag{4-2}$$

The function h is used to compute the predicted measurement from the predicted state and the function ϕ is used to compute the predicted state from the previous estimate. However, ϕ and h cannot be applied to the covariance directly. Therefore, a matrix of partial derivatives (Jacobian matrix) is computed. At each time step, the Jacobian is evaluated with current predicted states. These matrices are used in the EKF equations. It linearizes the non-linear function around the current estimate. The EKF equations are as follows:

Predict

$$(1) \rightarrow \hat{x}_{k+1}^- = \phi_k \hat{x}_k \tag{4-3}$$

$$(2) \rightarrow P_{k+1}^- = \phi_k P_k \phi_k^T + Q_k \tag{4-4}$$

Update

$$(3) \rightarrow K_k = P_k^- H_k^T S_k^{-1} \text{ where } S_k = H_k P_k^- H_k^T + R_k \tag{4-5}$$

$$(4) \rightarrow \hat{x}_k = \hat{x}_k^- + K_k \tilde{y}_k \text{ where } \tilde{y}_k = z_k - H_k \hat{x}_k^- \tag{4-6}$$

$$(5) \rightarrow P_k = (I - K_k H_k) P_k^- \tag{4-7}$$

Where

$$\phi_k = \left.\frac{\partial \phi}{\partial x}\right|_{\hat{x}_{k-1}^-} \tag{4-8}$$

$$H_k = \left.\frac{\partial h}{\partial x}\right|_{\hat{x}_k^-} \tag{4-9}$$

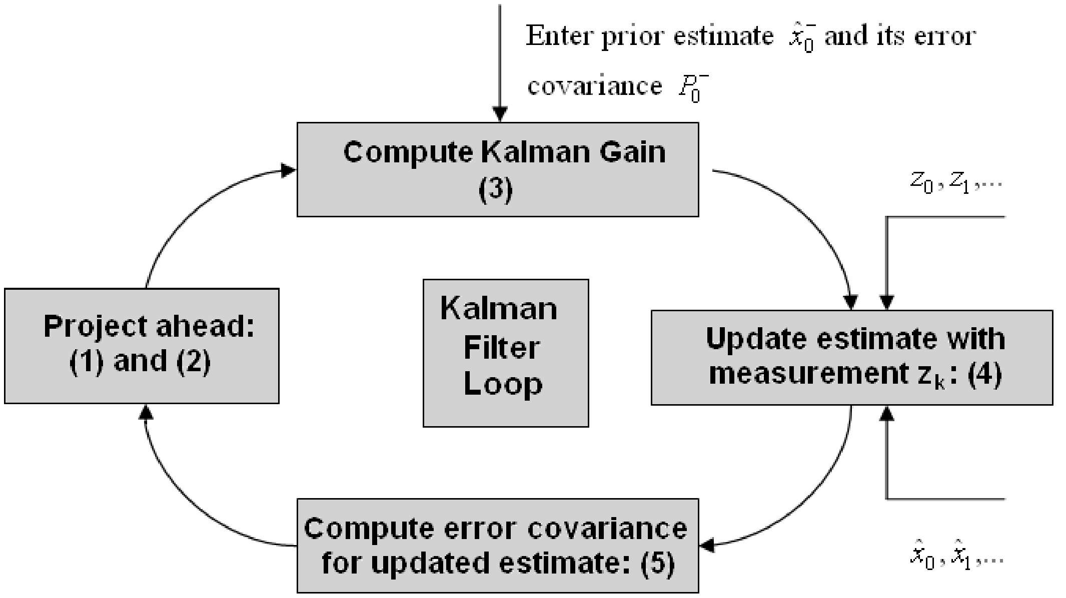


Figure 4-1. Kalman Filter Loop [23]

The hardest parameter to determine for the Kalman filter would be the Q and R covariance matrices. The higher the Q and R-values, the more volatile the estimate will be. This gives more flexibility to the EKF to track the underlying signal. Thus, the EKF estimate will track the signal faster but there will be more volatility instead as a tradeoff. For lower Q and R-values, less flexibility is given to the EKF to track the signal so its response is slower but it provides a smoother estimate. Electricity prices are very volatile and tracking the prices in a fast manner is important; however, accurate predictions are very important as well so determining the proper Q & R values is a difficult process.

The following outlines the steps taken in determining the underlying signals of the data, the spectral analysis, and the determination of the necessary data for the Kalman Filter.

- The autocorrelation of the input data is determined
- The Power Spectral Density (PSD) is calculated once the autocorrelation is known
- The Autoregressive (AR) Spectra & the Minimum Variance (MV) Spectra are determined for the input data
- The AR/MV Spectra & PSD all display the daily sinusoidal component of the time series and its harmonics. Significant harmonics can be determined by the MV spectra if the various AR models converge within 3 dB of one another.
  - The frequencies of these underlying sinusoids are determined based on the frequency peaks.
  - The first harmonic has a frequency of 366/sample, which corresponds to a daily frequency.
  - The second harmonic is also modeled since its dB value is significant as well. Its frequency is 732/sample. Other harmonics are ignored, as their dB values are 10dB less than that of the first harmonic, i.e. they are considered statistically insignificant.
  - The sinusoids follow the form S_K: $A*\sin\left(\left(\frac{2\pi}{T}\right)*(k+B)\right)$, where T is the period, A is the amplitude, and B is the phase shift.
  - The amplitude for the sinusoids is determined by the dB value at the peak from the MV Spectra. The amplitude = $\sqrt{10^{dB/10}}$
  - Once the amplitude is known, the phase shift for the sinusoid is determined by using an R-squared, R^2, method and an exhaustive search is performed in order to determine the best B value.

- $R^2 = 1 - \frac{sse}{ssm}$ (4-10)
- $sse = \sum (Y - \hat{Y})^2$, sum of square error (4-11)
- $ssm = \sum (Y - \bar{Y})^2$, sum of squares around the mean (4-12)

  - It is the assumption that there should also be a seasonal component for electricity prices. For this specific case, the frequency peak is difficult to determine; thus, a low pass filter is applied to the data.
  - Again, only the first harmonic & the second harmonic are modeled as the rest have insignificant dB values.

- Once all of the anticipated sinusoids (the daily & the seasonal components of electricity prices) have been determined, the residual is analyzed based on the MV Spectra to determine if there is anything else to be modeled.

The Extended Kalman Filter was tested on LMP data from 2005 from PJM's network [41]. The square root of the mean square error (MSE) is 6.61 and Figure 4-2 displays the EKF estimate as compared to the original LMP values [23].

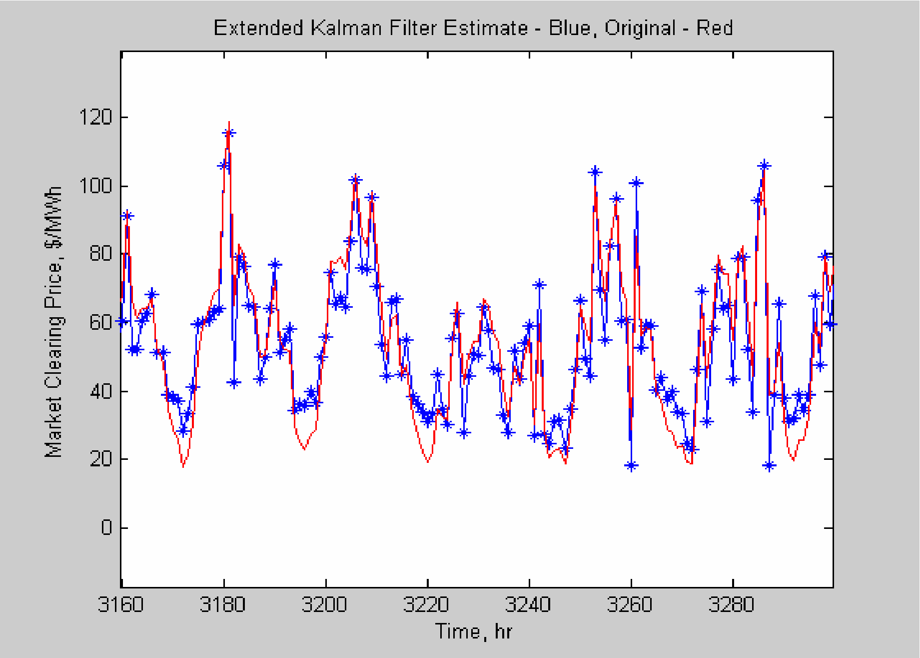


Figure 4-2. EKF Estimate (Blue -*), Original (Red) – Zoomed in [23]

4.3 Geometric Brownian Motion (GBM)

Geometric Brownian Motion is commonly used to model stock prices. It is also becoming a popular way to model electricity prices. GBM is used to forecast the possible power output of the wind turbine for the work related to Chapter 6. A sine wave model is incorporated in the GBM forecast to accommodate for the pattern that the wind speed is typically higher/lower at certain times of the days. The forecasts are based on data for one month. Monte-Carlo simulations are analyzed to determine a proper forecast of the expected value and variance.

The basic GBM equation for the fluctuation of the power supplied by the wind farm is shown below with Pw representing the power output as well as the cyclical form assumed for the variable. The parameters, A, B, & C, are determined by solving for the maximum R^2 value. R^2 is defined as 1-sse/ssm where sse is the sum of squared error & ssm is the sum of squares around the mean.

$$\Delta Pw = \mu * Pw * \Delta t + \sigma * Pw * (\Delta t)^{0.5} * \nu \qquad (4\text{-}13)$$

where ν is a normally distributed random variable

$$Pw(t) = A * \sin\left(\frac{2\Pi}{24} * (B + t)\right) + C \qquad (4\text{-}14)$$

CHAPTER 5: TRANSMISSION PLANNING

5.1 Introduction to Transmission Planning

The electric industry is switching from a regulated industry to a deregulated, market driven industry. Such changes also affect transmission expansion planning. There are different objectives and there is more uncertainty involved than before as now the key players in the industry compete with one another. Likewise, in the past, there was assurance that a project would receive a specified rate of return on the investment. Therefore, developing ways to take care of the risk involved, handle the uncertainties, and accounting for managerial decisions was not necessary.

Today, transmission planning is still not fully deregulated but the industry is trying to make the change. Companies typically still receive a guaranteed rate of return on projects so that the Independent System Operator (ISO) or the Regional Transmission Organizer (RTO) absorbs the risk. However, there is a push to develop new methods to analyze the value of transmission assets in a competitive market. Key issues include valuing the risk associated with the investment. Under a regulated industry, this was not a concern. The objective was to determine the lowest cost project that meets all of the required reliability concerns or to minimize cost to customers.

In a deregulated market, this would not be the best approach. Market participants now compete with one another so there are additional factors that affect the value of transmission assets: risk and managerial decisions. In the past, future network changes could be properly determined and modeled since market participants would work together under the regulated system. Likewise, the market participants’ strategies were well known as everyone was regulated and had set objectives. Thus, traditional transmission planning methods did not have to account for future uncertainties in network changes or uncertainties in market participants’ strategies as much as they would have to today under a deregulated market. New transmission planning methods that consider these factors are therefore needed in order to provide a more accurate value of the transmission asset. New methods are also needed to account for the competition that transmission companies will face among each other whereas this was not a concern under regulation.

Real options analysis accounts for this since it allows one to model the uncertainties accurately in order to have a proper understanding of the risk and it provides probability distributions as well. It also allows one to analyze when to scrap a project, when to further examine certain options in more detail, or when further analysis is or is not necessary. Such a technique provides the investors with knowledge of the risk involved, allows one to update/change managerial decisions in order to determine the optimal strategy, the ability to properly execute a strategy at the optimal time, what is the best strategy given your current situation while considering future options as well, etc.

This chapter begins by discussing the problem formulation for transmission expansion planning using real options analysis. The purpose of this section is to present and discuss what information is necessary in order to analyze the transmission investment appropriately using real options analysis. Such information ranges from possible contract formulation between the ISO and the TRANSCO, properly modeling uncertainty by choosing the right probability distribution, considering plausible managerial decisions, etc. A discussion of real options analysis and other valuation techniques is discussed in chapter 3.

Currently proposed transmission planning approaches are discussed in section 5.3. The first case study discusses transmission planning by using a cost/benefit method [38]. The second case study is based on a paper that looks into determining probabilistic LMPs through Monte Carlo simulations, using a value based approach, & performing a risk analysis on the expansion candidates [5]. The last topic is the CAISO TEAM methodology [9]. The focus of the discussion deals with the uncertainty analysis.

Section 5.4 discusses the author's current joint project with ASU & UIUC as previously mentioned [47], [48], and [49]. The author's part in the joint project is to analyze the transmission expansion investments using real options analysis [21]. This section includes a short discussion on the data being used for this report and the stochastic methods that are used to obtain such data.

Section 5.5 presents an example and results when using real options analysis. Section 5.6 discusses future work, how real options analysis could be used to value transmission investments as insurance policies. The final section is the summary.

5.2 Transmission Planning Problem Formulation

The decision to build new generation facilities lies with independent investors, while the decision to invest in transmission facilities lies with Transmission Owners (TRANSCOs) or the ISOs/RTOs. The transmission system has two basic functions:

- Providing the network infrastructure for electricity delivery.
- Assuring the reliability and security of the delivery process.

