EXPECTATIONS FOR LOSS OF SUPPLY IN THE NEW ZEALAND POWER SYSTEM

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Abstract

Predicting when, and how much, power may be lost on any given power grid is a world-wide issue. Statistical methods are employed to model historical records of power outages and to use these models as a predictor for what may happen in the future. In this paper, we discuss the issues facing Transpower, the supplier of power in New Zealand, and develop a model to predict for future power losses. It is found that using a power law with truncation is the best worst case scenario.

1. Introduction

Like all other developed countries New Zealand depends on an extensive power grid to move the electric power from the generating sites, mainly hydro power stations on the South Island, to the power consumers, primarily on the North Island and especially the Auckland region. So far the only power outage has been in Auckland in June 2006 where about 230,000 were affected. Compared to some of the blackouts in Europe and North America this was not a particularly large event. However, it does show that it is necessary to study the problems of potential power outages in New Zealand in a systematic way. We will use the terms blackouts, power outage and loss of supply interchangeably.

In recent years there have been some large blackouts involving millions of people. On August 14 2003 about 50 million people lost power in the US and Canada for anywhere from 8 hours to 2 weeks with a resulting economic loss of several billions of dollars. The initiating cause seems to

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have been lack of care in parts of Ohio in trimming trees near power lines, but the real causes seems to more associated with the lack of stability of a very complex power system. On September 23 about 2.4 million lost power in Denmark and Southern Sweden and the cause has been traced to faulty equipment.

Such large scale power outages lead to huge economic losses for both the power companies and society. The power companies will have to carry extensive improvements of the power grids such as upgrading and duplicating power lines, improved switching equipment etc., in order to prevent such events from taking place. However, such improvements are usually very expensive so in the case of New Zealand, the operator of the power grid, Transpower, requires a procedure for comparing the cost of a particular improvement to the cost of a potential loss of supply which may occur if the improvement is not carried out. This procedure, which is referred to as the Grid Investment Test, requires that Transpower estimate the probability of a failure leading to blackouts.

The problem for most power companies is that large failures are rather uncommon so very little data exists which can be used to predict the required probabilities. Most failures are not large so we must develop methods for using the existing data related to these small to medium sized failures to predict the probability of a large scale failure. Analysis of American data has suggested that large failures occur more often than the normal distribution would imply and that some form of a power law distribution should be used. We will show in this report that New Zealand data follows the same behaviour and that a truncated power law model is very useful in this case.

In Section 2 we will briefly review some of the relevant literature and in Section 3 we state the problem the study group was asked to analyze. In Section 4 we discuss the different definitions of the term blackout and then we give short descriptions of some of the recent large scale blackouts that have taken place. In Section 5 we state the grid investment test that governs how Transpower analyzes investment in the grid. A brief description of the procedures for analyzing data with a power law distribution is given in Section 6 and these procedures are then applied to the New Zealand data. Finally a conclusion is presented in the final section.

2. Literature Review

There is a vast literature on the analysis of power system collapse. However, we will concentrate on two aspects which are important in connection with our study: analysis of the blackout data in order to ascertain if the probability distributions follow power laws and, secondly, the review of the literature treating the technical aspects of determining the character and parameters in these power laws. For readers interested in a more general discussion of power system failures we can refer to [6] and the references quoted therein.

American data for power system blackouts has been analyzed in [4]. The authors considered 15 years of data from 1984 to 1998 and for this period there were 427 blackouts with an average time between blackouts being 12 days. An initial study of some of this data suggested that self-organized criticality may govern the system which would lead the probability of large failures to decrease as a power of the event size rather than an exponential decrease as is seen in more conventional systems. This complete study indicated that this is the case for American blackout data. A similar conclusion was also reached by [12] who considered many complex systems including US power outages.

3. Problem Statement

The working group at the workshop was asked to investigate three aspects of the analysis of the failure data for the New Zealand power grid.

- Investigate the current models being used
- Improve these models
- Discuss the effect of the model assumptions

4. Blackouts

We will define a blackout as the loss of supply at a point or in a region where power is obtained from the transmission grid. There are many different reasons for blackouts. The size of these blackouts can be described in different ways; some of the more commonly used are

- The amount of load interrupted measured in Mega Watts (MW)
- Energy not supplied measured in Mega Watt Minutes (MWminutes)
- Number of people affected

The data obtained from Transpower was in MWminutes format and so this is what will be used in this report.

