MODELLING THE SURFACE PLANT:
A USERS PERSEPCTIVE OF USING NUMBERS TO PREDICT GENERATION

Keith Wigram

Contact Energy Ltd, Wairakei Power Station, New Zealand

keith.wigram@contactenergy.co.nz

Keywords: *Modeling, Surface plant, Predicting.*

ABSTRACT

Predicting generation is an important function for a generation company. The data is used for justifying operational changes, budgeting and retail decisions. This paper is a users' look at the type of surface models that have been used by Contact Energy, their applicability and pitfalls.

Types of models will be discussed with their applicability in different circumstances: Historical trends have been very useful for short-term predictions and are both easy to create and accurate over short time frames. Spreadsheet models have been used with considerable success on a one off basis but are very time-consuming when present or new plant changes are incorporated. Modeling software has great potential with good outcomes from our limited use.

Modeling has had many other benefits with the discipline required to produce the model requiring an in-depth examination of the fundamental drivers. This process is potentially more beneficial than the model itself and has been used to identify significant generation opportunities in optimizing steam field layout and plant configuration.

1. PREDICTING GENERATION
1.1 Predicting Generation for budgeting

Predicting generation is an important task for prioritizing projects, justifying expenditure and planning. There are many different ways to predict the generation. Each method has a different confidence level, complexity and effort required.

The annual budgeting predictions, that this paper focuses on, have used reservoir predictions as an input to the calculations that predict the generation for the following year. In the last seven years, the annual budget predictions have had an average variance of 0.86% from actual.

This paper looks at some of the methods that Contact Energy Ltd has used for these predictions in the last 5 years. The intention is to highlight the limitations, benefits and opportunities that each method has as a basis for planning future modeling. It does not consider the reservoir modeling, even though it is critical for input.

2. PREDICTING GENERATION USING THE PAST
2.1 Historical trends

The first approach the author used was to look at the historical data and utilize that to predict the future. In general two major trends were identified. There is both a long term field effect and individual well effects. If these could be identified and predicted, then this gave very good results in the short term.

The field effect could just be extrapolated, while the well effect requires an understanding of the wells. Each well that calcites up is listed and the pattern identified. This can then be used to predict the well effect.

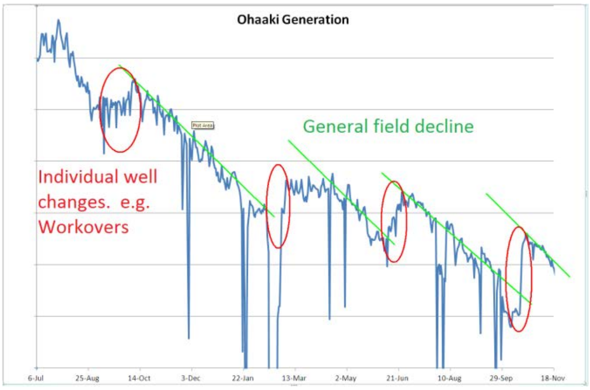

Fig 1 A graph of HP generation at Ohaaki over approximately 18 months.

General field decline is the effect of all the wells declining and in the graph above, four wells are worked over. This restores the output of this specific well but does not affect the average of the entire field.

In the graph above there were three well workovers per year that increased generation. This allows prediction for the following year. So if we continue the general field decline but allow for three well workovers at a time suitable for the rig. We might have a trend like this.

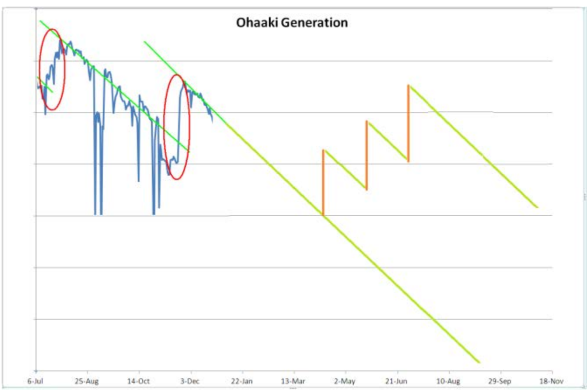

Figure 2 Graph of predicted generation with and without workovers.

