

**Use of Probabilistic Temperatures in the Calculation of
Transmission Line Ratings using PLS-CADD**

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Purpose

This paper describes the use of probabilistic ambient temperatures coupled with the innovative use of the capabilities of the modelling software PLS-CADD, in calculating the real rating of transmission lines.

Background

Transpower NZ has been researching various ways of augmenting the capacity of its transmission network to meet the growing power demands of New Zealand. One of them is to consider probabilistic ambient temperatures that would exist during each month/time of day and factor those into the calculation methodology, instead of the fixed summer and winter ambient temperatures (30°C and 20°C respectively) currently used.

It was felt that for many parts of the country summer and winter temperatures seldom touch 30°C and 20°C respectively. Even when they do, this happens only for a few hours around noon.

Therefore, if actual (possibly lower) line specific ambient temperatures were used to rate lines instead of the fixed ambient temperatures, additional transmission capacity could be extracted. However historical ambient temperature data was required to ascertain that the actual ambient temperatures are lower than the assumed 30°C summer and 20°C winter temperatures. In addition, a transmission line could pass through varying ambient temperature zones and therefore the highest ambient temperature at any point along that line would dictate the rating for the entire line. For instance, for the line from Bunnythorpe to Rangipo, when the ambient temperature at the Bunnythorpe end is approx 22°C that at Rangipo is about 12-13°C, and therefore, the rating of the entire line is decided by the hotter Bunnythorpe end.

The ground clearances for each span vary depending on the terrain and structure locations. Although lines must maintain the minimum statutory clearance above ground for all spans, in practice the clearances could be much greater. For instance, a span over a gully (with structures located on the top of the slopes on either side) could have a clearance of 25m or more between the lowest conductors and ground. The rating of the entire line at any time would be decided by the “bottleneck” span, which would be the one with the *least clearance* and the *highest ambient temperature* within that period.

The true rating of a line would therefore be correctly calculated only when the **set of the actual ambient temperature and the maximum allowable temperature (to attain the least clearance)** were jointly fed as inputs into the current calculation algorithm.

PLS-CADD, developed by Power Line Systems Inc USA, is an advanced transmission line modelling, design and analysis software. It uses surveyed data (X, Y and Z coordinates) of the ground, structures, conductors and components as inputs to create 3D models of transmission lines, so that the characteristics and mechanical behaviour of the transmission line can be simulated and analysed on a desktop computer. Over the past 2 - 3 years, Transpower has obtained this survey data by using the Airborne Laser Survey technology. The software can therefore calculate and graphically display the actual clearance within a specified envelope for every span at any desired operating temperature/condition. Also, the maximum allowable conductor temperature for each span (before the lowest point infringes

clearance norms) can be obtained as a standard Thermal Rating Report out of PLS-CADD. If this were coupled with the representative ambient temperature for that span, the maximum current that the span could carry before breaching violation criteria would constitute a more **realistic rating**.

Investigation

Obtaining Temperature Data

To get more exact temperature data, NIWA (National Institute of Water and Atmospheric Research) was engaged to supply the 99th and the 95th percentile maximum temperatures for the entire country **for each month** of the year. In addition, NIWA also supplied the 95th and 99th percentile maximum temperature **for every two-hourly period** of the day of every month. Statistically, these temperatures would not be exceeded 99% and 95% of the time respectively, and would approximate to about 28 or 29 days of each month. This data was obtained by analysing collated temperature data from various weather stations within New Zealand for approximately the past 50 - 70 years. Using sophisticated custom coded temperature mapping software, these temperatures were then interpolated, taking due note of the terrain contours, to depict an ambient temperature for every 500 x 500m square block within the country,

These temperatures were depicted on a grid with each grid point defined by its X and Y coordinate. The third parameter Z for each grid point represented the ambient temperature. The data was supplied in the form of text files with the three parameters (X, Y and Z) on each line, for the entire landmass of New Zealand, each text file containing upto approximately 1.25 million lines of data. The size of each electronic data text file was upto 31MB, depending on whether the data was monthly or time-of-day based. Likewise, the 95th percentile temperatures were computed from the 99th percentile for every month and every two-hour period of the day for every month.

Analysis of Pilot Lines

As a part of the investigation, it was decided to analyse 6 pilot transmission lines (5 in the North Island and 1 in the South Island) for their current ratings during each month, using the probabilistic ambient temperature under each span of these lines. It was therefore necessary to extract the precise representative ambient temperature for each span on the lines for every month, from the NIWA temperature data text files. These temperatures could then be used to calculate current ratings for each span using the standard current calculation method.

