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**WORKING PAPER**

# Resource Allocation and Reliability for the Transmission Provider

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Abstract
In the deregulated market structure, transmission provider will need optimization and decision making tools to be efficient. It will need better reliability analysis tools, which are probabilistic to enhance its service, make long-term investment decisions and use its resources efficiently through higher utilization and priority servicing. With these enhanced services, intelligent decision making mechanisms will enable the provider to maximize its profits. A dynamic programming approach is proposed for the transmission provider to make decisions season-ahead by accepting or rejecting requests for bilateral agreements over its assets. Transmission provider can simulate the season spot market with anticipated load and energy costs and determine which set of bilateral agreements in addition to the spot market will return the highest profits. Experimental setup with preliminary results and simulation challenges will be presented.

# 1. Introduction

Currently, the power industry is in search of robust market structures that will enable deregulation reach its goal of a more efficient system while keeping service reliability levels high. One structure that is proposed by Yoon and Ilic, is the Voluntary System Operator Model. Under this scheme, transmission provider allows both spot market trades and bilateral agreements to be run on its assets. Under the spot market operation, transmission provider is still responsible for balancing supply and demand in real-time. In this role, it operates under strict regulation; however, her operations in the bilateral agreement space are not restricted. Yoon and Ilic point out this for-profit characteristic to be a good incentive for efficient transmission operation and planning. [1] This paper will present preliminary design of a short-term, season-ahead planning tool for the for-profit transmission provider and explore computational issues that are being faced.

It is observed that transmission provider is now selling a stand-alone service. This has implications on the reliability concept for serving the load and requires deviation from its traditional approach namely the reliability of the bulk, composite generation and transmission system. In addition, as a new individual entity, the transmission provider will need to develop robust reliability tools assuring adequacy and security as well as optimizing the use of the line capacities for higher profits. A system-approach tool for reliability will be explored to supplement the service-approach tool described above. The work in both areas is currently going on.

The first section of the paper will focus on the optimal transmission resource allocation issue, will present a set-up for a simple system and mention the computational issues. The second section will point out the necessity for a new reliability approach for the TP to be a well-rounded service provider.

The paper will be introduced from the point of view of the transmission provider aiming for profit; however, this concept can be analyzed from various points of views. The tools here that are suggested for the transmission provider to allocate resources and maximize revenue by looking season ahead. Another market player could also do similar calculations for anticipated market prices and trade in that way. (More on that later.)

# 2. Dynamic Programming for Optimal Transmission Resource Allocation in Power Systems

Transmission Provider (TP) operates its transmission resources, the lines, to make profit. TP chooses to allocate its resources in bilateral transaction and spot market trades. This decision making process is extremely complex. Bilateral transactions are the trades between individual players in the market for a fixed quantity, price and duration. These parameters determine the revenue collected form the bilateral agreements. The spot market is the real time market where there is market based pricing and market clears. Revenue in the real market is determined by the quantity supplied and the nodal price. These two markets both influence the quantity of power transmitted on the lines, which have a certain carrying capacity. Higher the congestion on one line, the higher the price due to high demand. Even though, it may seem that the TP would like to use as much of its lines as possible thus accept any incoming bilateral and spot market request, that is not the case. Bilateral agreements that are accepted in one period of time, e.g. a day, might impact the line congestion levels of the next. While maximizing revenue for one period, they may decrease it for the next compared to the case where the agreement had not been accepted. Or an agreement may take up capacity that would be more profitable to sell later to another party. It is important to overcome such decision issues.

The goal is to a build a tool and a framework where the system revenue is maximized, season-ahead, by the TP who chooses the optimal combination of the incoming bilateral agreements, implements them in addition to the spot market in consideration of limited transmission resources. Using dynamic programming tools, this near real time resource allocation problem can be solved effectively. Since higher congestion on the transmission leads to higher spot prices, in a majority of the cases, the operator is expected to choose a combination including bilateral agreements while it can. However, certain circumstances will lead to the opposite decision due to higher revenue gains from operating only at the spot market or holding off resources for a future agreement. We hypothesize that, intelligence can be developed through many simulations where the TP can effectively use this tool to learn initially, and generate certain operational rules. This way, the subsequent decisions can be made without building the whole tree or building any dynamic programming tree at all. The concept of the tree and the computational issues surrounding it will be explained below. ( This work can also be extended for the following purpose: a near-real time tool can be developed for to make curtailing decisions on bilateral agreements as the transmission provider watched the real-time spot prices. This issue will be discussed later.)