This graph predicts the generation after workovers and the workover benefit which can be used for the project justification.

While this prediction method was successful it relied on good predictions of workover returns, and these were made by the reservoir engineer. The reservoir engineer also did an independent prediction and review of these predictions. These reviews often pointed out changes and other information that allowed for more accurate predictions.

2.2 Problems with using the past.

This prediction method failed when large operational changes to the field occurred, for example when a series of new wells are connected. In this instance the new well characteristics can affect the general field trend and the extra steam changes the pressure balance.

A new well might produce steam flow sufficient to increase generation by 3 MW, however the extra steam would cause an increased pressure at the other wells resulting in a decreased production from them. Hence the 3 MW well might only result in a 2 MW generation increase.

There could also be reservoir effects which are beyond the scope of this paper

2.3 A possible improvement

A practical solution to this was to create a surface work model that could use the reservoir data to predict generation. This would also allow for other changes to be tested. At Ohaaki, a separation plant has been decommissioned and this effect could have been modeled to predict the impact.

3. A MS EXCEL MODEL

3.1 Programming options

Ohaaki's design makes modeling easy as it consists of four steam turbine sets supplied with steam from five separation plants. The wells are generally connected individually to the closest separation plant. This makes all the single phase connections consistent. The well changes were therefore on individual two phase lines and did not affect the rest of the program. The result is a much more open choice of programs.

Microsoft Excel was chosen as it did not involve a new skill set and most staff could follow it. The result was a model that could be checked and used by many people. MS Excel is also a contact standard and portability was therefore assured.

3.2 Model Construction

An input sheet was created for well data which was in the standard format used by the Geothermal Resources section. Sang Goo Lee provided the well data and checked the outputs. This sheet also contained the length and size of the two phase pipes together with the number of bends. Another sheet calculated the well mass flows. The pressure drops in the two phase pipes were also calculated on this sheet based on the void fraction, pipe roughness, pipe size and length. The bends were included as an equivalent length of straight pipe.

A separation plant sheet summed the well flows for each separation vessel and averaged the enthalpy. This allowed for the steam, and separated geothermal water flows to be calculated. The separator inlet and steam velocities were calculated to ensure that the separator was within the design limits. The HP separated geothermal water was included as a flow into the IP separator in a similar way to the IP wells. The IP separated geothermal water was then used to calculate how many reinjection pumps were required at each separation plant.

The worksheet also included a low pressure separation to test the potential for a Low Pressure turbine, though this was never used.

The steam lines were included on a separate sheet and pressure drops calculated based on Reynolds number. Heat loss was assumed to result in a 6% steam loss. This was based on experience rather than calculations.

The pressures in the steam field on the east bank of the Waikato have declined so all the wells are IP producers. To minimize losses both the HP and IP steam pipe lines are used to transport the steam to the station. To get the HP steam into the IP turbine it goes through a pressure reducing valve. The pressure drop through the pressure reducing valve was set at a constant based on historic values. This is known to be over-simplistic, but since the volume was small the error is negligible.

The electrical generation at the station is done on its own sheet. Starting with the HP turbine, as it discharges in to the IP turbine, the steam flow is used to calculate both the generation power and the required inlet pressure.

This steam flow in to the HP turbine was reduced by a percentage to account for the condensation in the turbine and removed by the inline separator. The remaining steam was added to the IP steam supply available to the IP turbines. This steam flow gave IP turbine generation and the required IP inlet pressure.

The turbine algorithms were developed by Chris Morris who used the original test data but updated them with more recent data.

The calculations done for the station estimated the turbine inlet details however these estimations now needed to be used to recalculate the wellhead pressures. Using macros and iterations, these were used to recalculate steam flows and pressure drops until the difference between the previously calculated pressure and the new one was less than 0.01 bar.