4.1. Recent Blackouts

During the last few years there have been many large power blackouts which have affected a large number of people. For some of these blackouts the causes are few and well known, but for some the others there does not seem to be any single cause, rather it is a combination of several events, each of which is innocuous but together they cause a major event.

In 2003 there were three major power failures. The largest one took place in the Eastern United States and Canada starting on August 14. At the most severe point about 62,000 MW were interrupted and 50 million people were affected. For some the interruption only lasted a few hours but other communities were without power for two weeks or more. It seems that the problem started in Ohio and was initially caused by the failure of local power company to trim trees under and near power lines. This brought a few power lines down and it seems the quick and correct action of the local power company could have localized the problem to parts of Ohio. However, the proper actions were not taken and within a short time the power grid for most of the Eastern States and Ontario collapsed leading to about 50 million people being without power. Later a commission was struck to investigate the failure and a detailed report was published, see [10].

Two weeks later in London, incorrectly placed protection relays caused the interruption of 1000 MW with about 700,000 people being affected. This occurred during planned outages for upgrades in the national grid. A week later a similar incident happened in Birmingham, see [7].

On September 23 18,600 MW were interrupted and 2.4 million people were affected in Eastern Denmark and Southern Sweden. This was caused by a double busbar failure which caused four 400kV lines and two generating units to trip, [5]. Later that month a smaller failure took place in Italy with 26,500 people losing power, [9]. In August 2004 about 100 million people lost power on Java Island and as mentioned above 230,000 people were affected by a power outage in Auckland on June 12, 2006. A more detailed list of recent power outages is given in [11].

In Table 1, which is a modified form of Table 1 in [1], we show some of the underlying causes for the failures in 2003. In this table we consider the answers to the following 3 questions:

1 Was the power system designed to cope with the initiating event?
2 Were there overgrown trees?
3 What was the system condition prior to the blackout?

Blackout	**1**	**2**	**3**
USA and Canada	Yes	Yes	Normal
Italy	Yes	Yes	Normal
England	No	No	Normal
Denmark and Sweden	No	No	Normal

Table 1. Underlying Causes for Failures in 2003

5. Grid Investment Test

Transpower will be using the Grid Investment Test to evaluate new investment initiatives for the power grid in New Zealand. This test basically balances cost of carrying out in improvements in the power grid against the predicted cost of a failure. Thus for a new investment that will remove a possible cause of power failure, they will estimate the cost by multiplying the probability of such a event to occur with the cost to the consumers of this event. The cost to the consumers will be deemed to be proportional to the lost energy as measured by MW minutes. With this calculation it will be possible to rank different investments.

In order to carry out these calculations we require estimates of the probabilities that events of different sizes occur, but the existing data set does not include large events, so we must model the probability distribution.

6. Analysis of New Zealand Blackout Data

The data, obtained from Transpower, consists of events recorded over a 10 year period in New Zealand (Figure 1a). The size of the events are variable, with the smaller events being more common. The causes are many and varied and some events may have occurred on the same day.

Upon closer inspection and with guidance from the experts in Transpower, it became apparent that some of the observations that were being treated as individual events were components of one larger event. Hence, the data was concatenated so that events were being truly represented (Figure 1b). While there was not quite as much bunching in Figure 1b as there was in Figure 1a, this format of representation was not easily interpretable. We preferred to rank the events in terms of size. We used ranks to model the cumulative probability rather than frequencies in order to have a smooth representation of the data (Figure 1c). And the final adjustment to the original data was to look at this on a log-log scale which made it easier to recognise whether or not a distribution exists in the data. In this particular case, we restricted the study to