## 2.1 **Proposed Solution and Its Design**

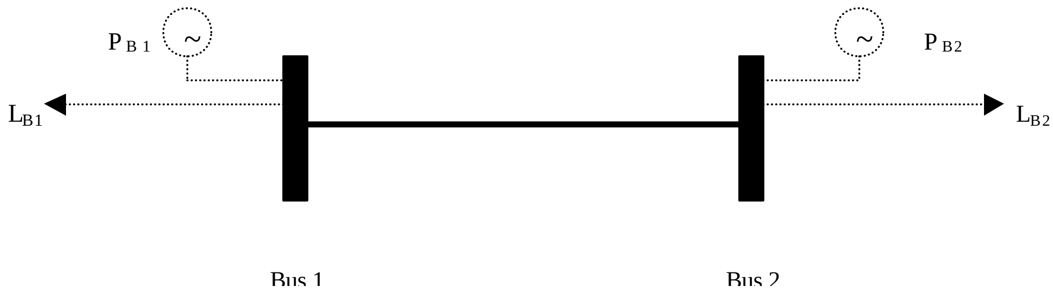
The proposed dynamic programming modeling calls for some design considerations that will allow the model to be computationally feasible. The design considerations and assumptions will be listed; however, the motivation will become clearer as the dynamic programming algorithm is introduced:

1) Season will be analyzed in discrete times as snapshots of the system. The arrival of bilateral requests and the ending times for implemented requests can only happen at these discrete time periods. Similarly, the continuously changing spot market will be sampled at discrete times. Initial experiments will be done over an unspecified time unit and period. In real implementations, the time step will be chosen through a tradeoff. It should be small enough so that we can assume the spot market stays the same, however, that would lead to more simulations and a bigger tree.

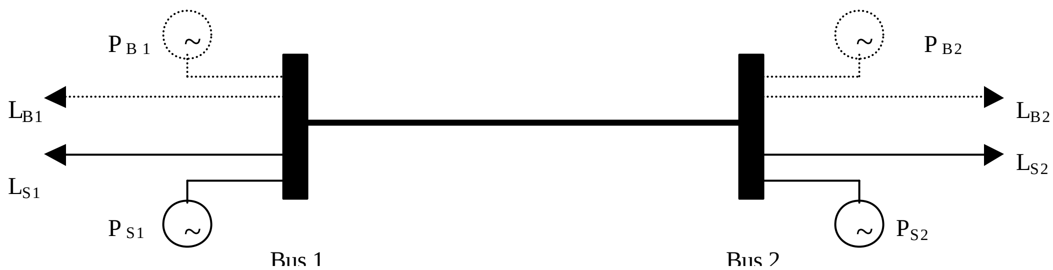
2) Although transmission systems have a very high number of buses, because the combinatorial issues arise quickly and make computational methods very costly, the initial experiments will be carried out for a 2-bus system. (In a later section, these two buses will be connected by two lines which will also allow us to look into line outage issues. )

3) When considering the bilateral agreements, the following simplification is made: In a 2-bus system, we have Bus1 and Bus2. Generators and loads at these nodes will be divided into two groups:

a. The generators that will only inject power for a bilateral agreement ($P_{B1}$ and $P_{B2}$) and loads ($L_{B1}$ and $L_{B2}$) that will only take place in a bilateral agreement. These generators and loads and their associated parameters are not included in the spot market considerations. In other words, the value of load for each bus under the spot market value will not include the power supplied by the bilateral agreement. We assume the generator always has enough power for the agreement.




b. Plain spot market where Bus1 and Bus2 will be associated with some aggregate load and generation bid curves that are dispatched only in the real time market. (Generators $P_{S1}$ and $P_{S2}$ and loads $L_{S1}$ and $L_{S2}$.)




Although the real separation of generators and loads in this fashion is very hard to do, this assumption was made based on the fact that the bilateral agreements will carry an inherent level of firmness. In other words, the price of the bilateral transaction will include extensive calculations by the end users such that they will increase their welfare by making long-term agreements in light of their expectations for the future electricity spot prices.

4) In a system, node pairs that are connected by a single line will be eligible to being pairs that can implement a bilateral agreement. So the number of lines will indicate how many agreements can be made. The actual possible number of agreements is twice the number of lines since the lines are bi-directional. So in our system of 2 buses, we can have 2 bilateral agreements: inject from $P_{B1}$ to $L_{B2}$ or from $P_{B2}$ to load $L_{B1}$. (A worst case scenario is when all buses are connected.)