Thus, pricing of transmission services has two corresponding basic elements:

- Charges for recovering the capital investment, operation, and maintenance costs for the transmission network facilities and equipment.
- Charges for assuring system reliability and security.

5.2.1 Transmission Services

The ISO's objective is to maximize the social welfare for the system while satisfying several specific responsibilities set by FERC. The ISO overlooks regional transmission facility planning, decides which expansions are appropriate, and evaluates the effects of differing pricing approaches for transmission services. Major categories of transmission service charges provided by the ISO include:

1. System connection charges
2. Wheeling, Access and Use charges, including
    - Capital investment charges,
    - Operation and maintenance charges, and
    - Congestion management charges

5.2.2 Evaluation Process of the Transmission Expansion

It is important to note that this evaluation is not inclusive in valuing the complete benefit the transmission expansion project will have on the network. However, the key points are considered in this problem formulation. The process of real options analysis is shown in Figure 5-1 for transmission expansion planning. There are five steps to finish the real options analysis:

Step 1: Formulate all costs/benefits and direct/indirect effects corresponding to the transmission planning project by future cash flows. Determine the eight factors listed below in order to obtain the projected future cash flow.

1. Congestion management charge: new transmission line will mitigate the congestion between different zones. Congestion management charge will be a kind of future cash flow. With a new transmission line, cheaper electricity will be imported from a cheap zone to an expensive zone. Given forecasted demand and past price information, forecast future LMPs.

2. Transmission Tariffs: this is the basic charge of transmission service. The MW-Mile Methodology is one method that is used to determine the transmission tariff revenue for the new line. Stochastic forecasts of the future transferred energy on the new line are used to determine the distribution of future tariff revenue payments. Joint work from [47], [48], and [49] provide probability distributions for the future transferred energy for possible transmission expansion projects.

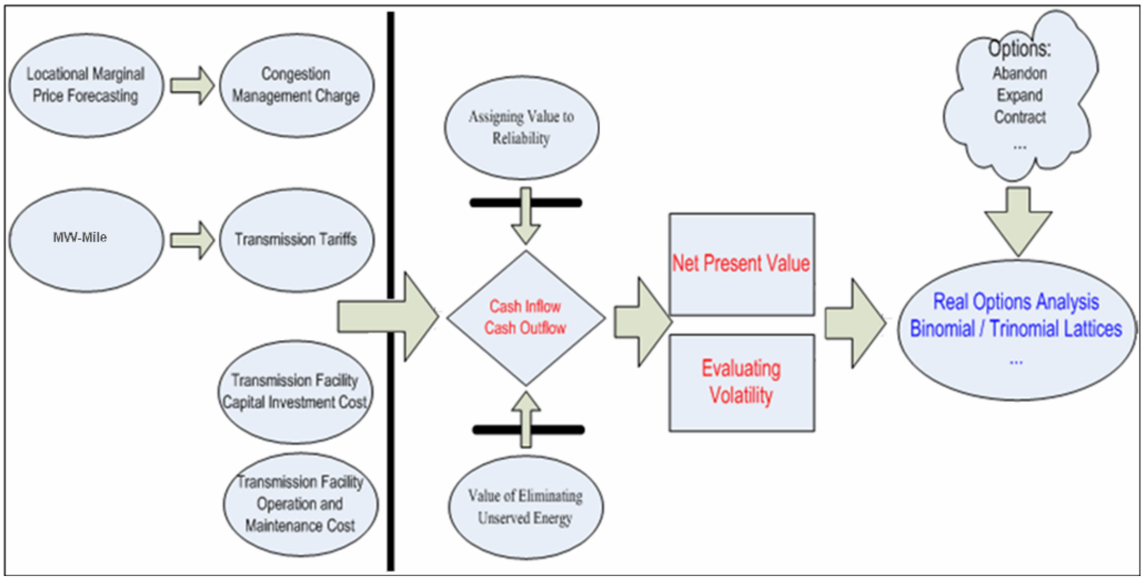


Figure 5-1. Real Options Analysis Process for Transmission Expansion Planning [21]

3. Value of eliminating unserved energy: system unserved energy should decrease due to the addition of new transmission lines. This would be accounted for by the MW-Mile payment.

4. Transmission facility capital investment costs: transmission facility capital investment cost is an important uncertainty source. Future cash flows will include the cost of the transmission line, relaying equipment, circuit breakers, etc.

5. Transmission facility operation and maintenance costs: transmission facility operation and maintenance costs are a kind of future cash flow. Transmission system faults and disturbances, such as blackouts, should be modeled accordingly in order to estimate the operation and maintenance cost. One method in which this could be accomplished is by analyzing the disturbances as a stochastic process.

6. Assigning value to reliability: system reliability is supposed to be enhanced by the new transmission line. It is assumed that the benefits (cash flows) from the improvement of reliability and stability are assigned in the contracts between the ISO and TRANSCOs. The benefits from the improvement of reliability and stability will be represented by future cash flows or assigned by the contracts between the ISO and TRANSCOs.

7. Determining the planning horizon: a key aspect to forecasting the long-term LMP is the planning horizon. The planning horizon is important by the fact that it is crucial to know to what extent the research needs to go in order to validate the investment project. Too much analysis into the future can be a complete waste of time since the uncertainty may become too large. Therefore, the real options analysis will consider whether further analysis is needed at any given time. If past uncertainties are resolved, then such future analysis is not required, as future states would then be known. On the other hand, if the uncertainty is getting too large such that the expansion project cannot be validated since there is too much risk involved, then the analysis will stop and the TRANSCO & the ISO would have to work out a grandfathering contract or the project would be not be implemented.

8. The planning horizon must also include the level of detail that is required, i.e. what is the best time-span for one period to cover such as seasonal, weekly, etc. Again, for this type of complex problem, too much detail will make it either such that the problem cannot be solved or it will be a waste of time. Too little detail will give a wrong interpretation of the value and risk of the problem.

Step 2: After formulating these eight factors, the project cash inflows/outflows will be discovered over the planning horizon.

Step 3: By stochastic power flow, different NPV of the project can be calculated. VaR provides the worst case of the NPV based on a defined confidence interval. Risk-adjusted rate of return can be determined based on either Monte-Carlo simulations with VaR analysis or CAPM model.

Step 4: A series of reasonable options are defined, such as abandon, expand, contract, compound, etc. The options can be exercised (American option) during any time periods within the time horizon. Beyond the planning horizon, the stochastic power flow data will be ignored and only the abandon, expand, contract, compound, etc. options are considered.

Step 5: Given risk-free interest and risk-neutral pricing model, binomial/multinomial trees can be applied to solve the real options problem. Monte-Carlo simulation can be used for each option in order to get the expected value of the project and provide the distribution of possible outcomes.

5.2.3 Data Acquisition

One main obstacle with researching transmission expansion is the data required. Since deregulation, companies will no longer share information with others since they do not want to give out information on their own company that could help their competitors. This makes data acquisition difficult on topics like future generation and transmission growth. However, there is some helpful information that can be obtained from the DOE’s EIA website [14]. This data ranges from current generation capacity & new generation plans in the next few years to recent transmission expansion projects.

5.3 Critique of Transmission Planning Methods

5.3.1 Cost/Benefit Analysis Applied to Transmission Expansion Planning

First, each case study is taken at face value. The first case study being presented, “Transmission Planning in the Presence of Uncertainties” [38], is based on analyzing the uncertainty of where the next generation facility will be built as well as size. Then, they determine an overall acceptable transmission expansion project for the network. Once they determine the different scenarios where the generation facility might be built, for each probable generation expansion scenario, they analyze the necessary transmission expansion possibilities that will meet basic network requirements, such as N-1 criteria. Next, they select one expansion plan for each scenario; the selection is based on minimum cost. The next step is a cost/benefit analysis. In addition, they mention that there is risk analysis involved with their process to determine the best plan. However, they mention that this goes beyond the scope of the paper and do not discuss how their method evaluates the risk and what decisions they make.

The next major step is the cost/benefit analysis on the selected minimum cost projects for each generation scenario. The benefits are based on reliability improvements, consumer surplus, reduction of losses, etc. and costs are based on capital expenditures, operational & maintenance costs, etc. They narrow down the projects being evaluated by first choosing one project from each generation expansion scenario and then apply a cost/benefit ratio on the remaining projects. Their method determined an acceptable expansion project with an internal rate of return above 12% for their case study.

The first case study that deals with transmission expansion planning using minimum cost & cost/benefit analysis is the closest to traditional methods. Their method was to determine a set of probable transmission expansion scenarios for new generation plants. Then, evaluate multiple transmission projects for each scenario independent of the other projects for the different generation scenarios. For each scenario, they choose the minimum cost plan that meets all requirements of the network such as the N-1 criteria. Once they have one single expansion project for each scenario, they perform a cost/benefit analysis on these remaining projects.

The main critique of this project is that minimum cost planning is used at the first stage when they choose one project for each scenario. Even though they then perform a cost/benefit analysis on the subset of projects, they have no assurance that the one project that was initially chosen for each scenario is better than the ones that were disregarded based on cost only. This reflects back on traditional methods that do not evaluate how much a project is worth and just consider whether it is the cheapest among the feasible projects that meet all requirements. Last, they do not talk about how they evaluate the risk involved. If real options analysis were used instead, it would provide a better way to evaluate the projects by evaluating all based on cost, benefit, and risk. It also would be better since real options analysis does not assume that managerial decisions are static throughout the planning horizon.

5.3.2 Probabilistic LMPs Using Monte Carlo Simulations

The next paper being discussed is, “Market-Based Transmission Expansion Planning” [5]. The main objective of this method is to determine how much a certain transmission expansion project improves competition in the market. Their main method to evaluate this is based on congestion cost. Congestion cost is the difference between two buses’ Locational Marginal Price (LMP) times the power flow across the line. As competition improves, this cost should decrease or essentially the difference in the LMPs should decrease. They use Monte-Carlo simulations to determine the probabilistic LMPs of the network. This includes having to determine the probability density function (PDF) to the random inputs involved throughout the planning horizon like change in load, generation, transmission lines, etc.

Once they have sets of buses that have a difference in LMPs beyond a specified level, they determine different expansion plans for each case and then ascertain how much each one improves the competition in the market through a set of market-based criteria that they specify. This deals with the congestion cost as previously mentioned, transmission planning costs, etc. The transmission planning costs are valued-based. The authors have two ways they evaluate the investment costs: “decrease in annual congestion cost divided by annual investment cost” and “decrease in weighted standard deviation of mean of LMP divided by annual investment cost” [5]. Essentially, they are using a cost/benefit method. Finally, they perform a risk analysis on all of the projects and then choose the desired expansion project.

This second case study uses Monte Carlo simulations and analyzes the projects based on cost, benefit, and risk, similar to the real options analysis approach. The one area that there is a difference though is that the second case study, like the first, assumes managerial decisions are static throughout the planning horizon. By doing so, they are not evaluating options that can occur such as when to implement the expansion, when to expand or abandon it, etc.

5.3.3 CAISO's Transmission Economic Assessment Methodology (TEAM)

The California Independent System Operator (CAISO) recently developed the Transmission Economic Assessment Methodology (TEAM), which they use to value transmission assets [9]. One key reason they developed this methodology is that transmission assets have certain public good aspects to them. Transmission lines are lumpy in size, they provide value to many market participants, and it is not possible to exclude someone from using the line. LMP differences themselves do not provide the proper incentives for transmission investments, as they do not reflect the overall societal benefit due to the new transmission. If additional benefits that the line provides are not recognized, then the optimal level of transmission to invest in will not be reached, as the total benefits are not considered. Likewise, a socially detrimental investment may be built if it is beneficial to those investing in it while it may be detrimental to the society as a whole. Thus, TEAM determines the overall societal benefit of the transmission investment, which is determined as the change in consumer surplus, the change in producer surplus, and the change in congestion revenue or transmission surplus. This considers congestion revenue as a positive factor when determining the value of the transmission investment, which is contrary to traditional transmission planning methods.

TEAM models the strategic bidding of GENCOs since transmission investments increase competition and decrease market power, which increases the societal benefit. TEAM methodology uses an econometric approach to estimate the relationship between market power, load, supply levels, etc. It equates the price-cost markup, which is the Lerner Index, to the residual supply index, the percent of load unhedged, a dummy variable for the summer period, and a dummy variable for the peak hours.

One region of improvement for TEAM entails the uncertainty analysis. TEAM employs a scenario-based approach to capture the affect of uncertainties like high/low fuel prices, load growth, available generation, hydro resources, etc. This is a simplified approach as methods that are more complicated like Monte Carlo simulations take much more time. However, this type of analysis is very crucial. The chair of CAISO's market surveillance committee states that if there were additional transmission lines connecting the east interconnection to the west interconnection for years 2000-2001, about $30 Billion could have been saved [9]. A very large project could have been beneficial based on this rare event alone. These sorts of rare events are not captured by their scenario-based approach.

Transmission lines have a value that is not being captured to this day that is based on what they provide during rare events such as the California Energy crisis. Transmission lines act essentially as an insurance policy against extreme events. In August 2006, CAISO proposed the Sun Path transmission expansion project to the Board of Governors, a $1+ Billion transmission expansion project. At this meeting, a representative for the California Energy Commission (CEC) spoke that one area that TEAM needs to be improved is to be able to value a transmission investment as an insurance policy [8].