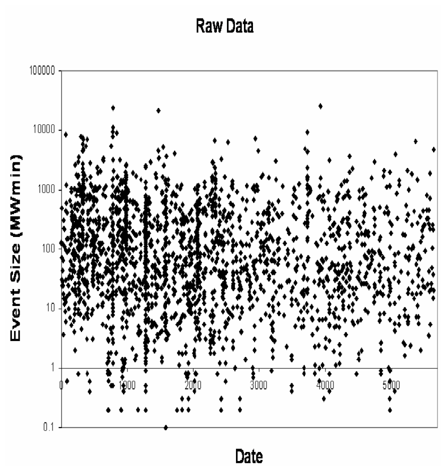

Figure 1a Event Size

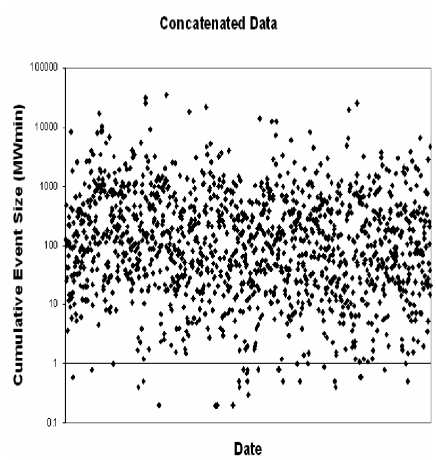

Figure 1b Cumulative Event Size

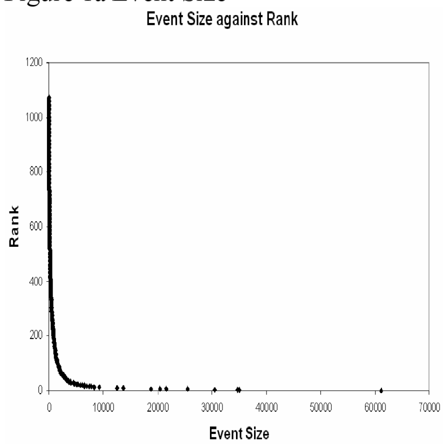

Figure 1c Ranked Event Size

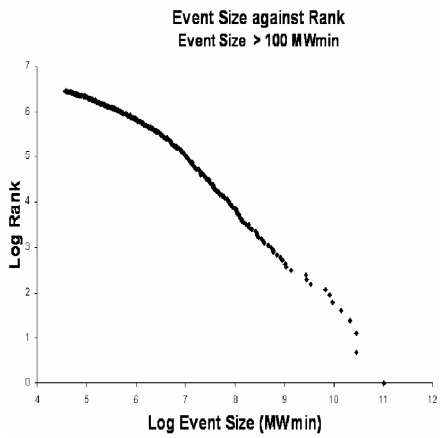

Figure 1d Large Event Sizes on a Log-Log Scale

Figure 1.

those events for which $\log(rank) < 5$, as the problem lies in predicting large sized events. In the case of small power outages, there are many historical examples and we are content to accept the empirical law that exists in the data itself.

6.1. Straight Line Fit

The most simplistic model to use is to fit a straight line to the data. The model is given by

$$\log(p) = -\alpha \log(x) + c,$$

where p is the rank and x is the size of the event. The estimate for α is 1.1454. Also, the mean of the data is 786MWmin. This is not ideal as we can see, graphically (Figure 2), that a straight line does not fit the data well in the area we are most interested in.

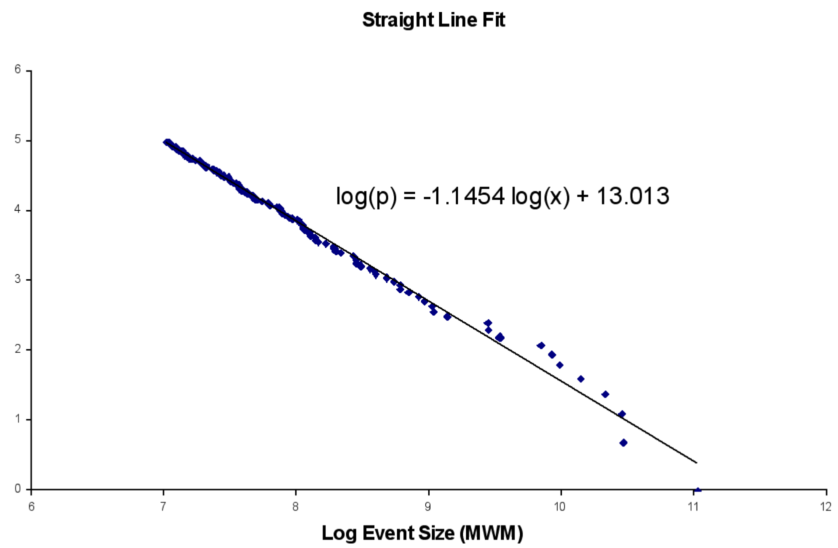

Figure 2. Straight line fit of data.