5) Although the number of pairs of buses is fixed in a system, if multiple agreements can be established between the same pair and the same direction, then the number of cases that will have to be analyzed in order to find the optimal solution will be very big and will grow exponentially due to the combinatorial characteristics. In addition, building a tool which can handle variable number of cases is even harder, therefore, a simplifying assumption is made: At any time, between a pair, in one direction, only one agreement can be implemented or can be operating. In other words, if there is a bilateral agreement in place from bus1 to bus2, no new ones can be made. If there are no agreements, then one will be accepted given it leads to optimal resource allocation. A second issues arises here. What if multiple requests for the same pair and same direction come at once? This also would lead to variability and indefinite computation size in the system. Therefore, this is avoided by limiting the number of incoming requests per time, per

node-pair per direction to one request. As the tool is made more efficient and rigorous, this can be relaxed.

6) While running the model initially we assume the following inputs and characteristics:

Spot Generation Bid: known deterministically ahead of time
Spot Load: known deterministically ahead of time
Transmission line: No line outages. ( Will be extended later.)
Bilateral Requests: each request with the necessary data about quantity its requesting, price of implementation and time duration. This information for all incoming requests through out the season will be available to the operator at time 0.

(The model characteristics under stochastic assumptions will be briefly investigated later. Under the stated assumptions and conditions, the dynamic programming question can be better structured.)

7) Since we are using deterministic inputs for the optimal power flow analysis, the resulting values will be static without any correlation between daily prices. This is again a simplifying assumption, where we treat each day as independent.

<u>Background to Dynamic Programming - Finite Horizon Unit Allocation Scheme</u>:

- The period is broken into time units. ( k = 1,2, …. N)
- At the beginning of each time, a control decision is made depending on the current state.
- Besides the current state and the evolution with the controls, the system also sees some (random) disturbance.

The actual implementation of the dynamic programming entails building a dynamic programming tree. The optimal allocation decision is determined once the tree is completed and the data is accumulated. This will be explained further.

While building the tree, at each time step, the current state $x_k$ will determine the possible set of admissible controls $U_k(x_k)$. Effectively, the number of elements of $U_k$ will determine how many branches will be build and we will have that many $x_{k+1}$ states. This procedure will be repeated at each time for each branch. The evolution of the state can be shown as:

$$X_{k+1} = f_k(x_k, u_k, w_k) \qquad \text{where} \qquad u_k = \mu_k(x_k)$$

This evolution will be basis to building the tree. However, the decision making process requires additional information about the cost that is associates with each resource allocation and the goal is to minimize the cost over all time. The cost function at each step is $g_k(x_k, u_k, w_k)$ and the accumulation of cost for the finite horizon can be expressed as follows:

$$J_N(x_N) = g_N(x_N)$$

$$J_k(x_k) = \min E\ \{ g_k(x_k, u_k, w_k) + J_{k+1}\ ( f_k(x_k, u_k, w_k) )\ \}$$

where we minimize over the set of admissible controls $U_k$ and take the expected value due to random variations $w_k$. It is at this iterative step, Bellman method, that the optimal allocation becomes apparent.

Applying this framework, we have the following setup:

The time of simulation can be thought of a season and the each time increment can be a day. Each day is associated with a state $X_k$. The state carries information about the bilateral agreements that have been implemented prior to day k but are those that are going on. And this information is available for each possible bilateral agreement pair. In other words, in our 2-bus system the state can be defined as $X_k$ = [ State 1-2 ; State 2-1] . Each state will tell us the quantity of power that the agreement uses, the price it pays for the whole power and how many more time periods it will continue for as well as which line capacity is being used. An example would be:

$$X = \begin{pmatrix} 12 & 10 & 0 \\ 30 & 18 & 2 \end{pmatrix}$$

This means from bus 1 to bus 2: there is an agreement for 12 MW for a total of $10 per time period and there are 0 time periods remaining which means this is the last period of execution. From bus 2 to bus 1, there is an agreement for 30 MW for $18 per day and that will be implemented for 2 more time periods after this one.

