2007 Professional Development Award Report

Andrew Ward, Transpower NZ

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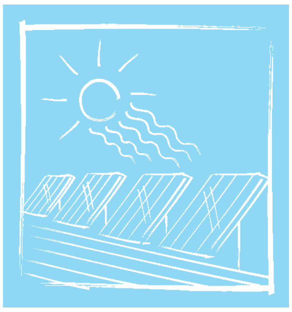

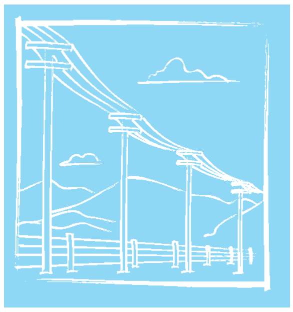

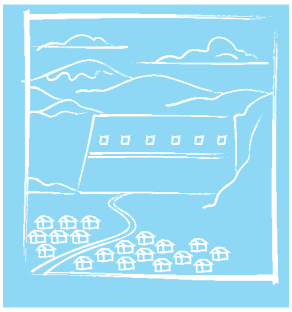

Engineering Excellence

Electricity Engineers' Association

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Executive Summary

The way in which Electricity Network companies do their planning of the transmission and distribution grids is changing. Part F of the Electricity Governance Rules (EGR) requires a greater focus on probability-based design over the more traditional deterministic approach of building a specific level of redundancy into the grid.

Therefore, as a Transmission Planning Engineer I need to understand probabilistic planning[1] from an engineering perspective in order to work effectively within the governance rules.

Purpose for Attending the IEEE PES Conference in Tampa, Florida

The IEEE PES Conference in Tampa, Florida provided me with a unique development opportunity. The EEA presented me with the Professional Development Award in order to attend this conference with the following objectives:

- to gain an international perspective on the use of “Probabilistic Planning” including how to account for high impact, low probability events when using Probabilistic Planning;
- to gain an international perspective on connecting large amounts of wind energy to the grid;
- to establish international relationships with industry peers so that we can share ideas and mutually benefit over time.

However, at the conference I realised my limited background knowledge on both probabilistic planning and wind energy. The large volume of conference information obtained on both probabilistic planning and wind energy meant that, after returning from the conference, I chose to focus solely on studying the probabilistic planning information rather than attempt to study both topics at the risk of mastering neither.

I chose to focus on probabilistic planning because:

- The minor Grid Upgrade Projects (GUPs) in which I am (and will be) involved require me to have a good working knowledge of probabilistic planning from an engineering perspective.
- Other Transpower employees attended many of the wind sessions that I attended. So they have brought the wind knowledge back into Transpower.

Plenary Session – Keeping the U.S. Transmission System Reliable

The United States have been focussed on reliability with the enforcement of the NERC reliability standards in June 2007. The Plenary speakers discussed the topic of “keeping the U.S. transmission system reliable” from national, regional and state perspectives.

It was interesting to hear the U.S. perspective on some of the issues that New Zealand is facing: corridors for the electricity grid, synchrophasor monitoring systems to monitor the real-time health of the grid, the need to increase the number and quality of engineers.

See Section 2.2 additional comments and Appendix C for the raw notes taken from the plenary session

Key Points on Probabilistic Planning

I attended a full day tutorial entitled “Probabilistic T&D Reliability Planning”. I learnt a great detail about the stages in the probabilistic planning process from creating component

[1] Probabilistic planning has many different names including “Reliability analysis”, “Value-based Reliability Planning” and “a probabilistic value-based approach to planning”.

failure models to calculating the value of unserved energy (ref. Section 4.3). I came away with an understanding of:

- the differences between Analytical simulation and Monte Carlo simulation,
- the strengths and weaknesses of the Analytical and Monte Carlo methods,
- when to use each method,
- various applications for probabilistic planning.

I have already been able to apply this learning in my current GUP.

Considerations when implementing a probabilistic planning model

The tutorial contained the following key points that could be useful for probabilistic modelling within the New Zealand electricity industry:

- Analytical/Monte Carlo hybrid models: Hybrid models appear to combine the best of the separate Analytical and Monte Carlo simulation methods. They can calculate statistical measures that cannot be obtained from average historical outage data (such as variance), while enumerating extremely rare contingencies (HILP events) so that they do not get overlooked by Monte Carlo's random sampling algorithm.

- The use of "Functional Grouping" to group all "components that operate and fail together …". For example, group together a circuit with all its circuit breakers, disconnectors protection relays, mechanical components, etc so that the probability of the circuit coming out of service is the sum of the probabilities of any of those components failing.

  Functional grouping is technique that might reduce the chance of an Monte Carlo simulation from overlooking rare HILP events because Functional Groups have probabilities that are higher than the underlying circuit(s) in those groups.

- Reliability indices can be used in their own right without the need to convert them into a "Value of Unserved Energy" as annualised indicators in order to visually report on the trends of possible weaknesses within the grid that would need to be addressed in time.

- Publicly available sources of historical outage data cited by the tutors (Ref. Section 4.2.5).

- The use capacity reserve margins to allow substations to be operated above their N-1 limits, thus saving money by delaying the need to upgrade those substations.

- The value of unserved energy is not a single value because it varies with the composition of the load at each Grid Exit Point and the duration of each outage. However, a lot of resource is required in order to obtain this information because it requires large scale load surveys across the grid. Note that the upper South Island and upper North Island load surveys performed by Transpower for engineering work are comparable to the surveys that Roy Billington (an industry expert on probabilistic planning) says must be done in order to adequately calculate the value of unserved energy.