Valuing transmission investments as insurance policies is something that has not been developed yet. Real options analysis is one method that could be used to value transmission investments as insurance policies. The focus of this work is to discuss how real options analysis can be applied to investment decisions in the energy industry and why real options analysis is a preferred choice. It is not the purpose of this work to develop a method to value transmission investments as insurance policies but an overview of how real options analysis can be useful for this topic is discussed in section 5.6 as a possible research topic for future work.

5.4 Transmission Planning Using Real Options Analysis

This research proposes the use of real options analysis in transmission planning in order to provide a more robust valuation of the economic benefits of transmission investments than traditional methods. A discussion of real options analysis is presented in Chapter 3. By applying real options analysis, one is better able to determine the proper value of an investment option since it incorporates managerial flexibility, it allows one to model nonrandom events such as unexpected generation expansions, it incorporates risk analysis, etc. [47], [48], and [49] proposes a method to model the stochastic nature of Available Transfer Capability (ATC) and power flows. This research is in collaboration with [47], [48], and [49] and their data has been provided for use in this work.

Some payment methods for transmission lines not only pay for the capacity that is used but also the available capacity, or ATC, as this adds value to reliability. Thus, the financial valuation of the transmission expansion can use stochastic ATC to obtain this benefit. Results from [47], [48], and [49] show that a proper representation for the stochastic ATC can be achieved for a single network but, for transmission planning, one needs to update the network for the various expansion projects being considered as well as various future changes in the network that are already in the planning process. Likewise, one might test the network for future changes that are not already known as is discussed in section 5.5.2. However, results show that there is an issue with tractability for the stochastic ATC when one begins to make changes to the network. Thus, at this time, stochastic ATC is not being considered within the financial analysis, as more research is needed.

The objective of a private transmission company (TRANSCO) is to maximize profit. Their interests rest on the transmission tariff revenue and the costs of the line. The objective of the ISO/RTO is to obtain the maximum societal benefit from the expansion project for the market participants. The societal benefit is defined as the change in producer surplus, change in consumer surplus, and the change in transmission surplus. An objective that maximizes societal benefit considers transmission surplus as a benefit, which is unlike traditional methods that see congestion as a negative. As shown by TEAM [9], the societal benefit is also defined as the production cost savings when assuming that the demand is perfectly inelastic. Since the ISO has to approve the transmission expansion, the TRANSCO must consider the ISO’s objective as well; otherwise, the project may be rejected by the ISO. The TRANSCO, however, does not have access to private market data on generator costs so it is not possible for the TRANSCO to determine whether a project provides the largest societal benefit or not. Not all ISOs take a position on transmission investments that are not required to meet reliability standards. Some claim that transmission planning for economic benefit should be handled by the market. In such situations, the private TRANSCO would only be concerned with maximizing the company’s profit and would not care about social welfare. However, no matter the objective, the use of real options analysis provides a more robust valuation of the investment.

Taking the ISO’s viewpoint, the associated cost will be the transmission tariff paid to the TRANSCO and the benefit is the reduction in production cost. A stochastic representation of the transmission tariff revenue stream is determined based on the stochastic line flow for the proposed line. Given the stochastic power flow data for the network before and after the expansion, one is able to determine the stochastic representation for the production cost savings. For the TRANSCO, their revenue is based on the transmission tariff while their costs are the capital, operating, and maintenance costs. In the event that the revenue stream for the TRANSCO is not adequate to fund the project or there is too much risk exposure for the TRANSCO relative to their return, then the TRANSCO and the ISO would engage in a grandfathering contract with a guaranteed rate of return.

A grandfathering contract may also be required if there is some future network change that reduces the revenue stream for the TRANSCO such that they are not able to recover their costs. For instance, if the new line provided access to additional supply for a load pocket but later local generation was built for that load pocket, the use of the line would diminish. The ISO and TRANSCO may have an agreement that if such an event were to occur such that the TRANSCO would not be able to recover its costs, that the ISO would then provide the TRANSCO with a guaranteed rate of return. Since transmission planning is a much longer process than generation planning, issues like this arise. This is one key reason why real options analysis is a better method over traditional methods that do not worry about these sorts of issues. Using real options analysis, one could model such an event by a stochastic process like the Poisson process. Then, when valuing the investment, this is taken into consideration. For instance, if such an event were to occur during the construction phase of the line, real options analysis considers the managerial flexibility to decide whether it is best to delay the project, terminate the project, or as mentioned earlier, be protected by a grandfathering contract if such an event were to occur. Similar events to consider would be unexpected load growth such that it is determined that the initial capacity of the line is not adequate and it is decided to expand the project. Real options analysis also incorporates methods like Capital Asset Pricing Model (CAPM) to determine if the return on the real asset is efficient relative to the risk exposure. These and similar examples are issues that real options analysis considers that traditional methods do not.

The flow diagram displayed by Figure 5-2 provides an outline of the steps taken in determining the proper investment. Based on the stochastic power flow data received, one can identify possible expansion projects. The reason you initially choose a subset of possible expansion options is because there is no way to know for sure what expansion plan is optimal. The objective of the ISO is to maximize the social welfare. Thus, one approach to determine possible expansion projects is to find the different locations with the largest Locational Marginal Price (LMP) gaps. A gap in LMP between two areas says that, if there existed additional transfer capability, then more power from the cheap are would be sent to the more expensive are. This improves social welfare as it reduces the overall production cost by having more energy be produced by cheaper generators. However, the improvement does not depend only on the LMP gap but also on the additional amount of power that is transferred from the cheaper area to the more expensive area. The ISO could choose projects based on the size of the LMP gap and the expected amount of power to be transferred across the new line, while considering the costs of the line as well. The objective of the TRANSCO is to maximize profit. There are different methods used to pay back a TRANSCO but for the MW-Mile method, they would look for the line that would give them the maximum flow. The length of the line must also be carefully considered, as it is both a positive and a negative for the TRANSCO as the cost of a line increases with the length while the MW-Mile method pays more for longer lines. Once a set of projects to examine has been determined, the next step is to determine the stochastic power flow data for each expansion option. Any project that is clearly not beneficial is discarded. The remaining expansion options are analyzed based on real options analysis to determine the optimal expansion plan.

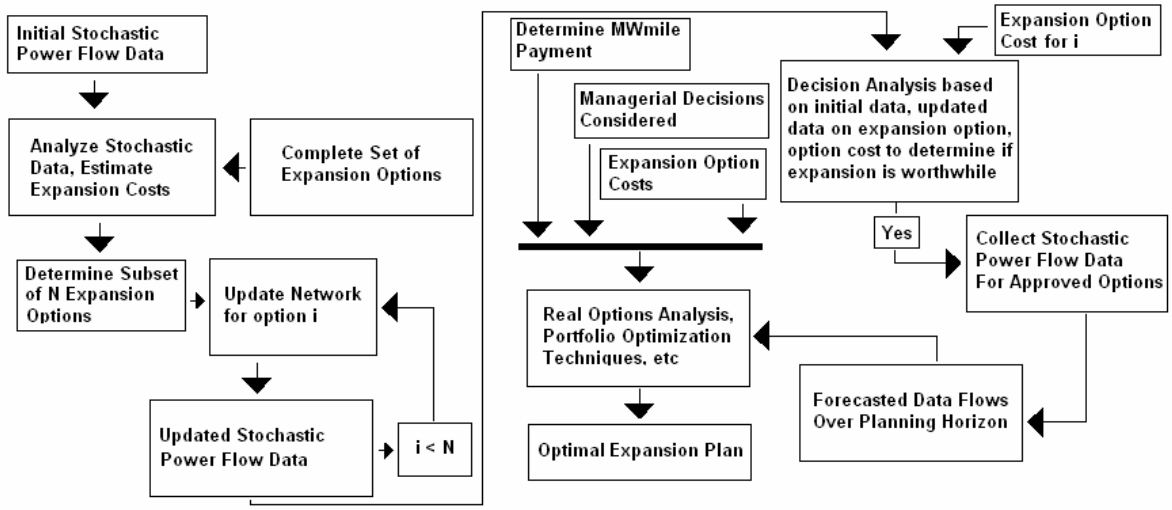


Figure 5-2. Transmission Planning Flow Diagram

5.5 Transmission Planning Using Real Options Analysis - Examples

This section presents examples of the methods discussed in the previous sections, as it is the focus of this research to show that these methods are feasible and that there is reason to further examine the use of real options analysis for transmission planning. It is not the objective of this research to perform a thorough transmission planning study as such work goes beyond the scope of a thesis.

The following example demonstrates the steps taken to perform real options analysis on a specific piece of the overall transmission planning process as it has been stated above that a complete transmission planning study is not presented in this report. That is to say, this example is performing the necessary real options analysis on one single branch of the lattice of the entire real options analysis problem that represents the overall transmission planning problem. Essentially, it is evaluating one single tree within a forest and, by following these steps, one can then apply this procedure to the entire transmission planning problem, i.e. one can apply this to the entire forest. The purpose of this example is to demonstrate the steps to solve a real options analysis problem for transmission planning but applying it to one piece of the problem; thus, the simulated data is based on results pertaining to one hour for the system. The intent of this report was to collaborate with the other universities involved in this PSERC project and their stochastic & forecasted data was to be used in this financial valuation. These research projects were developed simultaneously; thus, the necessary stochastic data for this research was created by modeling the load distribution of the PJM system and adjusting it so that it can be used in the following 14 bus example.

5.5.1 14-Bus Transmission Expansion Example

The example is based on a modified version of the IEEE 14-bus system [11] as shown by Figure 5-3. It is assumed that there is a generator and a load at every bus. Generator cost functions were modeled as quadratic functions. The power flow is solved by using a Direct Current Optimal Power Flow (DCOPF). Note that DCOPF is a simplified model that only considers the real power aspect of power flows; thus, the values are estimates. Thus, the DCOPF provides approximate LMP values.

A complete real options analysis valuation for an entire transmission expansion project would include future cash flows for every period during the life cycle of the transmission plan. For each period, the DCOPF is used to determine the stochastic power flow data, i.e. Locational Marginal Prices (LMPs), line flows, etc, which is then used by real options analysis to determine the distributions of the cash flows. This example simulates one instance of time that would be simulated by real options analysis, that is to say this example represents a subcomponent of the real options analysis that would be performed for the overall transmission expansion problem. The loads were modeled by lognormal distributions. For year 2006, PJM's load best matched that of a lognormal distribution. The stochastic load for the 14-bus system used in this example is shown by Figure 5-4. It follows the same distributional form as PJM's load, which is represented by Figure 5-5, with an adjusted mean and variance.

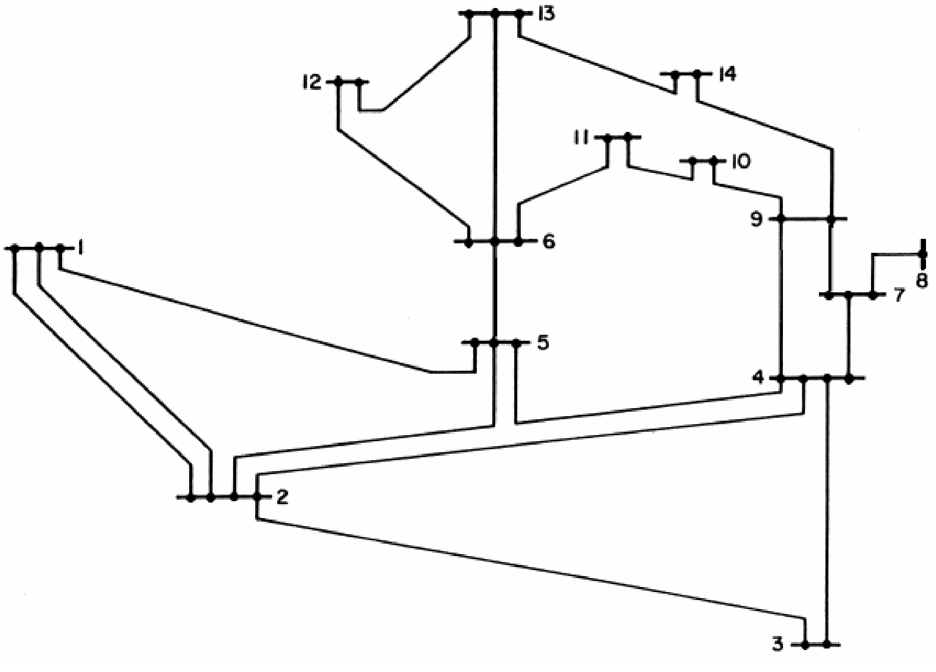
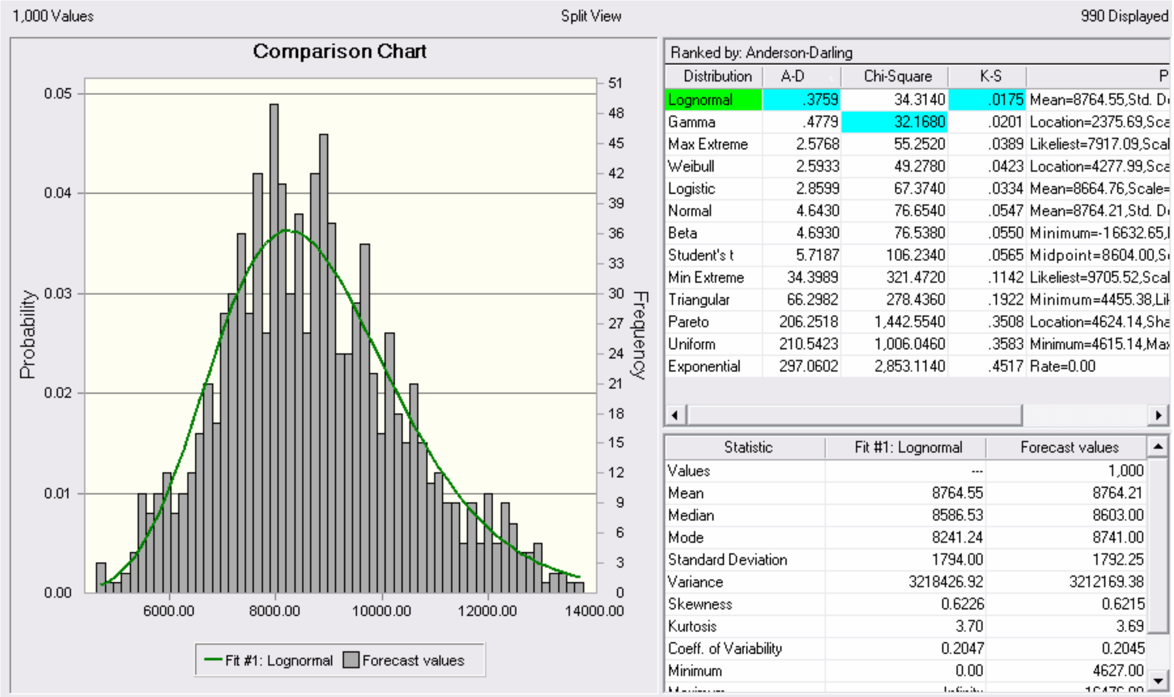