This information about the current state will describe the admissible control space. As we mentioned before, between any pair and direction of there is an implemented bilateral agreement, we cannot execute a new one. So unless a state i-j is not [0 0 0] we cannot accept another agreement. The unrestricted control space for this problem is

$$\text{baseU} = \begin{pmatrix} \text{0 0 ; do not accept any new agreements} \\ \text{0 1 ; accept an agreement for 2-1 pair direction} \\ \text{1 0 ; accept an agreement for 1-2 pair direction} \\ \text{1 1 ; accept both new agreements} \end{pmatrix}$$

These control parameters will be used to choose from the incoming agreement request W. Our request vectors W will have the same structure as the state vectors X and will alter the state. The state evolution will have two pieces to itself: One is the update of the current agreements that are described in X. This update is simply a decrease in the time remaining field for the current agreements. And the system will also make sure that the expired agreements with remaining time 0 will be discarded. The second element is the decision made at that time period with control vector u that is determined depending on X. This control vector will tell us which new agreement was chosen to be implemented.

$$X_{k+1} = X_k \text{ time decremented} + u_k * w_k \text{ time decremented}$$

This is the state evolution but we also need a function to determine performance. The performance will be the revenue collected by the system. This revenue will have two flows. One is from the execution of the agreements, and this is simply stated in the state description. The second part comes from the spot market at that time period. The need to couple these two elements comes from the fact that the transmission capacity used up by the bilateral agreements has an influence on the spot prices and therefore the revenue. So an optimal power flow calculation is done using the new line capacity altered by the bilateral agreement, deterministic generation bids of the generators only involved in spot market and deterministic system load which does not include any bilateral components.

These steps are done for all the branched and the black nodes that are shown in the below graph and the revenue are recorded. Once the tree is completed, the backward walk down the tree starts at the last time step, the leaves. For each same parent, the maximum child revenue is chosen. This gets added to the parents and the procedure is repeated for the time step before the end. How we work with a smaller tree and the parents become the leaves. This is repeated until we end up in the root node with the maximum accumulated revenue. The branch that results in this outcome is the decision made for the coming season.

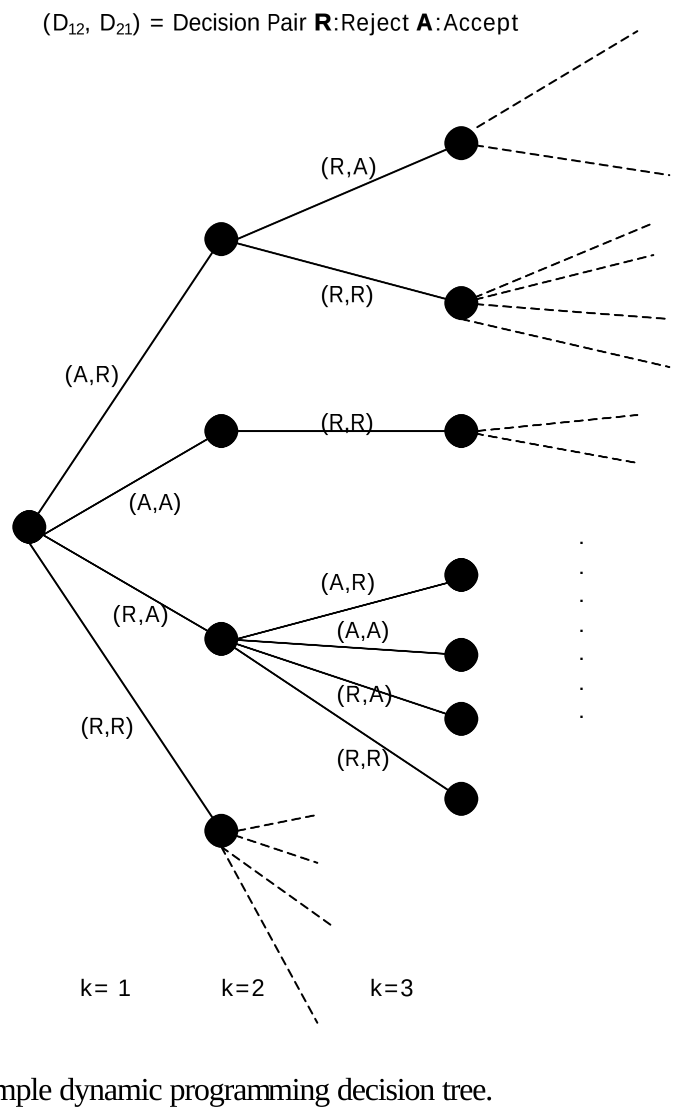



Figure 1: A sample dynamic programming decision tree.

## 2.2 Data and Simulation

For the 2-Bus system, the parameter of the setup and the pricing will be picked from values close to real data. Similarly, data streams will be created to emulate possible real bilateral agreements as well as spot market load data along with generation bids. The simulations will be conducted for different time periods. The tests will be geared towards understanding the general decision pattern to conclude with some rules of thumb for the TPs.