- Probabilistic planning model can be formulated as an Optimal Power Flow (OPF) in order to model the corrective actions of the system operator and the market, which will redispatch MW before shedding load.

- The tutorial discussed some probabilistic simulation techniques that could be used to reduce the computation time and convergence of the probabilistic planning models (Ref. Section 4.2.8).

- Probabilistic planning can also be used to optimise the maintenance cycles of equipment in order to strike the economic balance between preventative maintenance and corrective maintenance once the equipment has failed.

Industry Relationships

Contact was established with Bob Zavadil, expert in wind turbine modelling and Abraham Ellis, the current chair of the WECC and IEEE wind modelling task forces. DIgSILENT expressed an interest in participating in these task forces. So I have since had the privilege of introducing DIgSILENT to Bob and Abraham with the hope that this will result in DIgSILENT including more accurate wind turbine models in its PowerFactory software.

Contact has also been established with other engineers on the subject of probabilistic planning.

Summary

My attendance at the IEEE PES General Meeting was very productive, providing me with a thorough understanding of probabilistic planning while reporting back on several “international” ideas that could be applied to probabilistic planning models within the context of the New Zealand electricity industry.

1 Conference Outline

1.1 Award Recipient

Andrew Ward, Transpower NZ Ltd

1.2 Event Attended

The award was made for attendance at the 2007 General Meeting of the IEEE[2] Power Engineering Society (PES). The conference was held in Tampa, Florida from 24 to 28 June 2007.

1.3 Acknowledgements

I am extremely grateful to both the EEA and Transpower NZ Ltd for making it possible for me to attend the conference. Thank you to the EEA for granting me this Professional Development award. Thank you also to Transpower NZ Ltd for supporting with the remaining costs. A special thanks to the individuals who encouraged me to apply and kept encouraging me to persist in spite of physical obstacles. You are appreciated.

By attending the conference I have grown in my understanding of probabilistic planning and the impact of wind generation on transmission. For example, my effectiveness in the current Grid Upgrade Project has increased as a direct result and I now have ongoing contact with overseas power engineers. Thank you.

1.4 Conference Synopsis

The conference was described as providing "an international forum to address policy, infrastructure and workforce issues." It is one of the larger international meetings for professionals involved in power systems. 800-1000 people registered for this year's meeting.

The conference addresses many of the topics faced by members of the power systems industry. This is done via several different vehicles: the plenary session, panel sessions, paper sessions, day-long educational tutorials, working group and task force committee meetings, and technical tours (GE transformer repair and instrument facilities, and Polk Coal Gasification combined-cycle power station).

The technical panel and paper sessions were scheduled each day of the conference, with up to 18 parallel sessions each morning and afternoon. The sessions were organised by theme into five tracks:

1. Understanding and responding to system wide events;
2. Securing new sources of energy;
3. Improving reliability and power quality;
4. Using innovative measurement and control techniques;
5. Surviving new markets and new structures.

[2] Institute of Electrical and Electronics Engineers

Panel sessions consisted of industry experts talking on specific industry issues. Paper sessions allowed IEEE members to present their research as described in their papers. Each session comprised five to eight presentations. Each presentation included time for questions from the floor.

Working group and task force committee meetings consisted of members meeting together to discuss progress on revisions to standards, writing new standards, writing IEEE books, presentations to up-skill working group members on a related topic, etc. In the working group I attended, a 30 minute presentation was given on Interharmonics Theory. These meetings were scheduled in parallel with the technical sessions.

1.5 Purpose of Attending

My purpose for going to the IEEE PES conference was to attend sessions directly relevant to the following industry-related issues in order to gain an international perspective on:

- the use of “Probabilistic Planning” in planning methods and its implications. This included finding out how other groups account for high impact, low probability events when using Probabilistic Planning; and
- connecting large amounts of wind energy to the grid.

An additional objective was to establish international relationships with industry peers so that we can share ideas and mutually benefit over time.

It also afforded me the opportunity to experience the IEEE in operation and observe how the IEEE working groups are structured and run.

1.5.1 Revised Objectives

The IEEE conference provided more material on the topics of Probabilistic Planning and wind energy than I am able to adequately process. Since returning therefore, I have chosen to focus solely on the probabilistic planning and become proficient with this topic because I am able to apply it immediately to my current Grid Upgrade Project, which has a complex probabilistic planning component. Other Transpower colleagues, who also attended the conference, have focussed on the wind related information.

1.6 Sessions Attended

I chose to attend the following sessions from the general and technical programmes.

Table 1-A Sessions that I attended.

Date and Time	Session Theme	Type of Session
Sun, 24 June, PM	New Attendees Orientation Session	Instructional
Sun, 24 June, PM	Welcome Reception to meet other members of the power engineering community	Social
Mon, 25 June, AM	“Keeping the U.S. Transmission System Reliable – National, Regional and State Perspectives.”	Plenary
Mon, 25 June, AM	Blackouts and Restoration	Paper
Mon, 25 June, PM	Transmission Issues for Wind Power Integration	Panel
Mon, 25 June, PM	Combined Poster session and social function	Poster/Social
Tue, 26 June	Probabilistic T&D Reliability Planning (8am-5pm)	Full day tutorial
Wed, 27 Jun, AM	Harmonics Working Group (Interharmonics, Modelling and Simulation, Probabilistic Aspects). Attended from 8-9am	Working Group
Wed, 27 Jun, AM	Power Quality Issues on Existing Wind Farms 9am-12pm	Panel

Date and Time	Session Theme	Type of Session
Wed, 27 Jun, PM	Grid Performance with Wind Generation	Paper
Thu, 28 Jun, AM	Didn't attend a session – unwell	-
Thu, 28 Jun, PM	Wind and Hybrid Generation Schemes	Paper

The "Probabilistic T&D Reliability Planning" tutorial was one of six registration-only tutorials offered by the IEEE during the conference. It comprised seven presentations of papers on various aspects of probabilistic planning.