Additional calculations were done for parasitic load so that the exported generation could be calculated. The reinjection pump load was dependent on the amount of separated geothermal water at each separation plant and the gas extraction system is dependent on steam supply.

A summary sheet was made with a single line diagram. It was on this sheet that individual wells were turned on and off and the turbine availability was set. Flows rates, pressures and generation were displayed. Error checks were also highlighted on this sheet for Wellhead pressure variations, Separation pressure variations and Separation velocities. This sheet allowed for printing and comparisons with different scenarios.

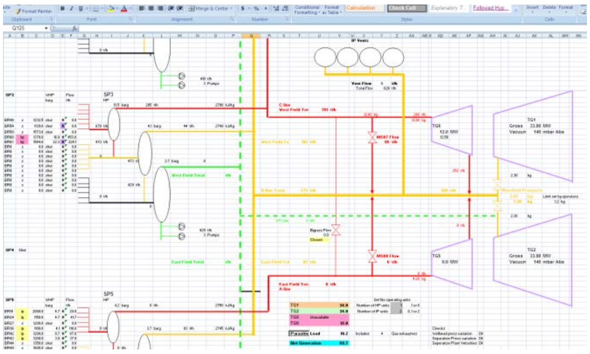

Fig 2 A screen shot of the Ohaaki MS Excel model summary page.

3.3 Model testing

After the model was completed, it was compared to actual plant data and it over predicted plant performance by about 15%. This was assumed to be due to decreased output from wells as some of the well output tests were old. To accommodate this difference a throttle factor was added to the wells and this was tuned to match real data before each use. More recent analysis implies that there are also other factors involved.

This model gave great results for new wells, flash plant outages and abandonments however the longer term predictions were not accurate enough.

3.4 Model benefits

The model accomplished most of what it was intended for. While the accuracy was not as good as was hoped the consistency meant that we could use the magnitude of changes. During the last couple of years, the predictions at Ohaaki have been poor as a plant failure had a large impact on generation, nullifying the prediction for two years.

By far the largest benefit to Contact Energy from this model was the ability to test possible plant modifications. It was noted during the modeling that additional generation could be obtained by restarting one of the mothballed HP turbines. There is a significant cost to surveying and restoring an old unit to service, so the model needed to be reviewed to give sufficient confidence before investment.

3.5 Model comparison

As this was an in-house model with an unknown accuracy, a decision was made to employ a contractor to do an independent analysis. Unfortunately the result was two different predictions and many hours were spent trying to identify the differences between models. This comparison identified issues in both models but did not resolve all differences and we were still left with only one model justifying the return to service of the HP turbine.

The biggest difference noted between the models was the turbine inlet pressure. To maximize efficiency, Ohaaki operates with fully open throttles, with the steamfield performance setting the turbine inlet pressure. The benefit is that a reduction in steam flow results in a pressure reduction at the wellheads allowing more flow. The contractors' model had assumed the more common approach of a fixed inlet pressure. This highlighted the importance of accurately defining the boundary conditions.

3.6 Return on investment.

Management backed the in-house model and the HP turbine was returned to service. This validated the in-house MS Excel model and has resulted in a return of about $4 million to Contact Energy Ltd.

3.7 Other applications

The success of this model also paved the way for an in-house MS Excel model of the heating in the Waikato River.

Wairakei Power Station uses the Waikato River water in the condensers. This heats the river. The consent allows this, as the effect on the river is usually minimal. In summer and at low river flows the heating could affect the wild life and generation is reduced to minimize the impact. In the past, generation has been reduced far more than was required, so a model was needed in order to minimise the generation loss.

A consultant had already been asked to provide a proposal for a detailed model. This proposal required additional weather stations and therefore the cost exceeded the potential generation gain.