## 2.3 Design Shortfalls and Proposed Solutions

As described above, the process of building a tree is computationally very hard. The 2-bus system is a remedy to this problem, but when long time periods are being considered, the problem re-emerges. There is couple of proposed methods to overcome such issues. One is the study of this model as a discrete event dynamic system. This will help us leverage studies done in this area for our problem. The other two proposed solutions, ordinal optimization and perturbation analysis aim to decrease the computational issues around the dynamic programming approach.

DEDS: Discrete Event Dynamic Systems are systems that evolve in time with the arrival of a discrete event. The analysis of such systems is studied under the DEDS concepts. The state space definition, state transitions can be mapped to the events of some other real system. In our model, the states are represented by the bilateral agreements that are being implemented. And the states changes with time as well as the arrival of the new events. That is why the concepts developed for DEDS can be applied to our model and synergies can be utilized. This is just another observational method that will put our model into a framework but will not influence the computationally issues immensely. In order to tackle the drawbacks around high computational difficulties, two other concepts will be studied: Ordinal Optimization and Perturbation Analysis.

Ordinal Optimization: When the goal is to find the values that maximize an objective function, one rigorous way is to enumerate all possible parameters and calculate the objective function. Then a simple comparison of the values will yield the input set that maximizes the function. However, this is a very costly process just like building a whole tree for a dynamic programming problem. Ordinal optimization aims to soften the goal and rather than getting to the best answer, it find a good enough answer that will get you to the softened goal. Two approaches define ordinal optimization. First is to make a complicated objective function into a simpler one that will give the same ordinal list of results, meaning that the order of the results when listed will be the same even though the exact function values may differ. Then when the best result is picked from the list, the exact value can be calculated. The second part is calculating only a set of the input cases rather than doing the whole set. This will still yield a good enough solution. Work will be done to ease the computation of the revenue calculations. These calculations are costly because of the spot market nodal price determination process.

Perturbation Analysis: A variation of the common perturbation analysis for discrete variables will help us determine performance of different decision paths in the tree without running the sample path, but rather perturbing a pre-build path to get the results. This will save us time since less branches of the tree will give us more information. Works around perturbation analysis of DEDS systems by Prof. Ho of Harvard University is the first resource for this extension.

Finally, approximate dynamic programming will also be looked into to offer solutions for bigger systems.

# 3. Transmission System Reliability

The promise of deregulation is to drive the inefficiencies of the system out, yet while doing this, reliability criteria, which protects the end user and the system should be preserved. Reliability concept for power systems is a very strong definition that dictates the service level to be delivered to the consumer. With the unbundling of the vertical utility, the reliability of the service is also unbundled requiring a new structure. A simple re-engineering of the current conservative reliability analysis, ie. N-1 contingency analysis, will conflict the efficiency goal deregulation has introduced. Instead, we suggest a probabilistic reliability analysis, which will justify the margins of operation. Moreover, a better understanding for the TP of the infrastructure it is operating, will enable it to introduce new concepts, such as differentiated services with different levels of firmness.[2] This work can also be extended to evaluate future transmission capacity investments as it will have the capability to determine the paths with high levels of congestion under different operating status. ( [3] is one successful study done on N-2 contingency analysis for the California region to observe voltage issues where about 25000 cases of outages were considered.)

There is literature on one kind of probabilistic reliability analysis. This group of studies has examined the probabilistic load duration curves in order to estimate the reserve capacity that will be needed. Since the reserve requirements will change with the load, the reliability parameter would gain a probabilistic nature. However, there is more to transmission system reliability. The equipment outages in the system also need to be considered. These events will be low probability events with significant impacts on the topology and carrying capacity of the transmission system. Until now, this analysis was too complex to carry out for the transmission system and the redundancy in the system seemed to handle these outages should they happen sue to equipment age, weather, etc. However, in a deregulated environment with competition and close scrutiny by the consumer, the transmission provider will need to develop this capability to compete effectively. (There is more previous work in this area for equipment outages in single or a group of generation units; however, it differs significantly from the transmission due to the lack of complex topological interactions. [4] )

## 3.1 Proposed Solutions and Its Design

The key to improving tools that work with transmission is to incorporate as much as one can to create an accurate model for the grid. This model should be able to represent the current status and predict the future of the topology reliably so the transmission owner, or provider, can rely on it to make decisions for further in time. Topology simply refers to the physical status of nodes and transmission lines with their associated maximum capacity at any point in time. The events that alter the topology from the norm is the equipment outages and repairs. Although the probability of a fail is rather small for a high voltage transmission line, the impact of such a critical event is so vast that this is a very crucial problem to work on. Therefore, it is desirable to include these measures in any transmission-modeling tool. The preliminary work will be done around independent transmission line outages. The information gained from the probability analysis will be brought together with the optimal power flow analysis to get more accurate pricing for the TP's service.