A small, but significant number of authors failed to present their papers. In both the Wednesday PM and Thursday PM sessions two-thirds of the authors did not present their papers, which significantly shortened those sessions. A factor may have been authors having difficulty obtaining visas due to USA being on high Homeland security alert.

1.7 Papers and Presentations from the Conference

Abstracts of the conference papers are free to read at www.ieee.org with individual papers and the conference proceedings available for purchase at this website. But, some of the panel presentations are free to download by searching for "2007 General Meeting Panel Presentations" on the website:

www.ieee.org/portal/site/pes/

Not all the panel speakers have provided the IEEE with a copy of their presentations to put on the website.

2 Key Points from the Plenary Session of Importance to NZ

2.1 General Comments

There were many topics directly relevant to New Zealand electricity supply industry ranging from technical issues to legislation and market issues. Although the North American electricity industry is structured differently to New Zealand, lessons can be learnt by observing the way in which North America solves the same fundamental market and technical issues.

2.2 NERC Reliability Standards

The topic of the Plenary session was "Keeping the U.S. Transmission System Reliable – National, Regional and State Perspectives." The essence of the session was national, regional and state perspectives on compulsory compliance with NERC's[3] reliability standards. The Reliability Standards contain over 1200 requirements in 118 standards relating to all aspects of the electricity industry and were enforced on June 18, 2007.

See Appendix C (p. 17) for detailed session notes.

<u>Key Points:</u>

- From a transmission perspective the NERC reliability standards are purely deterministic.[4] Consequently, one North American engineer I spoke with was of the mind that probabilistic planning is unlikely to become common place in North America even though there is interest in it because there is no FERC[5] (or NERC) mandate for it and is a low priority because many electric utilities have very high workloads.

- NERC is focussing on five areas for improving electricity reliability:

    1. Introducing mandatory reliability standards.
    2. Establishing National Interest Corridors dedicated for the grid.
    3. Developing a database to identify the availability of all transmission lines in order to determine if the standards have increased the reliability.
    4. Having synchrophasor measurements across the system to monitor the real time health of the system. Synchrophasor monitoring systems are being progressively installed in New Zealand's grid.
    5. Increasing the number and quality of engineers in the U.S.

[3] North American Electric Reliability Corporation (NERC)

[4] Reference [1], p. 5

[5] Federal Energy Regulatory Commission (FERC)

3 Establishing International Industry Relationships

3.1 Wind Energy Contacts Established

I had the pleasure of establishing contact with Bob Zavadil at the conference:

- Vice President, EnerNex Corporation, Tennessee, www.enernex.com;
- Chairman of the "Modeling and Interconnection User Group of UWIG (Utility Wind Integration Group in North America)"
- Ex-Chairman of the "WECC Wind Generation Modeling Task Force;
- Ex-Chairman of the IEEE PES Wind Generation Task force which is part of the Power System Dynamics Committee.

Bob has since provided me with the contact details of Abraham Ellis, current chairman of WECC and the IEEE PES Wind Generation Task force. It has been a privilege to put Abraham Ellis and Holger Muller of DIgSILENT in contact with each other. Holger is interested in DIgSILENT contributing their efforts to the above user groups and task forces on building models for the various wind turbines.

I am hoping this introduction will result in a long term positive effect for New Zealand in the variety of standard wind turbine models that DIgSILENT includes in its PowerFactory modelling software.

3.2 Probabilistic Planning Contacts Established

Contacts have been established with engineers on the subject of probabilistic planning from:

- Sierra Power, Reno, Nevada, USA, combined with Nevada Power, Las Vegas, USA;
- Top Energy, New Zealand;
- Auckland University

4 Key Points on Probabilistic Planning

4.1 General Comments

Part F, Section 2 of the Electricity Governance Rules requires Transpower to calculate the value of unserved energy when economically comparing transmission options for enhancements to the National Grid. This requires the use of probabilistic planning, which is performed by our Economics and Approvals Group. However, I need to understand probabilistic planning so that I can provide my colleagues with useful engineering advice as they do their economics analysis.

The introduction of Part F is still sufficiently recent that I am only now starting to become involved in projects that require probabilistic planning. Consequently, I had limited knowledge of probabilistic planning prior to attending the conference.

Therefore, the primary objective for attending the "Probabilistic T&D Reliability Planning" tutorial was to develop my own personal understanding of probabilistic planning. However, some of the knowledge presented during tutorial was useful for evaluating and confirming Transpower's current probabilistic planning approach.

The key points of learning are summarised below.

4.2 Considerations when implementing a probabilistic planning model

This section summarises key points from the tutorial that could be useful for probabilistic modelling within the New Zealand electricity industry.

4.2.1 The Benefits of an Analytical/Monte Carlo Hybrid Probabilistic Planning Model

Reference [3] describes an Analytical/Monte Carlo Hybrid simulation model (p. 33). This hybrid simulation enumerates contingencies, but performs the simulation for a *random* year rather than an *expected* (i.e. average) year. That is, the number of times that each component fails in the simulation year is randomly sampled using Monte Carlo techniques rather than using the average number of failures per year obtainable from historical outage data.