An in-house model was therefore attempted only using the variables that were already recorded. Formulae were developed for all the known heat inputs and losses with constants used for all unknowns. The model was then run against historical data. Using an iterative approach the unknown constants were then changed until a good match was found. While this was very time consuming it has resulted in a river heating model that is accurate to within 0.3'C. Better accuracy could be achieved if there was more meteorological data.

4. MODELING WAIRAKEI

4.1 Complexity issues

Having had such a good return from the Ohaaki model, priority was given to developing a model of Wairakei. Significant development was planned for the Te Mihi power station, therefore a good model had the potential to highlight improvements.

Warren Mannington had already written a MS Excel model for Wairakei. This model was initially created by Chris Morris who used the formulas created previously. There have been a number of iterations with Warren's being the latest version.

Warren's model had very good well data and separation information with all fluid stream accounted for. Pipe line pressure drops were calculated and included. Since Wairakei operates at relatively constant pressures, iteration was not required.

This model gave good results and was effective when wells were changed. Having evolved from a simple model rather than being completely planned, only Warren really understood it and changes were hard to make.

The complexity at Wairakei made a MS Excel model very hard to keep up to date so an alternative was sort.

4.2 Aspen Hysis

A number of alternative programs were considered and Aspen's Hysis was settled on, partially because it had been used for a number of overseas Ormat plants.

The Ohaaki experience showed that better predictions would require more integration with the underground reservoir model. Good work had been done on a Tough 2 model so the intention was to take the outputs of that model and use them as inputs to the proposed Wairakei surface works model. This would simplify the interface between the underground reservoir modeling and the surface works modeling.

The Wairakei steamfield is very complex compared to the other steamfields that Contact Energy operates. There were, before the Te Mihi development, an estimated 850 pipe lines, 68 wells, 39 flash plants and 12 turbines. It was therefore decided to outsource the first version of the model. The contractor estimated 370 man hours for model development.

Hysis includes separators, turbines pipes and valves as standard elements making programming easier. These elements however require a lot of detail, for example there is a choice of 9 different pressure loss calculations. For our model the Taitel and Dukler method has been used most of the time. Pipe element calculations include heat loss and so the drainage of condensate from the steam traps also needed to be modeled. One advantage is that the model includes steam tables and could include NCG's if required.

The well data uses a spreadsheet making the transfer of data from the Tough 2 model simple. There are a number of conversions that need to be made for example enthalpy as Hysis uses molar enthalpy.

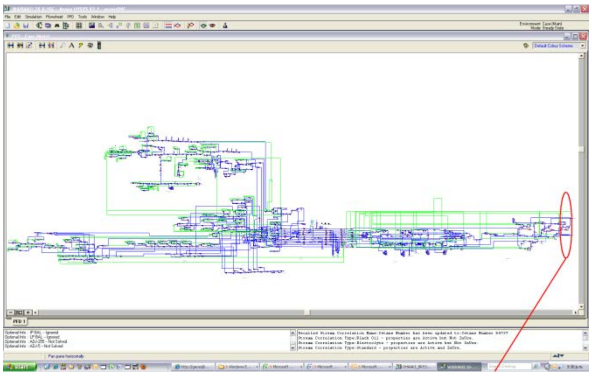

Figure 3 A screen shot of the Wairakei Model. When viewing the entire model like this the elements are not legible even on a 22" monitor. The circled area is shown in more detail in the next figure.

Hysis allowed most of the plant to be modeled straight from the drawings. A small number of elements needed to be adapted. The MP turbines are mixed pressure turbines and so these have been modeled as two individual turbines with their outputs combined. As shown in the figure below.

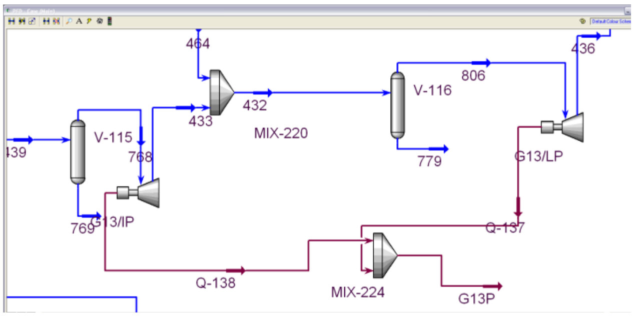

Figure 4 Detail of how the mixed pressure turbine generator set has been modeled.