Figure 5-3. 14 Bus System

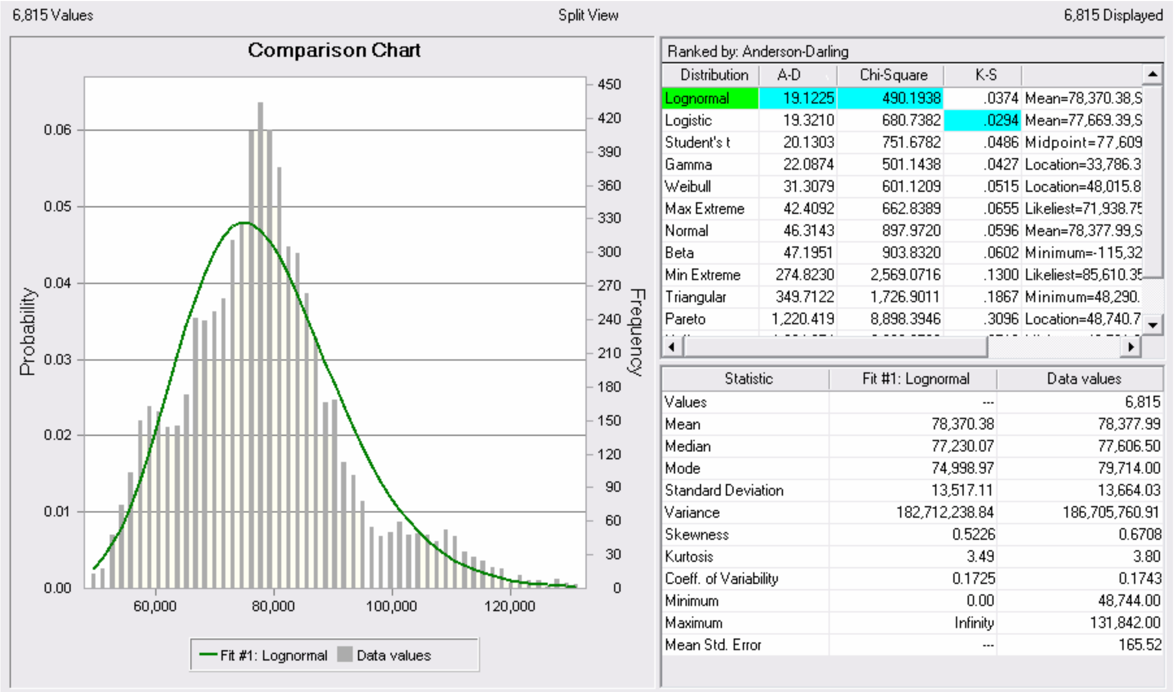


Ranked by: Anderson-Darling

Distribution	A-D	Chi-Square	K-S	P
Lognormal	.3759	34.3140	.0175	Mean=8764.55,Std. D
Gamma	.4779	32.1680	.0201	Location=2375.69,Sca
Max Extreme	2.5768	55.2520	.0389	Likeliest=7917.09,Scal
Weibull	2.5933	49.2780	.0423	Location=4277.99,Sca
Logistic	2.8599	67.3740	.0334	Mean=8664.76,Scale=
Normal	4.6430	76.6540	.0547	Mean=8764.21,Std. D
Beta	4.6930	76.5380	.0550	Minimum=-16632.65,
Student's t	5.7187	106.2340	.0565	Midpoint=8604.00,S
Min Extreme	34.3989	321.4720	.1142	Likeliest=9705.52,Scal
Triangular	66.2982	278.4360	.1922	Minimum=4455.38,Li
Pareto	206.2518	1,442.5540	.3508	Location=4624.14,Sha
Uniform	210.5423	1,006.0460	.3583	Minimum=4615.14,Ma
Exponential	297.0602	2,853.1140	.4517	Rate=0.00

Statistic	Fit #1: Lognormal	Forecast values
Values	---	1,000
Mean	8764.55	8764.21
Median	8586.53	8603.00
Mode	8241.24	8741.00
Standard Deviation	1794.00	1792.25
Variance	3218426.92	3212169.38
Skewness	0.6226	0.6215
Kurtosis	3.70	3.69
Coeff. of Variability	0.2047	0.2045
Minimum	0.00	4627.00

Figure 5-4. Lognormal Distributional Fit for the Simulated 14 Bus System



Ranked by: Anderson-Darling

Distribution	A-D	Chi-Square	K-S	
Lognormal	19.1225	490.1938	.0374	Mean=78,370.38,S
Logistic	19.3210	680.7382	.0294	Mean=77,669.39,S
Student's t	20.1303	751.6782	.0486	Midpoint=77,609
Gamma	22.0874	501.1438	.0427	Location=33,786.3
Weibull	31.3079	601.1209	.0515	Location=48,015.8
Max Extreme	42.4092	662.8389	.0655	Likeliest=71,938.7
Normal	46.3143	897.9720	.0596	Mean=78,377.99,S
Beta	47.1951	903.8320	.0602	Minimum=-115,32
Min Extreme	274.8230	2,569.0716	.1300	Likeliest=85,610.3
Triangular	349.7122	1,726.9011	.1867	Minimum=48,290.
Pareto	1,220.419	8,898.3946	.3096	Location=48,740.7

Statistic	Fit #1: Lognormal	Data values
Values	---	6,815
Mean	78,370.38	78,377.99
Median	77,230.07	77,606.50
Mode	74,998.97	79,714.00
Standard Deviation	13,517.11	13,664.03
Variance	182,712,238.84	186,705,760.91
Skewness	0.5226	0.6708
Kurtosis	3.49	3.80
Coeff. of Variability	0.1725	0.1743
Minimum	0.00	48,744.00
Maximum	Infinity	131,842.00
Mean Std. Error	---	165.52

Figure 5-5. PJM's Load Distribution for 2006

Distributional data to represent the LMPs, the generator output, and the line flows are obtained by performing Monte Carlo simulations. This stochastic data is used to determine possible expansion options. Given the possible expansion options, the network is then adjusted and the simulations are performed again in order to obtain the new stochastic power flow data. Table 5-1 displays the percentage that the lines are congested based on 1000 simulations. It is clear that the four lines that are frequently congested should be considered as possible expansion options. The mean and standard deviation of the LMPs for each bus are displayed in Table 5-2. Large differences in LMP values are also an indicator of the need of additional transmission as it allows additional electricity to be traded between expensive & cheap areas, thereby decreasing the LMP gap and reducing production costs. However, the gap in LMP is not the only significant factor, as the benefit of a transmission expansion will also depend on the amount of energy that will be traded between the two areas. Without loss of generality, it is assumed that the transmission expansion will occur where there already exists a right of way.

Table 5-1. Line Congestion Percentage

Line:	1 - 2	1 – 5	2 – 3	2 - 4	2 - 5	3 – 4	4 - 5	4 - 7	4 - 9	5 – 6
	0%	0%	0%	0%	0%	0%	0%	**95%**	0	**89%**
Line:	6 - 11	6 – 12	6 – 13	7 - 8	7 - 9	9 – 10	9 - 14	10 - 11	12 - 13	13 – 14
	3%	0%	0%	0%	**68%**	0%	**93%**	0%	0%	0%

Table 5-2. Mean & Standard Deviation of Bus LMPs

Bus:	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Mean:	$69.88	$69.68	$69.41	$69.07	$70.29	$68.04	$84.92
StDev:	11.22	11.10	10.95	10.76	11.44	9.73	21.76
Bus:	**8**	**9**	**10**	**11**	**12**	**13**	**14**
Mean:	$84.92	$77.07	$74.45	$69.19	$67.98	$67.72	$66.19
StDev:	21.76	14.93	13.29	10.03	9.68	9.47	8.28

Since this is a simplified model with only 14 buses, an exhaustive search was performed to determine the line that provides the maximum societal benefit, which is the same as the production cost savings when the demand is assumed to be perfectly inelastic. Based on production cost savings, the optimal expansion location is the line 4-7. The network is upgraded by placing a line parallel to line 4-7 with the same impedance and rating. The exact same load distribution is used for the upgraded network. Table 5-3 shows the new percentages that the lines are congested and Table 5-4 shows the mean & standard deviation for the LMPs.

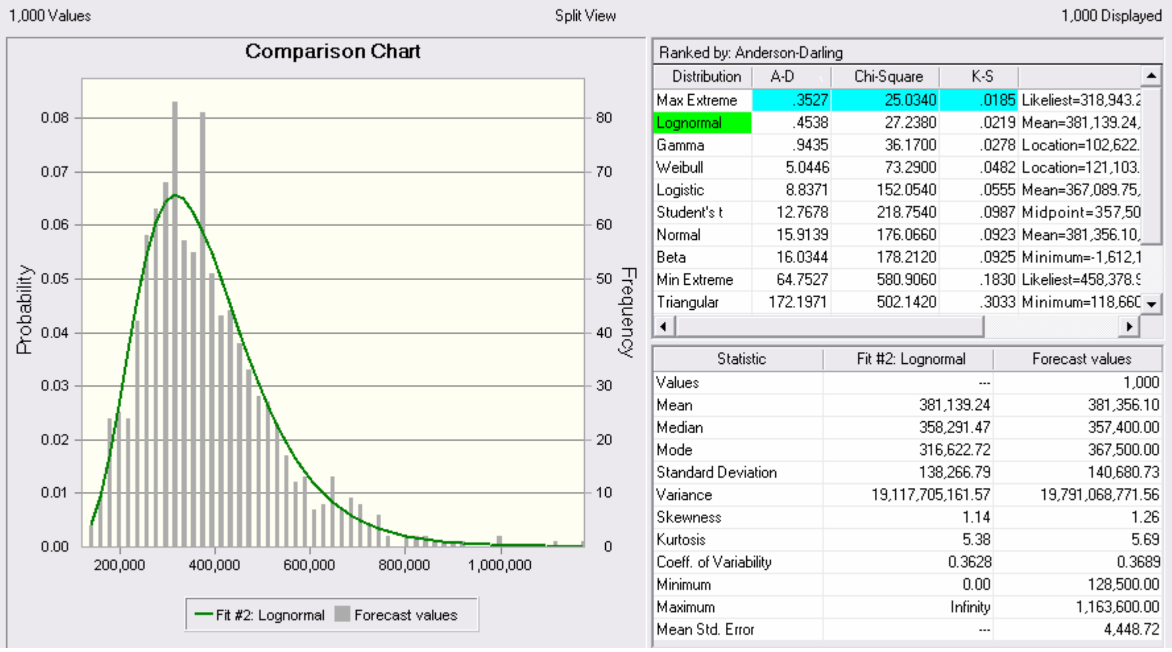
Table 5-3. Line Congestion Percentage for the Updated Network

Line:	1 - 2	1 – 5	2 – 3	2 - 4	2 - 5	3 – 4	4 - 5	4 - 7	4 - 9	5 – 6
	0%	0%	0%	0%	0%	0%	0%	**13%**	0	96%
Line:	6 - 11	6 – 12	6 – 13	7 - 8	7 - 9	9 – 10	9 - 14	10 - 11	12 - 13	13 – 14
	2%	0%	0%	44%	2%	0%	87%	0%	0%	0%

Table 5-4. Mean & Standard Deviation of Bus LMPs for the Updated Network

Bus:	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Mean:	$73.21	$73.23	$73.27	$73.31	$73.16	$69.07	74.24
StDev:	12.54	12.57	12.59	12.63	12.50	10.49	14.74
Bus:	**8**	**9**	**10**	**11**	**12**	**13**	**14**
Mean:	$78.00	$74.23	$72.72	$69.70	$68.92	$68.34	$64.84
StDev:	20.23	14.37	13.13	10.71	10.37	9.90	7.13

Figure 5-6 shows the probability density function (PDF) for the total production cost before the upgrade and Figure 5-7 shows the PDF after the upgrade. Figure 5-8 shows the difference between these two PDFs. The total cost for each case follows a lognormal distribution while the difference between the two follows a Beta distribution.