The benefit of this is that it provides statistical results not obtainable by using purely analytical methods. Analytical simulations calculate the average/expected unserved energy for an average year because they use average historical data. Incorporating Monte Carlo simulation allows the statistical variance of the Expected Unserved Energy to also be calculated. This is particularly useful when historical outage data has only published as average values with no other statistical information. See Section 4.3.4 below for a comparison of Analytical and Monte Carlo methods.

High Impact Low Probability (HILP) events are so rare that there is concern that a pure Monte Carlo simulation will overlook HILP events. Yet, they are also so rare that there are very little or no historical outage data associated with HILP events, which makes it difficult or impossible to perform an analytical simulation.

Therefore, the above hybrid concept could be extended by using the Analytical part to enumerate HILP events so that they are not overlooked, while the Monte Carlo part randomly sampling the number of failures per year in order to create artificial histories of those events. Other more common contingencies could also be randomly chosen as per a standard Monte Carlo simulation in order to prevent the number of contingencies from increasing exponentially, which is a weakness of enumerating all possible contingencies.

4.2.2 Functional Grouping of Components that Operate and Fail Together

It is impossible to anticipate every possible HILP event. For example, no one anticipated that a shackle would break and cause loss of power to Auckland. N-k events are also very rare. However, McCalley proposes the *functional grouping* of all “components that operate and fail together due to their connection structure and protection scheme” (Ref. [5], p. 55). This may help capture a greater number of HILP type events in our probabilistic planning simulations.

McCalley proposes two types of functional group probabilities that can be calculated:

1. The sum of the failure probabilities of all non-switching components, e.g. all components at each end of a circuit plus other components along the circuit that could cause the circuit to fail;

2. the probability that a component in a functional group will fail and the breaker connecting that group to a neighbouring group also fails, resulting in both functional groups being removed from service.

Consequently, when functional groupings are used, the occurrence of HILP events may be of higher probability than one might intuitively anticipate because the probability of a functional group can be significantly greater than the fault probability of a single component failure, especially if the switching configuration is such that two or more lines are included in the same functional group.

Full details of the functional grouping concept can be found in [5], pp. 54-55.

In the same paper McCalley also describes a method of estimating component failure rates using condition assessment measurements and Markov models (ref. [5], pp. 54-55).

4.2.3 Reliability Indices can be used as Annualised Indicators

Reliability indices can be used in their own right as annualised indicators without converting them into a “Value of Unserved Energy” in order to visually report on growing weaknesses within the grid that will need to be addressed in time. Reference [1] is a good example of using reliability indices in this manner. Often, indices are only calculated to measure the relative reliability of the various regions in the grid for various system problems (see Section 4.3.2 for further discussion), which are then combined with load duration curves in order to calculate the unserved energy.

4.2.4 An OPF can be used to model System Operator Corrective Actions & Market Behaviour

Reference [1] (pp. 11-12) indicated that the possibility of eliminating a system problem by corrective actions rather than a network upgrade can be modelled by using:

- An OPF with the object of minimising load curtailment, MW generation re-dispatched, and transformer phase angles adjusted, where adjusting phase angles redirects the flow of MW.

- An OPF algorithm that includes an AC power flow to model the automatic operations of tap changers, switchable capacitor banks and Mvar output of generator units and other dynamic reactive devices in order to relieve overloads and voltage limit violations. Such an AC power flow solution could also incorporate a power system network linearisation algorithm and a linear programming solution.

4.2.5 Sources of Historical Outage Data

The presenters of the tutorial referred to the following public sources of historical outage data that may contain useful data in the absence of New Zealand outage data:

- Equipment Reliability Information System of Canadian Electricity Association, “2001 Generation equipment status annual report”, Montreal, Quebec, Canada, December 2002.
- MAPP-CSRWG, “MAPP Bulk Transmission System Outage Report”, June 2001.
- C. R. Heising, et al, “Final Report on High Voltage Circuit Breaker Reliability Data for use in Substations and System Studies – Report on Behalf of WG 13.06”, in Proceedings of CIGRE Conference, Paris, 1994.

4.2.6 Capacity Reserve Margins for Substations Rather Than Specific Redundancy Levels

Probabilistic planning can be used to define capacity reserve margins for substations (Ref. [6], pp. 59-60). A reserve margin is the station load forecast minus the transformer and circuit short time overload ratings within the station, expressed as a percentage of the short-time ratings. This could be set at 5%, 10%, etc. This reserve margin considers the:

- Station hourly load profile;
- Station load growth rate;
- Load forecast uncertainty;
- Equipment reliability;
- Cost of supply unreliability to customers;
- Cost of carrying a specific reserve.

The benefit implied by the author is that, a reserve margin allows money to be saved by using reliability data in order to allow the substation to operate above its N-1 capacity, thus delaying upgrade projects.

4.2.7 The Value of Unserved Energy is not a Single Value

Roy Billington is one of the leading people in the world on Value Based Reliability Planning and an expert on calculating the value of unserved energy. Billington points out that the cost of unserved energy will and does vary due to the composition of the load at each grid exit point and also varies with the duration of each outage (Ref. [4]).

Points to note:

- Currently, Part F, Section 2 uses a single value, $20,000/MWh with sensitivities of $10,000/MWh and $30,000/MWh. There is benefit to investigating the cost/benefit of establishing multiple values for New Zealand either by location and/or by duration may be of benefit. The effort to calculate multiple values is not trivial due to the need for industry surveys, analysis of results and the correct application of that data. But, it is achievable. Some work has already been done to propose a different value for the Auckland region as part of the North Island Grid Upgrade Project [12].
- I spoke briefly with Roy Billington at the tutorial. The group that he helped establish (but has since retired from) does consult to utility companies on this topic.
- Transpower recently surveyed the load composition of several grid exit points in the upper South Island and upper North Island. The data was intended for an entirely

unrelated piece of work. However, the data might be useful if there is any work to calculate more accurate values of unserved energy.