6.2. Power Law Fit

For small values of X, the data fits a straight line, but as X reaches a certain point, in this case $\log(X) > 9$, a straight line is no longer appropriate. It seems that fitting a curve for $\log(X) > 9$ would be more suitable. The power law model is generally used to model data that is distributed in this fashion. We can fit an unlimited power law where

X is the random variable representing the event. Hence, the power law model is given by

$$P(X \geq x \mid X \geq k) = \left(\frac{k}{x}\right)^{\alpha}$$

for some minimium considered event $k > 0$; $x \geq k$ and $\alpha > 0$. Maximum likelihood estimation (MLE) is a statistical tool used to make inferences about the parameters of a probability distribution for a given data set. According to [8], the MLE produces very accurate and robust estimates. The likelihood function for the Power Law distribution with parameters α and k, given a sample $X = (x_1, x_2, \ldots, x_n)$ is

$$L(\alpha, k) = \prod_{i=1}^{n} \frac{\alpha k^{\alpha}}{x_i^{\alpha+1}} = \alpha^n k^{n\alpha} \prod_{i=1}^{n} \frac{1}{x_i^{\alpha+1}}.$$

We use this to find the maximum likelihood estimate of α:

$$MLE(\alpha) = \frac{1}{\log(\frac{g}{k})}$$

where $k > 0$ is the minimum event size considered and g is the geometric mean of the sample. For the data in this case, the MLE(α) = 1.2003, and given that MLE(α) $\sim \chi^2$ with $2n$ degrees of freedom, a 95% confidence interval for α is [1.015,1.401]. This includes the estimate for α under the straight line fit. Under this model we find the mean, denoted, $E(X) =$ 1407 MWmin. This is 79% more than the sample mean. However, this may not be the most appropriate model to fit, especially in the upper tail, as it suggests that the maximum event size is infinite. In reality, we presume there is a maximum size event and in order to incorporate this idea it may be more appropriate to fit a truncated power law.

6.2.1 Truncated Power Law. In this case, there is a maximum observable event b. For New Zealand, this constitutes an event size of 1.5 million MWmin corresponding to all of New Zealand losing power for 5 hours. The truncated power law is given by

$$P(X \geq x \mid X \geq k) = \frac{(\frac{x}{k})^{-\alpha} - (\frac{b}{k})^{-\alpha}}{1 - (\frac{b}{k})^{-\alpha}},$$

where $k > 0$ is the minimum observed event considered; $b > 0$ is the maximum observeable event; $x \geq k$ and $\alpha > 0$. We can fit a truncated power law with point mass (probability of events larger than b occurring is spread over probability of events $\leq b$) or with resampling. When fitting with a point mass we have $E(X) = 1036$ or 36% more than the sample mean. Also, 5% of the expectation is due to the maximum size events. In the resampling case, $E(X) = 982$ or 25% more than the sample mean, with 5% of the expectation due to maximum size events.

6.3. Lognormal Fit

Another option is to fit a lognormal distribution where:

$$P(X \geq x \mid X \geq k) = \exp\{-\alpha \log\left(\frac{x}{k}\right) - \beta[(\log x)^2 - (\log k)^2]\}.$$

This gives $E(X) = 1026$ MWmin (31% more than the sample mean)with 4% of expectation due to maximum sized events. Some of these methods are more optimistic in terms of what the largest event could be. Using the truncated power law as the most pessimistic we produce the following results (Table 2):

Quantile Results for New Zealand Data			
$P(X \geq x)$	x	**Return Period**	**Implication**
13.8%	1116	38 days	Smallest Event (k)
1%	21000	1.4 years	
0.1%	82000	14 years	Largest Observed
0.029%	240000	50 years	All Auckland loses power for 3 hours
0.0036%	1500000	400 years	All NZ loses power for 5 hours (b)

Table 2. Quantile information for blackouts using the truncated power law.

It can be seen that the worst possible event corresponding to all of New Zealand losing power for 5 hours is expected to occur once every 400 years.

7. Conclusions

It is evident that being able to predict power blackouts is very important both to the consumer and the supplier. The difficulty, however, is that large blackouts that actually cause problems for consumers are rare. This ‘shortage’ of events means that it is difficult to develop a model that will give accurate predictions. We have used the most pessimistic model for predictions giving us the results for the worst case scenario. In response to the queries Transpower posed, we can confirm the results that they previously achieved. Also, we have made suggestions as to other models that may be used. At this stage we have yet to confirm which is the most appropriate model to use and it is our intention to compare the results that we have obtained for the New Zealand data, with results obtained for other countries around the world.

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