Data Extraction and Analysis using PLS-CADD

The volume of NIWA temperature data to be searched to locate the specific temperature for each span of the pilot lines was significant. It would have been practically impossible to manually open each text file and locate the precise temperature to match the coordinates of every structure/span. Even with a fairly fast computer, a 31MB file would take a long time to open and even longer to scroll through. Therefore, as a solution, it was decided to use PLS-CADD in an innovative manner.

The NIWA text files were imported into PLS-CADD, similar to any other survey data. The Z coordinates, which actually represented temperature, were treated as any other elevation

points in survey data. If straight lines were drawn connecting each of the X, Y and Z coordinates, the surface would appear as a collection of triangles, creating a Triangulated Irregular Network (TIN). Thus the NIWA data X, Y and Z coordinate points supplanted the usual ground survey data, forming a fictitious “temperature” terrain.

The coordinates of the structures for each pilot line were then imported into PLS-CADD and superimposed on this “temperature” terrain. The structures were designated as stick figures and **were assigned a fictitious height of zero metres**. A single dummy conductor was then **strung ‘along the ground’** over the structure points (PI points), so that it ran all the way along the line alignment. Thus, a ‘single phase *ghost* line’ was created. Using PLS-CADD features, the NIWA data was then trimmed to eliminate all extraneous temperature points outside a corridor of 1000m on either side of the line. The ‘clearance to violation’ envelope in PLS-CADD was set to 1500m vertical and 1000m horizontal, so that all temperature points (on the “temperature” terrain) within this envelope would be precipitated as violations. The vertical limit of 1500m was decided based on the elevation above mean sea level of the highest structures in NZ. These violating points could then be reported using the PLS-CADD “Terrain Clearance to Survey Point” or the “Danger Tree Locator” reports.

Figures 1, 2 and 3 show the temperature data, after importing into PLS-CADD, with a sample transmission line superimposed on it.

A standard PLS-CADD ‘Terrain Clearance to Survey Point’ report, as shown in Table 1, was run to display the clearance of the dummy conductor to each violating point (X, Y, Z) coordinate. The ‘elevation’ column in the report, between structures (named Tower Base Points), was therefore the temperature within the spans. The ‘Offset’ column in the report was the proximity of the temperature point to the conductor.

A separate software program in Visual Basic was custom coded to access this PLS-CADD generated report file. This software selectively detected the temperature point closest to the mid-span location, creating a filtered data set. This ‘filtered’ data file was then exported to another database, and would become one of the inputs for the current rating calculation. Where, two or more temperature data points were found to be in close proximity to the conductor, the temperature for the span was decided by interpolation.

Similarly, by designating the Z coordinate as a “danger tree” in PLS-CADD, and using the danger tree locator feature of PLS-CADD, the violating temperature point could also be read.

The Visual Basic software also accessed the saved Thermal Rating report and picked up the maximum permissible temperature for every span after which it goes into violation. The value of the maximum temperature was extracted to the same database as the ambient temperatures and became the second of the two inputs for the current rating calculation. A separate software engine custom coded in Visual Basic named “Current Rating” was created to use the extracted maximum and ambient temperatures in the database. This engine produced a rating profile for every span along the line, which was exported to Microsoft Excel and charted as shown in Table 2 and Figure 4. The “bottleneck” span could then be easily identified. **The span showing the least current rating would dictate the rating for the entire length of the line.** Note that the seat of the “bottleneck” may shift from month to month because of variation in ambient temperatures. This rating would be more realistic than that calculated by the present deterministic method.

Figures 4 and 5 show the current rating and MVA rating profiles for a sample line consisting of 25 spans. It can be seen that the use of span specific probabilistic ambient temperatures and maximum allowable temperatures gives better results than the existing method. For the particular month analysed in Figures 4 and 5, an average rating increase of approximately 7% is possible by using the probabilistic ambient temperatures alone. This may vary according to the months, and the zones in which lines are located. It is also clear that if the “bottleneck” spans shown by the profiles are upgraded, the entire length of line could be upgraded to carry more power.

Summary

PLS-CADD was thus effectively used as a platform to merge temperature and structure data. It was therefore possible to extract the 99th or the 95th percentile maximum ambient temperature for any month/time of day for any line and any span in the country by sequentially importing NIWA temperature text files into PLS-CADD. The custom-coded Visual Basic software was then able to extract the representative temperature for every month and the maximum allowable temperature for each span on the line from relevant PLS-CADD reports. Also, by moving the cursor on the “temperature” terrain in PLS-CADD, the ambient temperature for any month could now be directly read.