Reference [3] discusses some of the cautions that should be mitigated when using the value of unserved energy:

- Wealth transfer from utility owners to utility customers;
- Cross-subsidies between areas with high/low cost to improve reliability;
- “Surveys almost always overstate a customer’s cost of poor reliability when compared to the customer’s willingness to pay for reliability improvements. Further, customer gaming behaviour can lead to intentionally overstated responses.”

4.2.8 Advancements in Probabilistic Simulation Techniques

Reference [2] discusses the following advancements in Probabilistic Simulation Techniques:

- There have been recent investigations into the use of non-random or intelligent searches for failed components, based heuristic optimisation methods. One approach is to use Genetic Algorithms (GA) as reported in References [7] and [8].
- Pure Monte Carlo Simulation is very time consuming because it randomly samples many similar states and must perform a power flow calculation for every state. Therefore, the following optimisations are possible (see Ref. [9], [10]):
  - Create and train a Self-Organisation Map (SOM), which recognises the loss-of-load states so that, once the training is complete, the SOM can be used along with Monte Carlo Simulation in order to recognise loss-of-load states without the need to perform a power flow calculation on states that have been previously sampled;
  - Identify system failure states using the “Group Method of Data Handling (GMDH)”. In this method, Monte Carlo simulation is used first to accumulate states. Then the SOM is used to cluster the states that are similar to each other. Then a single power flow calculation is performed on each cluster of states in order to determine whether or not the states in each cluster result in unserved energy.

4.2.9 Optimising Equipment Maintenance Cycles

Probabilistic planning is commonly known as reliability planning. Probabilistic planning techniques can be used to help strike the right balance between preventative maintenance and corrective maintenance (after equipment failure), minimising the costs associated with each form of maintenance. (Ref. [6], pp. 64-65)

4.3 Development of my Personal Understanding on Probabilistic Planning

The seven papers in the Probabilistic Planning tutorial worked together to provide an overall description of the various aspects of probabilistic planning. The key points from the papers are summarised below.

4.3.1 Deterministic Planning versus Probabilistic Planning

Table 4-A: Deterministic Planning versus Probabilistic Planning

Deterministic Planning	Probabilistic Planning
Pure deterministic planning achieves a specific level of reliability by designing to a pre-determined level of redundancy, N-1, N-2, N-k	Achieves a certain level of reliability in the network without enforcing a specific redundancy level. Reliability is quantified using indices and probabilistic methods, instead of N-k.
Can result in unserved energy with outage combinations exceeding redundancy levels. Eg. A double-circuit tripping on a line in a region that is designed to N-1.	Can result in unserved energy for events that were not investigated in the planning process because their probability of occurrence was considered negligible. That is, rare, improbable events do still occur. High Impact Low Probability (HILP) events fall into this category.
Has the potential to be uneconomic due to under/over investment. But, many jurisdictions actually link redundancy levels to economic decisions. E.g. the UK chose various N-k redundancy levels to match the size of their load groups and generation in their core grid	Reliability planning models can reduce the risk of under/over investment in a power system. But, the effectiveness of reducing that under/over investment is dependent on the quality of historical outage data and the probability distributions selected to model the failure rates of power system components.

In reality, deterministic planning is often mixed with an inherent probabilistic component such as using engineering judgement to only consider certain contingencies and/or linking the redundancy levels to economic decisions, such as in the UK. Because of this, probabilistic planning is sometimes referred to as a consistent and repeatable method of formalising the experience and reasoning that engineers draw upon when choosing sensible designs so that these decisions can be scrutinised.

Probabilistic planning has other names:

- Reliability analysis
- Value-based (reliability) planning
- Probabilistic value-based approach to planning

4.3.2 Objective of Probabilistic Planning: Calculating Indices

The objective of probabilistic planning is to calculate indices that measure a power system’s adequacy to supply energy. The two basic measures of reliability are frequency of system problems (in occurrences/year) and average duration of system problems. But, there are many other reliability measures such as mean duration in hours, unavailability, SAIDI, SAIFI, kilometre-years, etc. Reliability indices can be calculated at the system level, regional level, individual bus level and individual branch level.

These indices can be assigned to any measurable power system problem. These are some of the system problems for which indices can be calculated:

- Overload on transmission circuits
- Violation of bus voltage limits
- Voltage collapse conditions
- Isolation of individual buses
- Separation of the network into islands
- Loss of load caused by interruption of supply.

Hence, reliability indices give excellent insights into the dominating failure phenomena that govern system performance.

The annualised or relative versions of these indices provide the perspective necessary to make system design decisions. Indices will under/over state the absolute risk depending on the quality of historical outage data, but they provide useful relative reliability information when assessing the weaknesses in the system, relative to other areas, or relative to previous years. They also provide a good relative comparison between the effectiveness of various options for improving a particular system reliability problem.

That is, relative indices provide useful reliability information that can supplement the results from traditional contingency analysis.