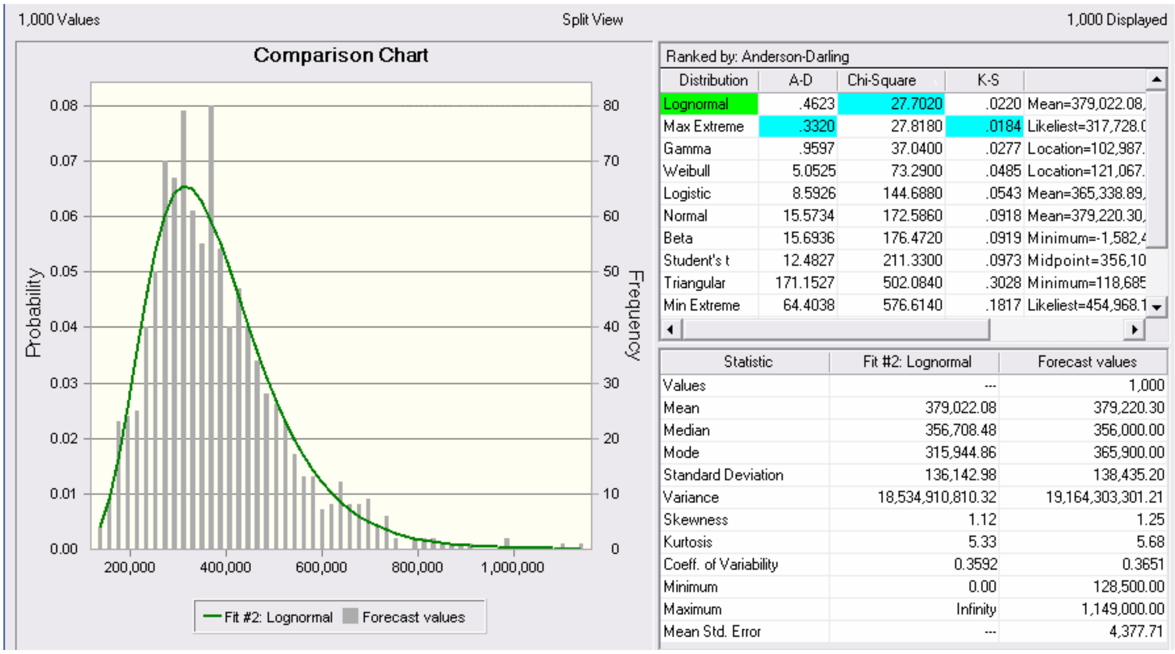


Ranked by: Anderson-Darling

Distribution	A-D	Chi-Square	K-S	
Max Extreme	.3527	25.0340	.0185	Likeliest=318,943.2
Lognormal	.4538	27.2380	.0219	Mean=381,139.24,
Gamma	.9435	36.1700	.0278	Location=102,622.
Weibull	5.0446	73.2900	.0482	Location=121,103.
Logistic	8.8371	152.0540	.0555	Mean=367,089.75,
Student's t	12.7678	218.7540	.0987	Midpoint=357,50
Normal	15.9139	176.0660	.0923	Mean=381,356.10,
Beta	16.0344	178.2120	.0925	Minimum=-1,612,1
Min Extreme	64.7527	580.9060	.1830	Likeliest=458,378.9
Triangular	172.1971	502.1420	.3033	Minimum=118,660

Statistic	Fit #2: Lognormal	Forecast values
Values	---	1,000
Mean	381,139.24	381,356.10
Median	358,291.47	357,400.00
Mode	316,622.72	367,500.00
Standard Deviation	138,266.79	140,680.73
Variance	19,117,705,161.57	19,791,068,771.56
Skewness	1.14	1.26
Kurtosis	5.38	5.69
Coeff. of Variability	0.3628	0.3689
Minimum	0.00	128,500.00
Maximum	Infinity	1,163,600.00
Mean Std. Error	---	4,448.72

Figure 5-6. Total Cost Distribution Given the Initial Network

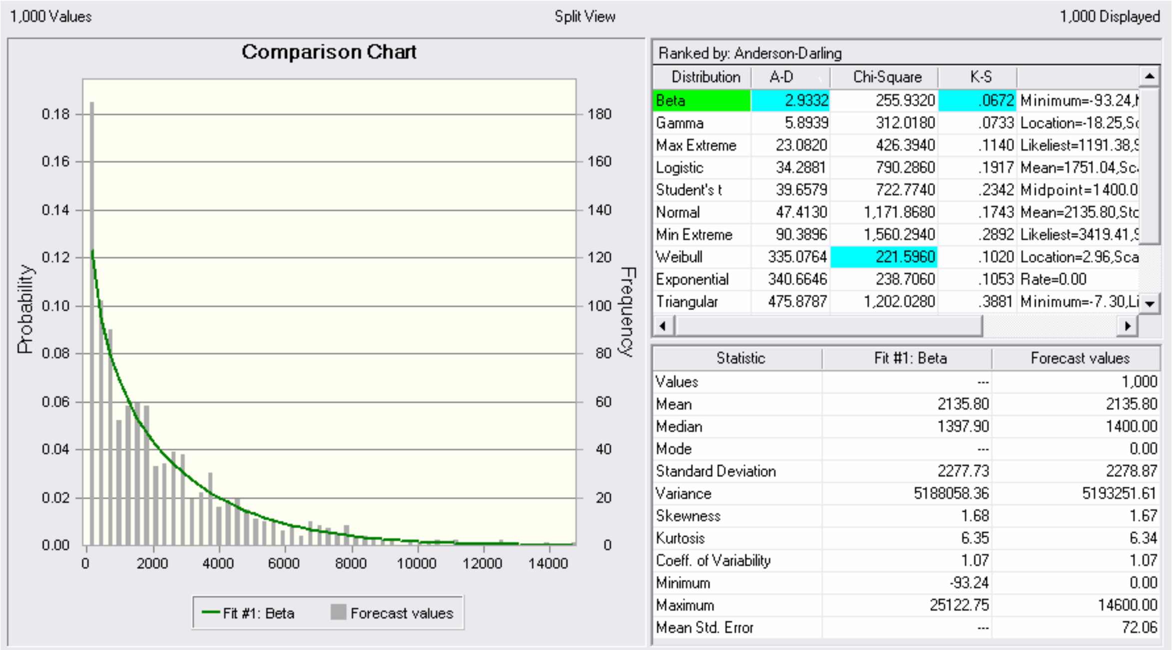


Ranked by: Anderson-Darling

Distribution	A-D	Chi-Square	K-S	
Lognormal	.4623	27.7020	.0220	Mean=379,022.08,
Max Extreme	.3320	27.8180	.0184	Likeliest=317,728.0
Gamma	.9597	37.0400	.0277	Location=102,987.
Weibull	5.0525	73.2900	.0485	Location=121,067.
Logistic	8.5926	144.6880	.0543	Mean=365,338.89,
Normal	15.5734	172.5860	.0918	Mean=379,220.30,
Beta	15.6936	176.4720	.0919	Minimum=-1,582,4
Student's t	12.4827	211.3300	.0973	Midpoint=356,10
Triangular	171.1527	502.0840	.3028	Minimum=118,685
Min Extreme	64.4038	576.6140	.1817	Likeliest=454,968.1

Statistic	Fit #2: Lognormal	Forecast values
Values	---	1,000
Mean	379,022.08	379,220.30
Median	356,708.48	356,000.00
Mode	315,944.86	365,900.00
Standard Deviation	136,142.98	138,435.20
Variance	18,534,910,810.32	19,164,303,301.21
Skewness	1.12	1.25
Kurtosis	5.33	5.68
Coeff. of Variability	0.3592	0.3651
Minimum	0.00	128,500.00
Maximum	Infinity	1,149,000.00
Mean Std. Error	---	4,377.71

Figure 5-7. Total Cost Distribution Given the Updated Network



Ranked by: Anderson-Darling

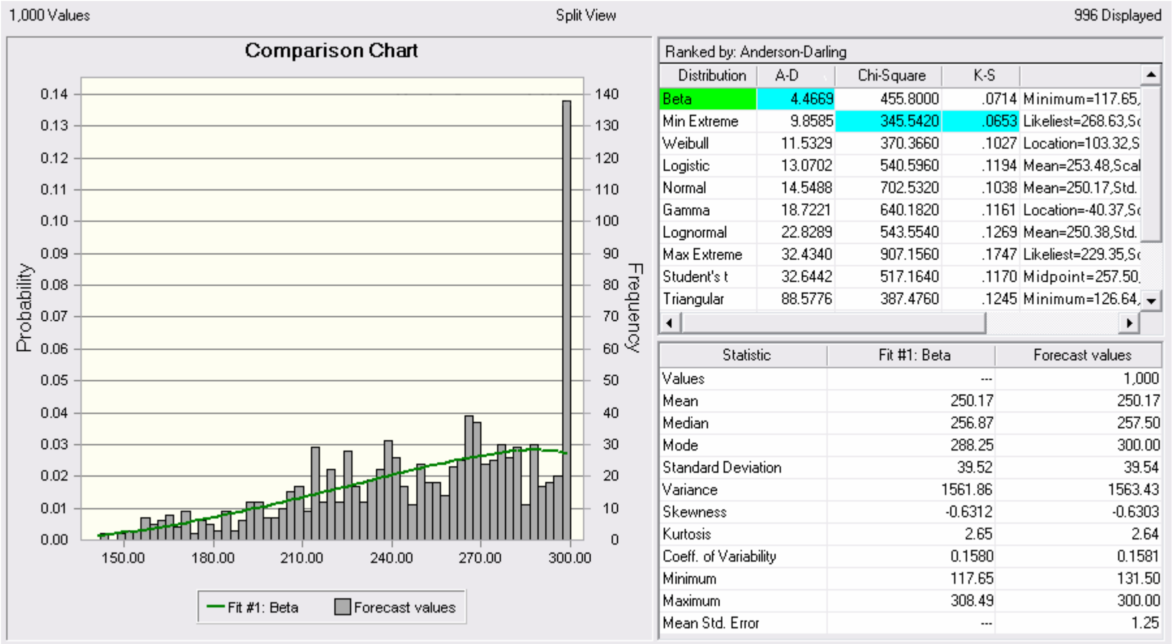
Distribution	A-D	Chi-Square	K-S	
Beta	2.9332	255.9320	.0672	Minimum=-93.24,
Gamma	5.8939	312.0180	.0733	Location=-18.25,S
Max Extreme	23.0820	426.3940	.1140	Likeliest=1191.38,
Logistic	34.2881	790.2860	.1917	Mean=1751.04,Sc
Student's t	39.6579	722.7740	.2342	Midpoint=1400.0
Normal	47.4130	1,171.8680	.1743	Mean=2135.80,St
Min Extreme	90.3896	1,560.2940	.2892	Likeliest=3419.41,
Weibull	335.0764	221.5960	.1020	Location=2.96,Sca
Exponential	340.6646	238.7060	.1053	Rate=0.00
Triangular	475.8787	1,202.0280	.3881	Minimum=-7.30,Li

Statistic	Fit #1: Beta	Forecast values
Values	---	1,000
Mean	2135.80	2135.80
Median	1397.90	1400.00
Mode	---	0.00
Standard Deviation	2277.73	2278.87
Variance	5188058.36	5193251.61
Skewness	1.68	1.67
Kurtosis	6.35	6.34
Coeff. of Variability	1.07	1.07
Minimum	-93.24	0.00
Maximum	25122.75	14600.00
Mean Std. Error	---	72.06

Figure 5-8. Production Cost Savings Distribution Due to Upgrade

The societal benefit is determined as the production cost savings, which is represented by Figure 5-8. The expected societal benefit for this one hour simulated is $2,135.80. The standard deviation is high, 2,278, since there are many large values with low probability as is evident from the PDF. The bounds for a 95% confidence interval would be (0 $/hr, 8,362 $/hr). The VaR is 2097.75$/hr, so 95% of the time the societal benefit will be above 38.05 $/hr. If every hour in the year followed this form, then the expected societal benefit for one year would be over $18 Million and the bounds for a 95% confidence interval would be ($0, $73 Million). The VaR would be $17,670,000 for a year. A traditional method would take these values, for instance the expected societal benefit of $2,135.80, and then determine that the optimal expansion option is to put a line between bus 4 & 7. However, it will be shown later, in section 5.5.2, that if this problem were to be solved by real options analysis, this line may not be the optimal investment and the value of this investment can be significantly different.

Figure 5-9 shows the PDF for the line flow for the proposed expansion. The mean value is 250MW with a standard deviation of about 40. Assuming a tariff of $0.04/MW-Mile [49], the line would receive about $88,000/mi for the year. With a general cost of $1 Million/mi, assuming a 40-year lifecycle for the new line, and an interest rate of 5%, the annual payment by the TRANSCO would be roughly $58,000/mi. The payback period given that yearly cost and revenue stream would come to be roughly 17 years. The return on investment for the TRANSCO is over 50%.