Sources for equipment outages in a system can be numerous. One of them is weather conditions that can either influence a single line, or a group of lines. Another kind is outages caused by overloads in the system. These two cases are grouped under common-mode events where one circumstance may lead to failure of lines otherwise independent. [4] As a start, we will only look at independent line outages inherent in the lines itself. A line's lifetime can be associated with a hazard function representing the change of rate of failure of a component, line, over its average life time. A typical example is a bath-tub function. Assuming that we will be looking at a period of time small compared to the projected life of the component, we can assume that we are operating at the flat section of the bath-tub hazard function with a constant failure arrival rate.

Once the failure probabilities of individual lines are determined, the next step is to define the conditions that the TP needs to evaluate. For ease, three modes of operation are defined: Normal, Alert and Emergency. Normal operation denotes all lines in service. The alert mode can be defined in a variety of ways. It can either be when the system loses transmission capacity above a critical limit. Or it could be defined as the simultaneous of at most X number of lines. An extensive study could further look into the topology and determine the actual combinations that are critical, but since that depends on the topology networks themselves, we will not go into detail in this method. Lastly, the emergency operation will refer to a condition where the system cannot serve any load and needs some high level intervention.

Let's look at a single independent line:

Line outages and line repairs are discrete time events that alter the topology of a system by changing any line from an operational stage "1" to a non-operational stage "0" as depicted in Figure 2.

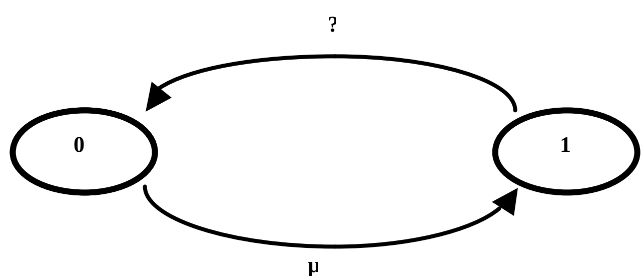



Figure 2: Markov Chain representation for status of one line.

The change from state 1 to 0 represents the arrival of an outage with a mean time to arrive as ?n. Similarly the change from state 0 to 1 represents the arrival of a repair with mean arrival rate of µn. Each line in the system has its own rates that are independent of any other line. This enables the use of a discrete events system analysis for the problem. The memoryless property assumption is the drive of the solution that will be described. Briefly,

- If ?t between observation points is small enough, it can be assumed only one event happens in ?t.
- Events in non-overlapping time intervals are independent.

Are the two main pillars of memoryless assumption and will be useful when we extend to multi-line systems.

Looking at a more complex sample:

The notation that will be used is as follows:

$L_{tij}$ is the status of line from node **i** to node **j** at time **t**. and $S_t$ is the status of the whole system at time **t**.

The vector notation for $S_t$ is

$$\begin{pmatrix} \textbf{State of Line 1 ? \{0,1\}} \\ \cdot \\ \cdot \\ \cdot \\ \textbf{State of Line L ? \{0,1\}} \end{pmatrix}$$

A 3-Bus Sample:

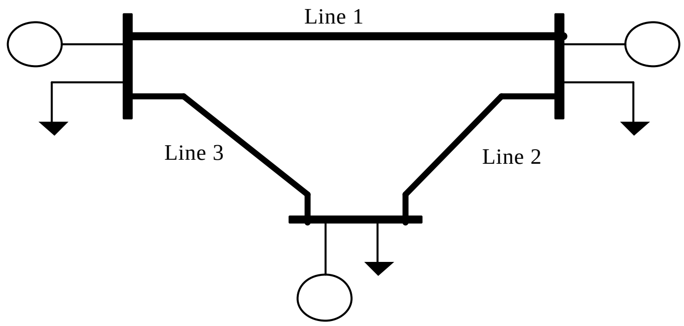
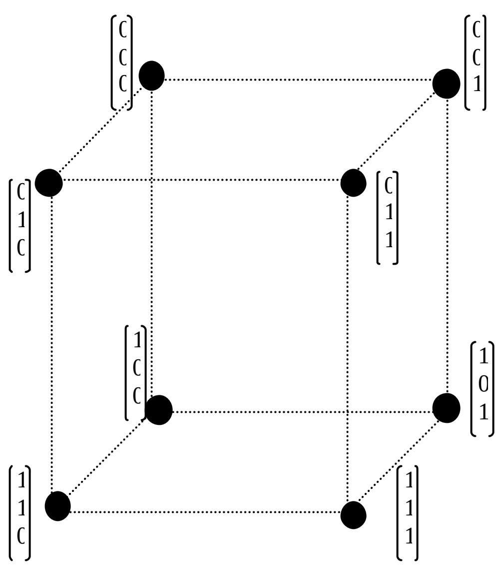