4.3.3 The Overall Process of Probabilistic Planning

Most approaches to probabilistic planning follow the same generic steps:

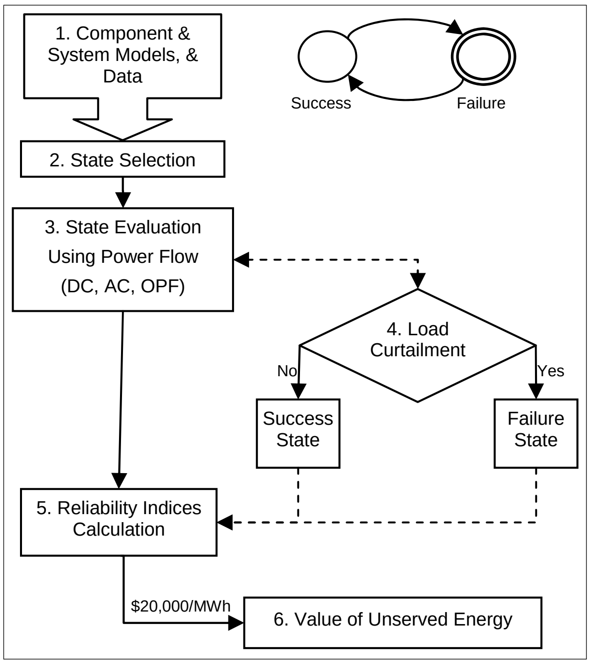

Figure 1: Steps the probabilistic planning process.

1. Two sets of models must be created: 1) power system models to calculate power flows, and 2) Component models to represent the failure/success states of power system equipment.

   Component models can represent the failure/success states of individual pieces of equipment (e.g. a generator unit, a transmission line, a transformer, a busbar) or groups of equipment. Equipment can be grouped functionally (e.g. grouping a transmission line with all CBs, disconnectors and other station equipment that might fail, causing that line to enter a failure state) or grouped to represent common-mode failures (e.g. a flooded river sweeping away the towers on two functionally unrelated lines).

   Data is also required to determine the rate at which each component (or group thereof) will fail and the mean time to return to service. Depending on the simulation technique used in Step 2, these rates may be derived from historical outage data or from randomly sampling probability distributions that are known to represent typical failure behaviour of the various types of components (circuits, transformers, generator units, etc).

2. A simulation method is used to determine the states of all these power system component models. The output of this simulation method is a list of failed components and combinations of failed components, i.e. a list of power system contingencies. The two most common methods are the Analytical method and the Monte Carlo method.[6] These are described later.

3. A power flow simulation is then run (DC, AC or OPF) for every power system contingency on the list in order to determine whether or not those failure states causes an immediate system problem (see the list in Section 4.3.2 above). If it does, this is a system failure and affects the reliability of the power system (i.e. decreases the reliability for that region by increasing the frequency and duration for that kind of system problem). If it doesn't cause a system problem then that contingency isn't

[6] The Monte Carlo method was originally devised to beat the casinos in Monte Carlo, hence the name.

affecting the reliability, so the probabilistic planning algorithm moves onto the next contingency.

4. Failure rates (from historical outage statistics or from repeated sampling of probability distributions) are then used to calculate reliability indices for the "failed" contingencies of each system problem in terms of frequency and duration. The amount of unserved energy (in MWh or kWh) can be determined by combining these indices with load duration curves. These indices form a picture of the reliable and unreliable areas in the power system.

5. A dollar value is then assigned to the amount of unserved energy so that it can be incorporated into standard economic analysis. Part F-2 of the Electricity Governance Rules uses $20,000 MWh.

4.3.4 Analytic versus Monte Carlo: When to Use Each Method

Analytical Simulation Methods	Monte Carlo Simulation Methods
General Overview • Enumerates every system contingency, computes the impact of each contingency and weights this impact based on the expected frequency of the contingency. [3] p. 29	• Similar to analytical simulation, but models random contingencies rather than expected contingencies. This allows component parameters to be modelled with probability distribution functions rather than expected values. [3] p. 29
When to use this method • This is the best method for transmission or distribution system reliability assessment when expected (i.e. average) values are required. [3] p. 29	• Monte Carlo simulation becomes necessary if statistical results other than expected (i.e. average) values are required, such as variance of results. [3] p. 30 • For example, a power system has an expected (i.e. average) value of reliability. In some years, the power system may experience near expected reliability or greater reliability (e.g. no loss of load in a particular area). In other years however, the power system may be unlucky and experience far worse than expected reliability. [3] p. 32
Evaluation of Component States: • The algorithm is provided with an enumerated list of all possible contingencies that can occur in the power system. This may include single component contingencies, common mode contingencies, station related contingencies and maintenance outages. It calculates a power flow for every contingency to determine whether or not that contingency results in loss of load (i.e. a failed system state).	• Component states are sampled using random numbers and each component's probability distributions for its success/up state and failure/down state. This assumes the basic concept that the states should occur proportional to their probability of occurrence. [2] p. 19 Once the list of failed states (i.e. contingencies) has been created it performs a power flow for every contingency in exactly the same way as the Analytical simulation method.
Computing Reliability Indices: • Once all failed system states have been identified, the probability of each failed system state is calculated from the probabilities of the failed/down component states causing that failed system state. The probabilities of the failed component states are determined using actual outage data (i.e. the actual history of the power system). • Indices are then computed using the probabilities of the failed system states and the magnitude and location of the load loss. [2] p. 19	Artificial histories of the power system are created by using the probability distributions of component state residence times. [2] p. 19 Reliability indices are then estimated by statistical inference from these histories in the same manner as would be done on the history of the real system. [2] p. 19