Ranked by: Anderson-Darling

Distribution	A-D	Chi-Square	K-S	
Beta	4.4669	455.8000	.0714	Minimum=117.65,
Min Extreme	9.8585	345.5420	.0653	Likeliest=268.63,S
Weibull	11.5329	370.3660	.1027	Location=103.32,S
Logistic	13.0702	540.5960	.1194	Mean=253.48,Scal
Normal	14.5488	702.5320	.1038	Mean=250.17,Std.
Gamma	18.7221	640.1820	.1161	Location=-40.37,S
Lognormal	22.8289	543.5540	.1269	Mean=250.38,Std.
Max Extreme	32.4340	907.1560	.1747	Likeliest=229.35,S
Student's t	32.6442	517.1640	.1170	Midpoint=257.50,
Triangular	88.5776	387.4760	.1245	Minimum=126.64,

Statistic	Fit #1: Beta	Forecast values
Values	---	1,000
Mean	250.17	250.17
Median	256.87	257.50
Mode	288.25	300.00
Standard Deviation	39.52	39.54
Variance	1561.86	1563.43
Skewness	-0.6312	-0.6303
Kurtosis	2.65	2.64
Coeff. of Variability	0.1580	0.1581
Minimum	117.65	131.50
Maximum	308.49	300.00
Mean Std. Error	---	1.25

Figure 5-9. Distribution of the MW Flow for the New Line

CAPM can be used to determine the required rate of return for the project to be worth investing. The difficult part is determining the beta. [26] states that one can create a proxy beta for a real asset by averaging the betas of companies that are in the same business. For transmission planning, one can consider past transmission investments in place of the companies. The betas are determined by the slope of the regression line when regressing the difference between the asset’s return and the risk free return against the difference between the market’s return and the risk free return. Once this proxy beta is determined, the required rate of return for the real asset is equal to the risk free rate plus the proxy beta times the difference between the market’s return and the risk free rate. This equation is also listed in Chapter 3 as (3-8).

APT can also be used to determine the required expected return on a real asset. By using past transmission investments and regressing their return against the various factors that are being used for the model, one can determine the necessary parameters for these assets as described by (3-15). Then, taking past investments that were well diversified, one solves for the lambdas from (3-16) of Chapter 3. For real assets, the lambdas are determined by minimizing the least squared error as the equality constraint will not hold for all real assets. The error is the difference in the calculated return from (3-16) and the actual return. Next, one can extract the parameters for the current transmission investment relative to the factors. These parameters are then used with the lambdas in (3-16) to provide a required rate of return for the asset to be considered efficient.

To determine the future revenue for the TRANSCO, one would need to forecast the stochastic load flow over the lifecycle of the new line. Chapter 4 presents an overview of forecasting methods that can be used to accomplish this. Since it is very difficult to get accurate forecasts, some transmission planning methods use an approximation method. For instance, CAISO's TEAM [9] forecasts their necessary data for two years, calculates the benefits for these two years, determines the benefits for the years in between these two years by linear interpolation, and then assumes a constant growth in the benefits from the latter forecasted year to the end of the lifecycle. The advantage of using real options analysis is that, though there is a lot of uncertainty, some of these uncertainties will be resolved in the future and will affect the managerial decisions. Modeling such managerial decisions improves the accuracy of the evaluation. For instance, the load growth can be modeled just as a stock's price can be modeled. If the load growth surpasses some threshold by some certain time, say before the construction of the line is finish, the management will realize that it is then worthwhile to expand their investment by increasing the capacity of the line or adding a parallel line. This is the expansion option and real options analysis can be used to model such unexpected events and the managerial decisions.

For this example, such an event can be modeled by basic options theory, as it resembles an American option, as it can be exercised at any time, with an expiration date reflecting the end of construction. The forecasted stochastic load can be transformed into a stochastic benefit. Typically, investors look for at least some level of return so the option is not exercised just because it is profitable but because it reaches a certain profit level. Thus, this required cushion would be negated from the actual benefit and this end value would represent the actual spot price in the formulation of the American option with a strike price of the cost of the expansion. The required profit margin that was subtracted from the overall benefit would then need to be added back onto the overall payoff, which can be done based on a decision tree that would reflect whether the option was exercised or not.

Determining the optimal investment time is also important. For transmission investments, one would get a forecast of the future stochastic loads and analyze the investment over its life. Then, you essentially take a window of time that represents the length of the lifecycle, shift it through time, and then compare the benefits of the different investment dates to determine the optimal time to invest. This can be modeled by developing a decision tree with a branch representing the different year and the choice of which branch to take is based on the branch that provides the most benefit. This is an example on how real options analysis allows one to model the managerial decisions that take place in the real world. Likewise, for transmission planning, the choice of the optimal size of the line is something that is important and a decision tree can be used to model this managerial decision as well.

5.5.2 Modeling of Unexpected Network Expansions

A substitute for building a transmission line to import power to an expensive area from a cheaper area is to build local generation in the expensive area. Transmission planning takes a lot longer process than generation planning so generation that was not recognized during the researching phases of transmission planning may be present by the time the line is built or soon after, thereby affecting the value of the transmission investment. Traditional methods do not account for this. Obviously, if there is new generation that has been proposed and is known during the transmission planning process, then they can consider a sensitivity study but that only happens when the generation planning is already in the pipeline.

Referring to the previous example in section 5.5.1, if there was another generator located at bus 8 identical to the one already there, the percent of time that the line 4-7 would be congested, without the transmission upgrade, would drop from 95% to 11%. If a generator were to locate at bus 8, the value of the previously discussed transmission upgrade would all but disappear. The expected societal benefit would be 18 $/hr with a value of zero 74% of the time based on Monte Carlo simulations. This is something that the TRANSCO and the ISO need to recognize. In the deregulated environment, GENCOs keep their strategic planning to themselves. In this situation, whether the line is there or not, it is still profitable to locate another generator at bus 8; thus, there is still an incentive for a GENCO to locate there even after they hear about the transmission expansion. Consequently, placing a new line between bus 4 & 7 would not be the optimal investment if a generator were to locate at bus 8 but the problem is that the ISO and TRANSCO face this uncertainty of whether a GENCO will decide to locate there or not. In one case, it is beneficial for the ISO to go ahead with the expansion whereas for the other case, it is not. Modeling such crucial uncertainty is critical in determining the true value of the line. Real options analysis is a method that can account for such events that are critical in determining the value of the investment.

The arrival of a new generator can be modeled as a Poisson process. Since it might be difficult to get an approximation at what the rate should be for bus 8 specifically, one could look at historical data for the entire network and determine the arrival rate for a generator at any bus. Since the sum of two Poissons is a Poisson, the overall rate can be broken down by probabilities for each bus to get a proxy for the arrival rate at bus 8. By modeling the arrival based on a Poisson, more than one generator may locate at bus 8 but the only concern is when the first arrival happens. It is appropriate to model the arrival rate as a Nonhomogeneous Poisson Process (NHPP) as generation must adapt to meet load over time and load grows with time. Thus, it is likely to have the arrival rate increase with time instead of assuming it is fixed. Modeling the arrivals as NHPP is especially important for long term planning like transmission planning. Once the first arrival occurs, it is logical to assume that the arrival rate should decrease, as now there is less of an incentive for the next generator to locate at bus 8. This would suggest that the arrivals are dependent random variables. Since the focus is only on when the first arrival occurs, this is not a concern. Future research can examine whether modeling generator arrivals by a Poisson is appropriate or not but such goes beyond the scope of this work. The probability that the k^{th} arrival occurs by time t given a mean measure of u(t) is provided by (5-1).

$$\Pr[N(t)=k]=\frac{e^{-u(t)}(u(t))^{k}}{k!} \tag{5-1}$$

For simplicity, assume that the managerial decisions are as follows. The planning and construction of the transmission expansion lasts 5 years starting from time zero. The lifecycle is 40 years. If the first arrival is within the first 5 years of the planning and construction phase, the expansion is abandoned. The payback period for the TRANSCO to recover its costs was determined to be 17 years in section 5.5.1. Thus, if the first arrival is between years 5 and 25, the first 20 years of the line, the ISO will initiate a grandfathering contract with the TRANSCO so the TRANSCO receives a guaranteed rate of return for the remaining years of the investment. If the first arrival is between years 25 and 45, the last 20 years of the lifecycle, the ISO will not initiate a grandfathering contract and such risk is assumed by the TRANSCO. An arrival after year 25 will not force the ISO into a grandfathering contract with the TRANSCO but it will still affect the value of the line. If the first arrival is after year 45, the line's lifecycle is over so this event is not a factor in determining the benefit or cost. Before the arrival occurs, the benefit to the ISO is expected to be $18 Million/yr; after the first arrival, the benefit is $160,000/yr. The revenue to the TRANSCO before the arrival is $88,000/mi per year. If there is a grandfathering contract, their revenue is $58,000 * (1+r)/mi per year with the r determined by the guaranteed rate of return. The expected revenue after an arrival when there is no grandfathering contract is $48,700/mi per year, which is less than the annualized cost of $58,000/mi. The investment cost is always $1,000,000/mi unless the project is abandoned in the first 5 years. It is assumed that if a generator arrives during year 3, after 2 years are completed, the cost is 2/5th of the $1,000,000/mi. Based on these findings, the expected annual benefit for the ISO is shown by (5-2), (5-3) represents the TRANSCO's expected annual revenue, and (5-4) represents the investment cost. Note that there is no benefit for the ISO or revenue for the TRANSCO during the first 5 years. To determine the PDFs for these variables, one can perform Monte Carlo simulations by modeling the Poisson arrivals and developing a decision tree to represent the managerial decisions that would take place base on whether a generator locates at bus 8 or not. The different paths of the decision tree would then lead to the PDFs representing the different outcomes as previously described.

$$\text{ISO\_Yrly\_Benefit} = \frac{1}{40}\left[\sum_{t=6}^{45} \Pr[N(t)=0]*18{,}000{,}000 + \sum_{t=6}^{45} \Pr[N(t) \ge 1]*160{,}000\right] \tag{5-2}$$

$$\text{Transco\_Yrly\_Rev} = \frac{1}{40}\left[\begin{array}{l} \sum_{t=6}^{45} \Pr[N(t)=0]*88{,}000 + \sum_{t=6}^{25} \Pr[N(t) \ge 1]*58{,}000*(1+r) \\ + \sum_{t=26}^{45} \Pr[N(t) \ge 1]*48{,}700 \end{array}\right] \tag{5-3}$$

$$\text{Total\_Inv\_Cost/mi} = 1{,}000{,}000 - \sum_{t=1}^{5} \Pr[N(t) \ge 1]*200{,}000*(6-t) \tag{5-4}$$

$$\Pr[N(t) \ge 1] = \sum_{k=1}^{\infty} \Pr[N(t)=k] = \sum_{k=1}^{\infty} \frac{e^{-u(t)}(u(t))^{k}}{k!} \tag{5-5}$$

This example demonstrates the importance of analyzing future managerial flexibility as well as these possible options, option to expand, abandon, etc., by using real options analysis. A traditional transmission planning method would take the expected value of the line as stated on page 49 and determine that putting a new line between bus 4 & 7 would be optimal, with the expected societal benefit to be roughly 2,000 $/hr. However, section 5.5.2 has demonstrated that the value of this line would all but disappear if a new generator were to locate at bus 8. By applying real options analysis to model this possible option to abandon the investment as described above, one can determine the true value of adding a line between bus 4 & 7 once an appropriate Poisson arrival rate is determined to represent the likelihood that a generator were to locate at bus 8. Depending on the determined arrival rate, real options analysis may show that investing in a new line between bus 4 & 7 is not optimal. For instance, if the arrival rate was extremely high, which means that there is a high probability of a future new generator at this location, the result is obvious as then the societal benefit drops from 2,000 $/hr to 18 $/hr.

There is limited research on modeling the arrival rate of a generator within a network. The likelihood of a generator to locate somewhere in the network depends on many different issues that cannot be easily modeled. These issues may include: whether such construction is allowed at that location, whether property is available, if there is a way to provide the generator with its needed fuel source, adequate transmission available, the ability to connect to the network, environmental concerns, etc. Even assuming all of these issues are already satisfied, one still needs to consider the economic incentive for a generator expansion at this location, which then depends on load growth, market prices, fuel prices, emission restrictions, etc. Thus, getting an accurate arrival rate for this example goes beyond the scope of this research but if the arrival rate was assumed to be ½, the hourly benefit would drop from roughly 2,000 $/hr to 500 $/hr and if the rate was assumed to be 1, the hourly benefit would drop to 18 $/hr.

This example explains how real options analysis can incorporate an unexpected event, like a new generator at a key location in the network. Traditional transmission planning methods do not incorporate such modeling flexibility as seen here with real options analysis. Such an approach can be expanded to include other future transmission expansions, variability in hydro resources, etc.

5.6 Future Work

As previously mentioned in section 5.3.3, the California Energy Commission is interested in a method to value transmission investments as insurance policies [8]. Typical transmission valuation techniques do not consider the savings that a transmission line provides during rare events and these rare events can be so costly that the savings from the transmission line can outweigh its costs based on this rare event alone. Such rare but catastrophic events are the reasons why people buy insurance. The electric industry has yet to analyze investments in such a way even when our society is strongly risk averse when it comes to electricity, which is evident by our strong reliability standards.