Figure 3: 3-bus system

Given the above definitions, and a sample transmission network shown in Figure 3, one can build the graphical system state space representation where the states are defined as $S_t$. Please see Figure 4. It is crucial to observe that each pair of adjacent states are different from one another in only one $L_{tij}$ value which corresponds to only one outage or repair difference between the states. Combining this with the first definition of the memoryless property, “If ?t between observation points is small enough, we can assume only one event happens in ?t.” Therefore, in ?t, the state will either stay the same or move to one of its neighboring states only. Making use of the outage and repair rates, the relations between states can be easily obtained. Below is an example where the starting state is given as (1 1 1) and Figure 5 shows the states of interest for the next time period and gives an example for a probability calculation of moving between states:

Figure 4: System states representation.



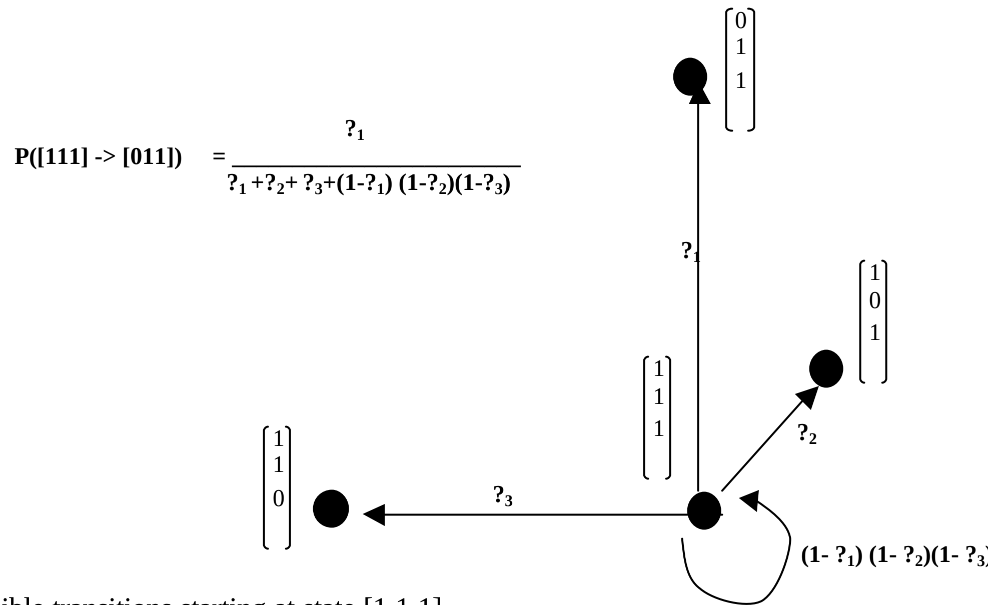
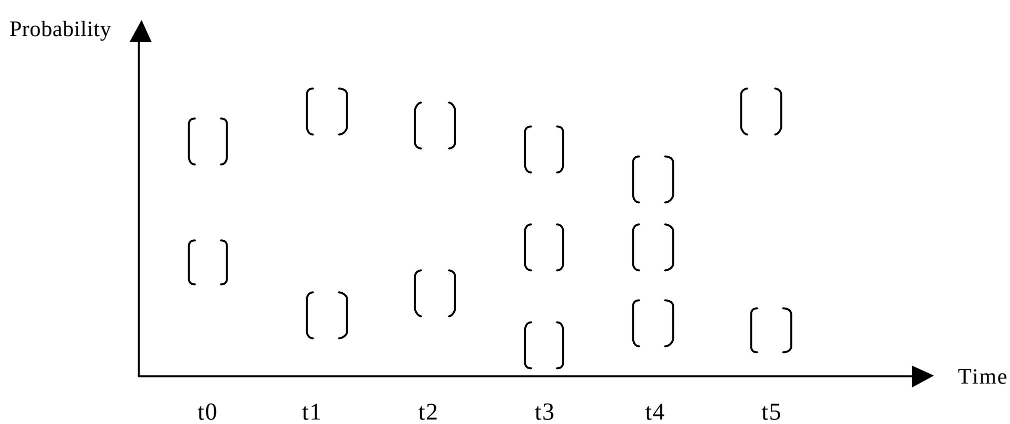



Figure 5: Possible transitions starting at state [1 1 1].