4.3 Model benefits

The Wairakei model has so far provided little return on investment as it has had little use. The main reason for this has been a lack of manpower when major changes were being undertaken. The model now requires significant work to get it up to date and many opportunities are being missed.

A project has now been proposed to dedicate the resources to update the model.

Despite the lack of use that the Wairakei model has had, Aspen has proved itself with a number of minor projects.

Poihipi was constructed with a single liquid ring vacuum pump and a decision was made to fit a second pump. The design team estimated that a 1 inch balancing line would be large enough but wanted this reviewed.

A simple Hysis model showed that it needed to be at least 3 inches in diameter. Since remedial work would have required a station outage this was a major cost saving.

4.4 Possible improvements

The Wairakei model is detailed and complex making it easy to get in to an endless loop. Unfortunately, it is not always obvious if the model is refining its answer or just looping. It was often found still in a loop, having been left calculating overnight.

With hindsight, it might have been better to simplify the model by assuming that each flash plant was being fed from a generic well. This would have reduced the number of feedback loops speeding up calculations and simplifying the model. The loss in accuracy is not expected to be significant though it would require more work to confirm.

4.5 MS Excel again

Since the Aspen Hysis model was not up to date and budget predictions were needed Christine Siega created another MS Excel model.

This consists of 4 MS Excel files each of which is almost 60MB. The summary file consists of 17 work sheets of which the first one is almost 1600 rows by 100 columns.

Contact Energy has been constructing the Te Mihi station which will use the Wairakei Steamfield. This has resulted in a complex steamfield with design work still progressing during the model creation. In addition to this the planned timing of commissioning activities have changed numerous times. Each change has required significant model rework which has been time consuming.

Pressure drops in the pipe lines have been included only as constant. The accuracy could therefore be improved by calculating these pressure drops.

This model is a great piece of work giving predictions out to 2019. The results appear to be good though as it is relatively new we have not been able to confirm its ability to predict long term generation. Despite this, it has been extensively used and relied on.

5. CONCLUSIONS

The modeling experience has resulted in some learning's that will be used for future work.

1. A good model can result in huge benefits. $4 million from an in-house spreadsheet is a very good investment.
2. Team work: Contact Energy has some great experts and the successful models have all been the result of work by many people.
3. Be careful with the boundary conditions. The biggest gain from the Ohaaki model was from its use of a floating turbine inlet pressure.
4. More accuracy does not necessarily result in better returns. More complex models have resulted in more manpower and therefore not always been used.
5. Consider accuracy and consistency. The Ohaaki model was not accurate however its consistency meant we could rely on its results.
6. The largest return was from using the model to test ideas. This would imply that the best modeler might be an engineer involved with the process rather than a programmer.
7. There is no substitution for real plant experience. Models output numbers and these need to be evaluated against plant experience. Many typing errors have been found because an indicated flow did not "look right."
8. Test the results: All the models described were checked against actual plant data.
9. Mistakes can be beneficial. There were a number of times when errors paved the way to opportunities.

ACKNOWLEDGEMENTS

Chris Morris: Chris provided the Turbine performance data and checked much of my data. His experience and help has been invaluable.

Christine Siega: Christine created the latest Wairakei MS Excel model which is currently being used with good results. It has been good working with her and seeing a different approach to Wairakei modelling.

Sang Goo Lee: Sang Goo provided the Ohaaki well performance data and many hours of checks. He also developed his own predictions which improved the accuracy of the Ohaaki model. I have valued his wisdom and input.

Warren Mannington: Warren has always been willing to help and has had significant input into the modelling projects.

There are many others at Wairakei that have helped with these models. In particularly the Geothermal Resources team at Wairakei.