During rare events, such as the Northeast blackout or the California energy crisis, there were large financial losses. If a person did not want to be exposed to such risk, one could purchase insurance, if it existed. The person would be willing to pay a premium so that there would be no risk exposure and that the insurance company would assume the risk. To protect against such events in power systems, you increase your transmission capability or take other measures to increase the reliability of the network. Buying an insurance policy and building up the network are, therefore, substitutes as they protect against the same event. If these two options were perfect substitutes, one would choose the cheaper of the two to implement, as they would provide the same service. This provides a way to put an upper bound on the value of either option. Consequently, this provides a mechanism at which one can extract the value of a transmission investment based on calculating the premium for the equivalent insurance policy.

One very important factor that is commonly overlooked in other financial evaluation methods is the tail of the probability distributions, which represent these rare events. This is something that is given much attention when dealing with insurance since people are risk averse. These events are rare but are unbearable for the insurer and proper analysis of these events is critical. Real options analysis is a method that can be used to value transmission investments as insurance policies. It allows one to analyze the rare events as well as the managerial decisions that would take place during such events.

Research in the insurance field is very active; however, research on insurance methods applied within the electric industry is limited. [15] & [16] look at developing a reliability insurance plan so that consumers can pay for a guaranteed reliability level to protect against blackouts or receive a financial payoff if such a level is not maintained. This provides the proper incentive in the industry by having those that control the power systems assume the risk of a blackout while receiving a fair value payment to assume such risk. Likewise, by allowing the consumers to choose their desired level of reliability, this provides the proper economic signals to the distribution companies regarding whether or not they need to invest more in reliability or not.

A simplified insurance premium calculation and outline is provided below. The model can be easily adjusted in order to reflect the desired risk aversion. Value at Risk, CAPM, and other financial valuation techniques are also used to determine the insurance premiums. The premium rate depends on [3]:

- The profit required by the insurance company
    - The profit will be determined by an assumed return on investment to benefit the insurance company for assuming the risk
- The degree of risk associated with the policyholder

- The exposure of the policy holder and the insured goods or services to the various insured perils
- The expenses of acquiring and administering the business

The basic equation to calculate the insurance premium is shown below and the parameters are discussed along with how they will be modeled for this problem.

$$P = \frac{R + l * f * c + j + \frac{F}{N}}{1 - k} \tag{5-6}$$

- P: Premium
- k: proportionate factor applied to the gross premium – it might reflect commission payable to intermediaries, and can include other acquisition costs; the premium structure might be such that it also includes contingency and profit loadings.
- R: risk premium – the expected total claim amount
    - R = f * c
    - This can be adjusted to R(1+d) where d is a measure of the variability of the risk.
- f: expected number of claims per policy
    - This reflects the number of events that the transmission line is expected to prevent over the life expectancy of the line. Such events are commonly modeled as Poisson Processes.
- c: is the expected severity of the claim amount
- The remaining terms are listed below.
    - l: is the fixed cost of handling each claim
    - m: is the variable cost of handling claims
    - j: is the per policy set up cost
    - F: is the total business overhead expense
    - N: expected number of policies to be sold

5.7 Summary

As previously discussed, traditional power systems planning techniques were based on whether or not the project was justifiable if it achieved a specific rate of return as well as the necessary reliability requirements. These techniques did not consider risk as important as it is and, at the same time, did not compare overall benefit between different projects. They also assume that managerial decisions are static. Real options analysis does a better job at providing information relating to the uncertainty involved in projects, the risk, it considers the managerial flexibility, and it uses options theory to determine if the investment is worthwhile. It also provides ways to adapt the project plan and evaluate such changes that happen in the real world that will take place throughout the lifespan of the project. This also applies to evaluating when is the appropriate time to consider different options like expansion of a current project, when to abandon, etc.

Overall, this research provides a description of real options analysis, the necessary information required to formulate a real options problem for transmission expansion planning, presented three case studies related to this topic, and provides two examples of how to use real options analysis for transmission planning. The methods of the case studies were compared with one another and, for the ones that did not apply real options analysis, it was explained how the use of real options analysis would provide a better representation of the value and risk of the project. In summary, this research has demonstrated why real options analysis is a preferred method for transmission expansion planning.

CHAPTER 6: WIND ENERGY PLANNING

6.1 Introduction to Wind Energy

As fuel prices soar and environmental concerns grow larger, the demand for renewable energy sources increases. One type of renewable resource is becoming more and more popular throughout the world, wind energy. However, the main setback for wind energy is the uncertainty and uncontrollability of the energy source, wind. Some of the newer methods try to remedy this problem by taking the electrical energy from the wind farm and converting it into a different form of energy that can be stored for use when desired. Examples range from using pumped storage facilities to underground compressed air facilities. [10], [22], [31], [42], [44], [58], & [59] have researched these options. However, having to build a separate facility just to deal with the uncontrollable nature of wind energy requires a large sunk cost, which is a setback for this approach. This approach is a physical hedging method; however, this method may require a financial hedging position as well since there are limits to the capabilities of the facilities, thereby limiting the physical hedge.

Alternatively, a different approach does not require large investments into additional power plants. This alternative approach involves the purchasing of call and put options to hedge risk. Thus, this alternative is a financial hedging method whereas the previous method is a physical way to hedge the risk associated with the uncontrollable nature of wind.

For this financial hedging approach, the wind farm can buy call options to protect against the case where they have been obligated to provide energy but there is not enough wind to do so. Likewise, they can buy put options that will give them the right to sell their power at a given time for a given price when it is available. This research presents a method to determine proper pricing of such options, when it is appropriate to purchase such options based on wind forecasts and market prices, and then this approach is compared to a contractual agreement method between a pumped-storage facility and a wind farm. For proper comparison purposes, it is assumed that the wind farm and the pumped storage have the same owner. Thus, the financial comparison is based on the owner choosing to use both plants together or have them operate separately. When they operate separately, call options must be purchased to deal with the uncontrollable nature of the wind. When they operate together, the pumped storage facility is used to deal with the uncontrollable nature of wind energy.

Real options analysis is used to attack this problem. The Black-Scholes options pricing formula is used to determine the price for the call and put options (Section 3.5.1). A basic forecasting method is used to predict the wind (Chapter 4). For simplicity, it is assumed that future market prices are known. For both plants, it is assumed that they are already operational and thus, the valuation does not consider sunk costs. This favors the joint option between pumped storage and the wind farm considering if the alternative option is preferred, one would not need to invest in a pumped storage facility; however, this factor is not being considered at this time. Monte Carlo simulations are performed to reflect the distribution and confidence intervals. Future work beyond this research will use forecasting methods for the market prices, consider the required spread necessary between the forecast for wind and market prices to determine the optimal bid and options to purchase. Further work will also consider the fact that the investment option where call/put options are used to hedge risk does not need a secondary plant; thus, fixed costs are extremely lower compared to the other case where it is required.

6.2 Pumped Storage Units & Wind Energy

The first step is to determine the optimal bid for the pumped storage facility. Assuming that electricity prices are known, this becomes an optimal dispatch problem of when to dispatch & when to refill the reservoir while meeting constraints. It is assumed that the reservoir holds an equivalent source of water to produce at its maximum output for 12 hours. The maximum output is assumed to be the same total capacity of the wind farm, 2.5MW. It is assumed that the cycle efficiency of the pumped storage hydro facility, η, is 2/3rd [62].

This study is setup such that the maximum bid that can be placed is the maximum producible energy of the pumped storage so that there is no risk of not meeting the bid quantity. Then the problem becomes the same as the previous setup for the pumped storage only now the pumped storage will produce the difference between its bid quantity and the amount of energy the wind farm produces. Then, it will refill its reservoir by buying energy equal to the amount needed minus the energy produced by the wind farm at that time. The equations below represent the profit margin and the reservoir level over time.

$$\Pi = \delta \sum_t MCP_t * W_t - (1-\delta)\sum_t MCP_t * \frac{1}{\eta} * \max((W_t - WF_t),0) \tag{6-1}$$

δ : 1 for bid hours, 0 for refill reservoir hours

MCP_t: Electricity Market Clearing Price, time t

W_t : Bid quantity

η : cycle efficiency

WF_t : wind farm power supplied at time t

$$R_{t+1} = R_t - \delta * \max(W_t - WF_t, 0) + (1-\delta) * W_t \tag{6-2}$$

R_t : Reservoir Level at time t

6.3 Options Purchasing & Wind Energy

The variable this time is not a stock price but the value of the asset over time. The current price, S, is represented by the market price for the bid period. Note that if the wind farm cannot meet its bid with its own producible energy as well as by exercising the call options, then it must buy energy on the open market at an emergency energy price. Thus, it does not make sense that the strike price could be higher than this emergency price since it would be optimal to never buy the call options and just rely on buying from the emergency energy market when the wind farm cannot meet its bid. Thus, the strike price has an upper bound equal to the emergency price. However, for simplicity, it is acceptable to assume that the strike price is the same as the market price. Note that the variable that is actually fluctuating over time is not the price but the asset value, i.e. the value of the energy the wind farm supplies. Section 3.5.1 presents an overview of the Black-Scholes options pricing equations.

It is important to understand whether the characteristics of the wind power output match the assumptions of the Black-Scholes model. One assumption of Black-Scholes is that $\ln(S_{K+1}/S_K)$, with S_K representing the stock's price at period K, follows a normal distribution. For the historical wind data used in this analysis, Figure 6-1 presents a histogram that provides the results of $\ln(P_{K+1}/P_K)$, with P_K representing the wind power output at hour K. The wind power output data used for Figure 6-1 depends on various factors as shown in (6-3) through (6-6). The air temperature and wind speed data came from [27] and contains 8200 data points representing almost every hour in year 2005. There is a large percentage lumped at zero, as the wind speed is often zero; however, the histogram still roughly reflects a normal distribution. Black-Scholes also assumes that stock prices are increasing exponentially over time. Wind speed and air temperature are the underlying variables and neither of these variables are exponentially increasing over time so this assumption is not consistent with the characteristics of the wind power output. What is happening is that the wind speed is exponentially increasing over short time intervals, roughly speaking, and then it dies off. Since the model is only applied over a very short interval, for the following day, the assumption of the variable increasing exponentially over time was therefore negligible for this work and will be considered in future work. Another assumption that Black-Scholes makes is that the successive ratios in the stock prices, S_{K+1}/S_K and S_K/S_{K-1}, are assumed independent. This also may not match the characteristics of wind power output since the ratios of successive wind speeds are dependent; however, this assumption for stocks is not always true even though Black-Scholes is still commonly used. Therefore, for this simplified model, this assumption is ignored with the possibility of investigating this assumption in future work.

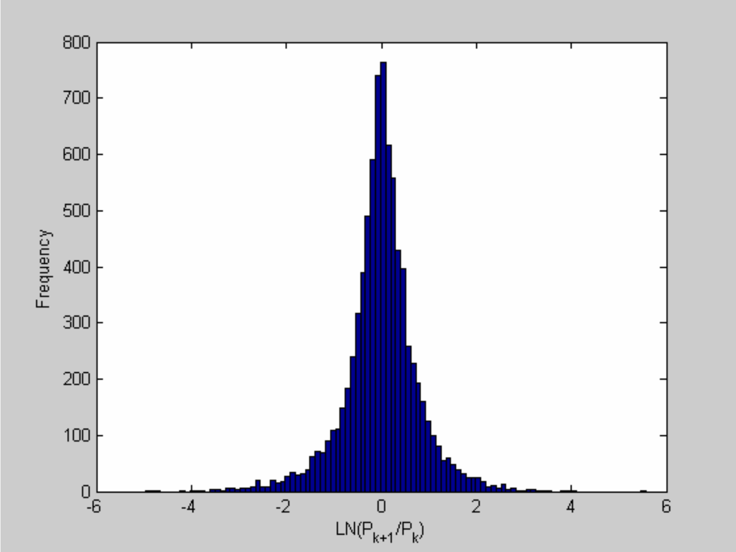


Figure 6-1. Histogram of Historical Wind Power Output Data in the form: LN(P_{K+1}/P_K)

6.3.1 Hedging the Variability of the Wind

This case study considers the performance of the wind farm operating independently from the pumped storage facility and using call options to hedge against the uncertainty of the wind to ensure that the promised energy supply is delivered. However, the amount of call options purchased is based on a chosen confidence interval. The first case study looks at the two working together as one firm. Thus, for simplicity in comparing the two, the second case will also include the results for the pumped storage working independently so that both cases have equal assets.