Given a start state, ? and µ vectors, the probabilities of changing states can be calculated and a random walk in the space can be simulated. Combining this with the second part of the memoryless property, "Events in non-overlapping time intervals are independent," it is seen that it does not matter which state transition happened before. This is the key to the simplification of the problem. Given L lines in a system, there are $2^L$ possible states; effectively they make up the L-dimensional system. If the state changes were not limited to one hop between adjacent states, one would have to simulate all cases. Not only would that take a lot of computation, but also even calculating the transition probabilities would be a significant issue. The discrete events system method bypasses this combinatorial problem by limiting the cases. If there are L lines in a system, each state has (L-1) neighbors and itself to move to in the next time period. Current tools can simulate one state transition in $\log_2 L$ calculations. These individual steps can be repeated to full simulate a random path of states for a total time T. (This results in $\log_2 L$ x T/?t calculations only.)

The current problem that needs to be resolved is the following. It is quite easy to simulate a random path for time period T. However, before assigning this as the projected topology, more simulations should be carried out to get a better solution. While doing this, it is very important to there is a lower bound to the number of simulations which need to be completed since an accurate estimate if the steady state solution is sought. Once many simulations are run, how should the data be aggregated to conclude on the most probable topology? This is the next step of the tool, which needs to be designed. However, the end desired outcome is shown below.



Once these parameters are defined and a robust mechanism is implemented to predict the changing topology, this information will be brought together with changing load and supply information to carry out the rest of the pricing decisions. For now, these optimization problems will be calculated by picking discrete points on the time axis. But improvements are being thought out to bypass time and just work in the probability space.

## 3. 2 Procedure and Theory

As described above, the most crucial toolkit for modeling any system is the use of Discrete Event Dynamic Systems (DEDS). Extensive work on DEDS is being carried out at MIT, Harvard and BU. The data required for system state definitions is merely the existing topology and the line characteristics. These are the hazard functions that are used to model the lifetime and reliability of any physical component. In Reliability Modeling in Electric Power Systems by J. Endrenyi, he works with hazard functions and focuses on their use. Although, the description above works with one set of outage and repair rate for a line, it is important to note that they change by time and the system should update its parameters accordingly.

In all the simulations, the proposed tool is Matlab; however, further discussion with other groups who are working on DEDS modeling might reveal more suited tools. Graphical representations are ideal to work with such topics and must be exploited. This will also create the basis for creating a real time online tool for TPs to actually use for themselves.

Initial work on creating tools for probabilistic optimal power flow was again done in MIT Energy Lab under Prof. Marija Ilic's supervision by Chien Ning Yu. An Algorithm for Implementing Transmission Rights in a Competitive Power Industry is a brief summary of the methods he used to model the transmission system. He took a Monte Carlo approach that computed the value of transmission given network topology and probability distributions as well as generation capabilities. He joined this with a decision tool for the independent system operator to decide which short-term transaction to curtail in order to avoid network congestion. He first estimates the equilibrium quantity for the market. This is later combined with constraints of the system and random deviations in load. Membership functions are used to model individual buses since the data is an aggregate data for the whole system. For each line, Yu finds the probability of occurrence of each load pattern. Each pattern is then analyzed separately and a possible generation dispatch and line flows are obtained from an optimization function. [6]

**Extensibility**

Another new area that emerges with competitive markets in power utilities if the prioritization of services and differential pricing depending on the level of reliability required by the customer. [7] This decision system again relies heavily on a robust modeling of the system as well as successful load predictions. However, due to amount of statistical data that have accumulated over long periods of time, estimation of load is being carried out very accurately. It is also an idea to create a self-learning neural network for the transmission system topology estimations.

Further extensions to the project include the comparison of large network topology of transmission systems and its modeling to the other large networks such as telecommunication networks and grids. This comparison must be carried out very carefully since there are significant differences in the nature of the services provided, ie. system cannot give a busy signal to a load in need of electricity. However, the comparison hold very well when the characteristics of the physical elements are compared such as the lines and cables that make up the transmission system. It is very likely that the life of such elements are also modeled in hazard functions with changing rates of failure.

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