Analytical Simulation Methods	Monte Carlo Simulation Methods
Advantages: • This method allows power system companies to quantify system reliability, calibrate models to historical data, compare design alternatives, perform sensitivity analyses and run optimisation algorithms. [3] p. 30 • It can accurately model complex system behaviour and dynamically enumerates each possible state. [3] p. 29 • Enumerative consideration of possible system states is important since some states may be rare, but have a major consequence on the system when they do occur. [3] p. 32	• Can accommodate higher levels of system complexity. [2] p. 19 • Can model complex system behaviour, non-exclusive events and produces a distribution of possible results rather than expected values. [3] p. 29 • Provides statistical results that are not available using purely analytical methods • Useful when historical outage data is not available • Time sequential Monte Carlo simulation is very flexible and can handle complex models, but are computationally slow and data intensive.
Disadvantages: It suffers from the problem of dimensionality. In all but very small systems, complete enumeration of all states is not feasible as the number of states increases exponentially with the increase in components. Various approaches are available to reduce the number of states that must be evaluated for load loss such as ([2] p. 19): • An enumerated list of only important contingencies (i.e. a contingency being one or more failed components) such as [1], which limits the list to those states with a probability of occurrence above 10^{-6}; • State space reduction • State space truncation • Implicit enumeration	• It can be difficult to achieve convergence of the reliability indices. • Pure Monte Carlo simulation is very time consuming [2] p. 27 • Monte Carlo simulation is not enumerative and may overlook rare, but important system states. [3] p. 29 • Computational intensity [3] p. 29 • Potential imprecision. That is, multiple analyses on the same system will produce slightly different answers due to the use of (pseudo) random numbers. ([3] p. 29) But this can be avoided by using the the same seed to generate the sequence of random numbers when comparing alternative design configurations. [2] p. 22

5 Summary

My attendance at the IEEE PES General Meeting was very productive.

Since attending the conference I have focussed my energy on understanding the probabilistic planning information in order gain the most out of the development experience. However, productive contacts were established in the areas of both wind and probabilistic planning.

The “Probabilistic T&D Reliability Planning” tutorial provided me with a thorough understanding of probabilistic planning, which is already aiding me in my work on Grid Upgrade Projects. Furthermore, the tutorial covered many different applications for probabilistic planning. These could be applied at many levels of the New Zealand electricity industry: transmission and distribution, asset management, system operations and network planning. In this report I have discussed some of the most relevant applications that I have learnt about in order to serve as a thinking piece for anyone involved in probabilistic planning.

Appendix A References

These papers are available through the IEEE website.

[1] Chowdhury, A. and Koval, D., "Application of Reliability Techniques in Transmission System Planning and Analysis", IEEE Tutorial Course on Probabilistic T&D System Reliability Planning, Course Text 07TP182 (Tampa, USA: IEEE PES AGM 2007), Chapter 1, pp. 5-18.

[2] Singh, C. and Jirutitijaroen, P., "Monte Carlo Simulation Techniques for Transmission Systems Reliability Analysis", IEEE Tutorial Course on Probabilistic T&D System Reliability Planning, Course Text 07TP182 (Tampa, USA: IEEE PES AGM 2007), Chapter 2, pp. 19-28.

[3] Brown, R. and Venkata, S.S. (Mani), "Predictive Distribution Reliability and Risk Assessment", IEEE Tutorial Course on Probabilistic T&D System Reliability Planning, Course Text 07TP182 (Tampa, USA: IEEE PES AGM 2007), Chapter 3, pp. 29-36.

[4] Billington, Roy, "Data Concepts and Requirements for Value-Based Transmission and Distribution Reliability Planning", IEEE Tutorial Course on Probabilistic T&D System Reliability Planning, Course Text 07TP182 (Tampa, USA: IEEE PES AGM 2007), Chapter 4, pp. 37-47.

[5] McCalley, James D., "Estimating Component Reliability Indices for Electric Transmission Decision Problems", IEEE Tutorial Course on Probabilistic T&D System Reliability Planning, Course Text 07TP182 (Tampa, USA: IEEE PES AGM 2007), Chapter 5, pp. 48-56.

[6] Hamoud, G. "Use of the Probabilistic Value-Based Approach in Transmission Planning and Asset Management", IEEE Tutorial Course on Probabilistic T&D System Reliability Planning, Course Text 07TP182 (Tampa, USA: IEEE PES AGM 2007), Chapter 6, pp. 57-66.

[7] N. Samaan and C. Singh, "Assessment of the annual frequency and duration indices in composite system reliability using genetic algorithms", in Proc. IEEE Power Engineering Society General Meeting, Jul 2003, vol. 2, pp. 697-702.

[8] N. Samaan and C. Singh, "Adequacy assessment of power system generation using a modified simple genetic algorithm", IEEE Transactions on Power Systems, vol. 17, no. 4, Nov 2002, pp. 974-981.

[9] C. Singh, Xiaochuan Luo, Hyungchul Kim, "Power system adequacy and security calculations using Monte Carlo Simulation incorporating intelligent system methodology", Proceedings of the 9th International Conference Probabilistic Methods Applied to Power Systems, Stockholm, Sweden, June 2006.

[10] P. Yuanidis, M. A. Styblinski, D. R. Smith, C. Singh, "Reliability Modeling of Flexible Manufacturing Systems", Microelectronics and Reliability, Vol. 34, No. 7, pp. 1203-1220, 1994.