The amount of power delivered to the blades of a wind turbine depends on more than just the wind though wind is the main source. Another uncertain factor is the air temperature, which affects the air density and thus, the delivered power to the blades. Therefore, the actual variable that we will focus on is the power that the turbine can supply based on fluctuations in wind, temperature, efficiency of the wind turbine, etc. This is the variable instead of price for the Black-Scholes option pricing model. The equations to determine the power supplied by the wind turbine based on wind speed, temperature, elevation, blade diameter, efficiency, etc are shown below as (6-3), (6-4), (6-5), & (6-6). Note that P_blades is the power captured by the blades of the wind turbine and P_grid is the power delivered to the grid. The power delivered to the grid is not the same as the power delivered to the blades. One main manufacturer listed their product at 30% efficient. The actual power delivered to the grid is assumed to be the power delivered to the blades multiplied by the efficiency coefficient of the wind turbine, ε. Other factors that need to be determined, like the proper gear ratio, are not discussed as such is beyond the topic of this research. The total capacity of the wind turbine is assumed to be 2.5MW.

$$\sigma_{AD} = \frac{353}{T+273} * \exp^{\left(\frac{-H}{29.3*(T+273)}\right)} \tag{6-3}$$

$$\rho = \frac{1}{2} * \sigma_{AD} * V^3 \tag{6-4}$$

$$P\_blades = \pi * \left(\frac{D_B}{2}\right)^2 * \rho \tag{6-5}$$

$$P\_grid = \varepsilon * P\_blades \tag{6-6}$$

σ_{AD} : Air Density (kg/m^2)
V : Wind Speed (m/s)
ρ : Power Density (W/m^2)
P_blades : Power Delivered to Blades (MW)
P_grid : Power Delivered to the Grid (MW)
ε : efficiency of the wind turbine
D_B : Diameter of Blades (m)
H : Elevation (m)
T : Temperature (c)

6.3.2 Determining Call Options Quantity

The next step is to determine the amount of call options that the wind farm wishes to buy in order to decrease the risk. The following equations represent how this is determined. The wind farm chooses a certain confidence interval that they wish to have and they will buy call options to protect up to this confidence interval. If a confidence interval of less than 100% is chosen, there is the possibility that the wind farm will not have enough power to meet its bid quantity. If this is the case, the wind farm buys emergency energy at a higher price.

W : Bid Quantity in MWh for a given period
X : Call Options Purchased $= \beta * W$
β : % of the bid that is covered by call options
$0 <= \beta <= 1$
Y : The actual producable amount of energy for the period
$Y \sim N(\mu, \sigma^2)$
confInt : Confidence Interval in % (lower tail distribution only)
Y : $\mu - \alpha * \sigma$ (assumed to be confidence interval value for now)
$\alpha = inv\_CDF[confInt]$ (normal distribution assumed)
for confInt = 95%, $\alpha = 1.65$
$W - X - Y = 0 \rightarrow W * (1 - \beta) = Y = \mu - \alpha * \sigma$
Solving for Beta :

$$\beta = 1 - \frac{\mu - \alpha * \sigma}{W} \qquad (6\text{-}7)$$

Now that we have obtained the proper amount of call options to purchase according to the chosen risk level, Monte-Carlo simulations are now used to determine the desired bid quantity based on confidence interval, profit, and risk. This is done after the forecasting is completed in order to determine an appropriate forecasted mean and variance. Appropriate forecasting techniques are discussed in Chapter 4. For now, shown below by Figure 6-2 is a sample of the results in order to describe the decision process.

Figure 6-2 displays the graphs representing different confidence intervals and the standard deviation versus profit corresponding to these confidence intervals. The far left curve represents choosing a confidence interval of 95%, the middle is 85%, and the right curve is 75%. The curves are somewhat jagged by simulating a limited number of possible bid quantities. The Monte-Carlo simulations were done for various bid quantity levels. Obviously, the 95% curve in green is optimal with a higher expected profit and a lower variance. The optimal bid quantity would be a point in the left region of the curve. The optimal point would be chosen based on risk preferences. In this study, risk preferences were adjusted such that the variance for this case (the wind farm acting independently from the pumped storage and using options) was similar to the variance of the first case (the wind farm and the pumped storage acting together) for ease of comparison. After doing further analysis, it was determined that the curves start to converge around 95%. Thus, the optimal confidence level is 95%. However, it is possible for the optimal confidence interval to vary for different periods.

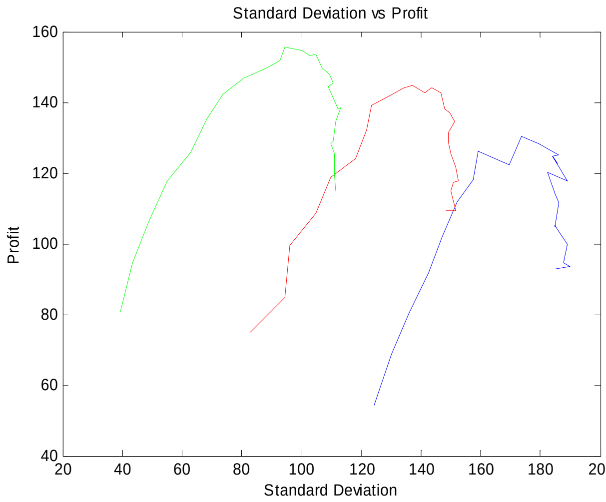


Figure 6-2. Profit vs. Standard Deviation based on Bid Quantity & Confidence Interval

6.3.3 Cash Flow Calculations

The revenue for the wind farm is the multiplication of the bid quantity and the electricity market clearing price (MCP). It is assumed that the bid is always accepted. The costs include the cost for purchasing the call options, the cost of exercising a certain amount of call options, and the cost of buying emergency energy if there are not enough call options plus producible energy from the wind farm to meet the bid quantity. The cost for purchasing the call options is the multiple of the call premium (3-19) and the quantity of call options purchased, β*W. The cost of purchasing emergency energy is equal to the quantity not able to be supplied by the wind farm and the call options multiplied by emergency energy price (ep). The emergency energy price is assumed to be 1.2 times the market price. The cost of exercising a call option is the market price times the quantity that is exercised. The equation for the profit is defined by (6-8). The terms are listed as revenue – call options cost – emergency energy costs – exercised call options cost.

$$\Pi = \sum_t \begin{bmatrix} W_t * MCP_t - call\_premium_t * X_t \\ - ep_t * \max(W_t - X_t - Y_t, 0) \\ - MCP_t * \min(\max(W_t - Y_t, 0), X_t) \end{bmatrix} \tag{6-8}$$

X : Call Options Quantity
W :Bid Quantity
Y : Actual Energy from Wind Farm
MCP : Market Clearing Price (spot price)
ep : Emergency Energy Price

The cash flow calculations for the pumped storage acting by itself are similar to those discussed in section 6.2 and (6.1) & (6.2). The only difference is that there is no wind farm term this time. (6.9) & (6.10) list the equation for the profit and the reservoir level at time t.

$$\Pi = \delta \sum_t MCP_t * W - (1-\delta) \sum_t MCP_t * \frac{1}{\eta} * W \tag{6-9}$$

δ :1 for bid hours, 0 for refill reservoir hours
MCP_t: Market Clearing Price, time t
W : Bid quantity
η : cycle efficiency

$$R_{t+1} = R_t - \delta * W + (1-\delta) * W \tag{6-10}$$

R_t : Reservoir Level at time t

6.4 Data Acquisition

The real electricity market data is taken from [41]. The wind speed & air temperature data was collected from [27] for the location Sutherland, IA. The source for the wind data, [27], was missing data for certain hours; thus, this data was replaced by interpolating the data based on surrounding hours. The data for the electricity prices and the wind are taken from different regions since this data was easy accessible.

6.5 Comparison of Hedging Methods: Pumped Storage versus Options Purchasing

Table 6-1 contains the expected profit and standard deviation for one month for every season. Monte-Carlo simulations are performed on the variable Y representing the energy produced by the wind farm based on the forecasts to give expected profit. It can be seen by the results that the hedging method based on buying options should be the preferred method since it has a higher expected profit while having a lower standard deviation. For case 2, there is a region of possible bids that are optimal according to risk preferences, i.e. for higher bid quantities, the risk is higher. Thus, for comparison purposes, the bid quantities were adjusted such that the standard deviation for case 2 was similar to case 1. As shown by Figure 6-2, there is a region where profit increases with the standard deviation so that there is an appropriate increase in expected profit to compensate for the higher risk level. Thus, case 2 gives the wind farm the option to match the bid quantity according to ones risk preferences.

Table 6-1. Expected Profit & Std. Dev. for both Cases

	Case 1 – Joint		**Case 2 – Independent**	
	E[Profit]	**Std Dev.**	**E[Profit]**	**Std Dev.**
Nov. 2004	$12,543	280.30	***$12,784***	***227.30***
Feb. 2005	$9,749	285.30	***$9,909***	***271.00***
May 2005	$24,686	672.90	***$25,160***	***601.80***
Aug. 2005	$10,798	324.00	***$11,025***	***295***
Total:	$57,776		***$58,878***	

6.6 Future Work

Future work will not assume that the electricity prices are known. This then becomes a combination of how the prices fluctuate over time as well as the wind. Likewise, the affect of other assumptions needs to be examined such as the assumption that both plants are already operational and thus, sunk costs are ignored. The point of this study was to see whether it is necessary to rely on a pumped storage facility to compensate for the uncontrollable nature of the wind power versus if the wind farm could purchase options to achieve the same. Thus, further analysis should look at the case where you have just a wind farm using options theory to hedge risk versus using a wind farm and a pumped storage facility together. For such research, one needs to consider more than just expected profit since the investment costs will vary substantially. Thus, things like value at risk, rate of return, payback period, etc should be investigated as well.

Other things to be investigated concern how the assumption that wind follows a lognormal distribution affects the results. Black Scholes also assumes that the stock price is increases exponentially over time, which is inconsistent to the wind power output of the wind farm. Future work would model the wind distribution and the process over time more appropriately and the call option prices can be determined by other methods such as Binomial Trees. Another main assumption that needs to be further researched is the assumption that the wind speed over one hour is constant. Without this assumption, the outcome would favor the joint merger of the pumped storage and the wind farm since the pumped storage hydro could just respond as the power output from the wind farm fluctuates. However, the case when they are independent, the cost of the call options would increase due to this uncertainty over the hour. The model should be further expanded to involve put options as well as call options. Last, the affect of a wind farm on ancillary services needs to be researched as well. One main reason for the support of a pumped storage facility is due to its ability to offset the increase in ancillary services due to the wind farm.

6.7 Summary

Overall, this research provides a description of two methods to hedge the risk involved with wind energy. One method is already being used: combining a wind farm with a pumped storage hydro plant. The other method proposed here is to use options purchasing for the wind farm to hedge risk. This involves using the Black-Scholes options pricing model, forecasting, real options analysis, etc. The purpose of this comparison was to investigate whether it is necessary to make such a large investment into a pumped storage facility when there are other methods like options purchasing that can be used instead and thus, do not require such large fixed investment costs. This research has demonstrated that such a method of purchasing options is financially competitive. Further research is needed to determine if there is one preferred method. At this time, a complete & competitive options purchasing market does not exist in the deregulated electric industry; however, future research should focus on cases like these in order to encourage such progress in the industry since such a market would open up more and better options, especially for wind energy as shown by this research.

CHAPTER 7: CONCLUSIONS

The electric industry is adapting to the changes caused by deregulation. Deregulation has changed the objectives for the different market participants. The objective of transmission planning has switched from minimizing cost for the consumers to maximizing the societal benefit for all market participants; however, some still disagree with this method as it treats the savings for the customers equal to the profit of the GENCOs and it treats congestion revenue as a positive as well. The generation companies are no longer willing to release their cost information or their strategic plans to one another as that would give an advantage to their competition while their new objective is to maximize profits. This complicates transmission planning as it adds to the uncertainty since now there is less known about where the next generator is going to locate. There also is the question with transmission planning on who should carry the risk. Under the vertically integrated system, such was not an issue but now there is the question of whether the ISO/RTO should cover the risk or the TRANSCO. As a result of these changes, traditional transmission planning methods are no longer adequate and new methods are needed. This research has investigated real options analysis as a method to value transmission assets.

Real options analysis does a better job than traditional methods by considering the managerial flexibility that is present in the real world, providing information relating to the uncertainty involved in projects, and it uses options theory to determine if the investment is worthwhile. This work provides a description of real options analysis, the necessary information required to formulate a real options problem for transmission expansion planning, presented and critiqued three case studies related to this topic, and provides two examples of how to use real options analysis for transmission planning. The examples presented a 14-bus example, discussed how CAPM and APT can be used to determine required rates of returns, discussed how to model unexpected events based on a stochastic process, presented how to model managerial decisions, etc. Overall, this research has demonstrated why real options analysis is a preferred method over traditional methods.

As fuel prices rise and environmental concerns increase, the demand for renewable energy sources is increasing. Wind energy is specifically becoming more popular but the problem with wind energy is that it is not controllable. Researchers are looking for ways to make wind energy a more desirable investment so that it can compete with fossil fuels. To achieve this goal researchers are proposing methods to handle the uncontrollable nature of wind energy by converting the electric energy to potential energy by using pumped storage hydro facilities. This work analyzed the option of using a pumped storage hydro plant together with a wind farm from a financial viewpoint. In addition, this research analyzed whether or not such an option is truly best by comparing it to the case where the wind farm can purchase call options to protect against the uncertainty of the wind. This research has demonstrated that the use of options is a possible and financially competitive method in comparison to using a pumped storage facility with a wind farm.

This thesis has covered two topics in power engineering: transmission planning and wind energy planning. Both areas are experiencing changes in the planning process. Transmission planning has changed due to deregulation while those supporting wind energy development are searching for ways to offset the setback that wind energy faces since it cannot be controlled. Real options analysis is a new method that is being applied in power engineering and this work has documented how real options analysis can be applied in these areas as well as why it is a preferred method.

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