[11] C. Singh, Course notes: Electrical Power System Reliability, www.ece.tamu.edu/People/bios/singh/. (Free download)

[12] Castalia Ltd, "Assessment of the Value of Unserved Energy", Report to Transpower, August 2006 http://www.electricitycommission.govt.nz/pdfs/opdev/transmis/GUPOct06/M-Assessment-of-the-Value-of-Unserved-Energy.pdf

Appendix B Glossary of Acronyms

Acronym	Definition
EGR	Electricity Governance Rules (or Electricity Governance Regulations depending on the context)
FERC	Federal Energy Regulatory Commission
GUP	Grid Upgrade Plan
HILP	High Impact Low Probability
IEEE PES	Institute of Electrical and Electronic Engineers, Power Engineering Society
NERC	North American electric Reliability Corporation
OPF	Optimal Power Flow
SAIDI	System Average Interruption Duration Index
SAIFI	System Average Interruption Frequency Index
WECC	Western Electricity Coordinating Council

Appendix C Plenary Session Notes

Below are my notes from the Plenary Session. I was unable to record all the key points from each speaker due to the speed of delivery.

C.1 Topic

"Keeping the U.S. Transmission System Reliable – National, Regional and State Perspectives."

C.2 Presenters

Table A-1 Presenters at the Plenary Session

Perspective	Presenter
National Perspective:	Richard P. Sergel, President & CEO, North American Electric Reliability Corporation (NERC), Princeton, New Jersey, USA.
Regional Perspective:	Peter Brandien, Vice President, System Operations, ISO New England Inc, Holyoke, Massachusetts, USA.
State Perspective:	Linda Campbell, Director of Reliability and Compliance, Florida Reliability Coordinating Council (FRCC), Tampa, Florida, USA.

C.3 Key Points Recorded – National Perspective

NERC's reliability standards began being enforced on June 18, 2007. E.g. it is now an offence for tree trimming contractors to trip a circuit.[7]

Five areas for improving reliability:

1. Reliability is being improved by mandatory standards.
   - Many standards are administrative. They require increased focus and attention to reliability.
   - The standards were set up by experts.
   - Have taken time to identify owners, operators and users of the power grid.
   - Have got a register encouraging groups to comply with the standards.
2. National Interest Corridors dedicated for the grid.
   - Corridors are currently out for comment from engineers and other interested parties.
3. Database to identify all transmission lines and how often they are available
   - Used to inform the standards process to determine if the reliability has been increased. E.g. outages due to tree contact has been reduced.
4. Synchro-phasor measurements across the system.

[7] There is a range of views on the usefulness of the NERC reliability standards. For example, Chowdhury and Koval make the following comment on the transmission planning criteria aspect of the reliability standards: "In most cases, contingencies listed … are not clear in their definitions, fault types, system impacts and limits, and are therefore, difficult to interpret and use in practical situation." p. 7 A. A. Chowdhury and D. O. Koval, "Application of Reliability Techniques in Transmission System Planning and Analysis", IEEE Tutorial Course on Probabilistic T&D System Reliability Planning, Course Text 07TP182 (Tampa, USA: IEEE PES AGM 2007), Chapter 1, pp. 5-18.

- Allows the System Operator to have a wide-area view on the health of the system.

5. Have the talent/engineers to operate the system.
    - Programmes to increase the number and quality of engineers in the U.S.

C.4 Key Points Recorded – Regional Perspective

This is also a state perspective by default because ISO-New England operates a region that is also a state.

The New England power grid comprises:

- >250 market participants;
- >20 network companies;
- Several interconnections.

Mandatory NERC reliability standards have:

- forced generators to ask what their responsibilities are rather than leave it to others;
- over 1200 requirements in 118 standards
    - ISO-New England must comply with approximately 860 requirements;
    - Some relate to Transmission Planners.
    - When ISO-New England sets market rules, these rules must comply with the NERC standards.

As people in the community become more educated in the standards, ISO-New England is being forced to justify why building every line complies with the reliability standards.

C.5 Key Points – State Perspective

FRCC – Florida Reliability Coordinating Council

- Florida only has a few tie-lines to the north. FRCC can therefore limit the power import as required.

FRCC Communication System:

- Private intranet;
- Hotline phone communication;
- Satellite hotline (needed if severe hurricane damage).

FRCC Generation and Transmission Adequacy Review:

- Currently have 15% reserve margin

FRCC 10 year transmission studies

- Conducted in two stages.
- Short term of 1-5 years;
- Longer term of 5-10 years to identify developing trends.
- Gas / Electricity interdependency
- Energy produced from gas-fired generation forecast at 45% in 2016. Risks:

- Problem with hurricanes because the platforms shut down;
- Pipeline damage;
- Aiming for fuel diversity.

FRCC has demand-side management (including interruptions).

C.6 Questions Asked of Plenary Presenters

1. How does ISO-New England define system adequacy?

   90/10. 10% probability of exceedance. We run various load flows to stress various interfaces. Once needs of the grid have been identified, this goes to a 'panel' to determine whether it will be met through new generation, new transmission, demand-side management, etc.

2. Comment: Global warming. Restrictions on coal impact reliability. Greater reliance on renewables.

3. Who bears the reliability risk and at what price?

   NERC hasn't properly correlated the mandatory standards with the cost to implement. NERC requires experts to point out when the cost is too much to implement.

   FRCC requested a cost/benefit analysis on each standard. But, it wasn't well received by industry with "How do we do this? Very difficult."

4. What focus is on ageing assets?

   Both ISO-New England and FRCC answered that effort is being made to replace ageing assets.

   Transmission database will show increase in reliability.

   NOTE: the database is not recording the cost of obtaining that reliability. NERC justified this by pointing out that there are two different cost concerns: 1. Cost when implementing some new standard; 2. Cost of complying with a standard that other groups are already complying with. He argued that Concern 2 is the applicable one with respect to the NERC standards.