It is possible that the ambient temperatures in relevant winter or summer months are greater than 20°C or 30°C respectively, for certain areas in New Zealand. For instance, in 1970, a high of approximately 38°C was recorded on the Canterbury plains. However, a rapid drop to 16°C followed in just three hours, due to a cool southerly change. In such cases the calculated ratings could be lower than the existing ratings. However such instances are few and the overall increase over the year would outweigh the shortfall. For the analysed pilot lines, a consistent benefit could be seen for a significantly large part of the year.

Conclusions

1. Calculating line ratings with probabilistic ambient and actual maximum allowable temperatures, instead of assumed fixed ambient and maximum temperatures has the following advantages:
 - (a) The most critical ‘bottleneck’ spans could be pinpointed for rectification/uprating, thus optimising on costs;
 - (b) The post-contingency overload rating duration could be significantly higher, thus improving security; and,
 - (c) Latent pockets of capacity during the year or the time of the day could be selectively exploited.
2. It is possible that the ambient temperatures for certain areas and months/times of day could be greater than the currently used bi-annual temperatures. However, such instances are few and an overall gain in ratings could be achieved over the year.

Tools and Time Frame

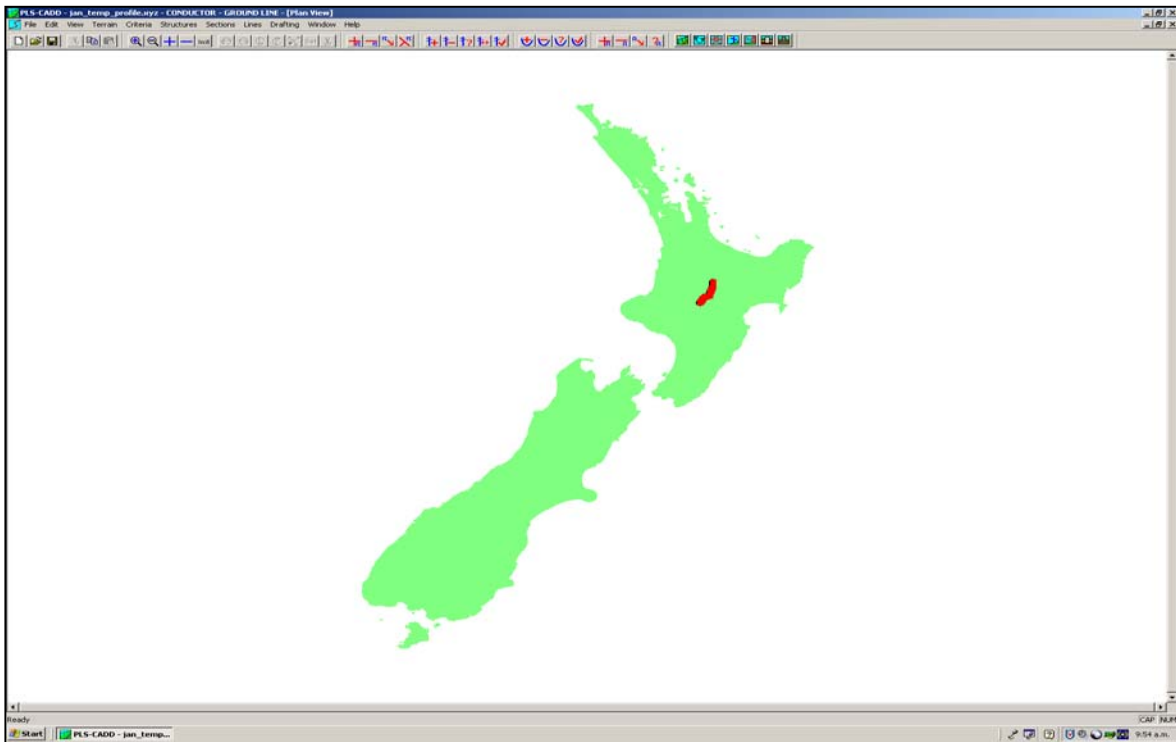
It is envisaged that significant development would be required on the current market tools, system operator tools, SCADA and other systems before the temperature data could be practically used. Extensive databases would need to be built, and reliable and robust data

transaction/interaction tools would need to be set up to work in real time. At this stage, approximately 3 to 5 years is envisaged as a time frame for implementation if the process is found suitable from all standpoints.

Temperature Data for NZ for one month with the structure coordinates superimposed.

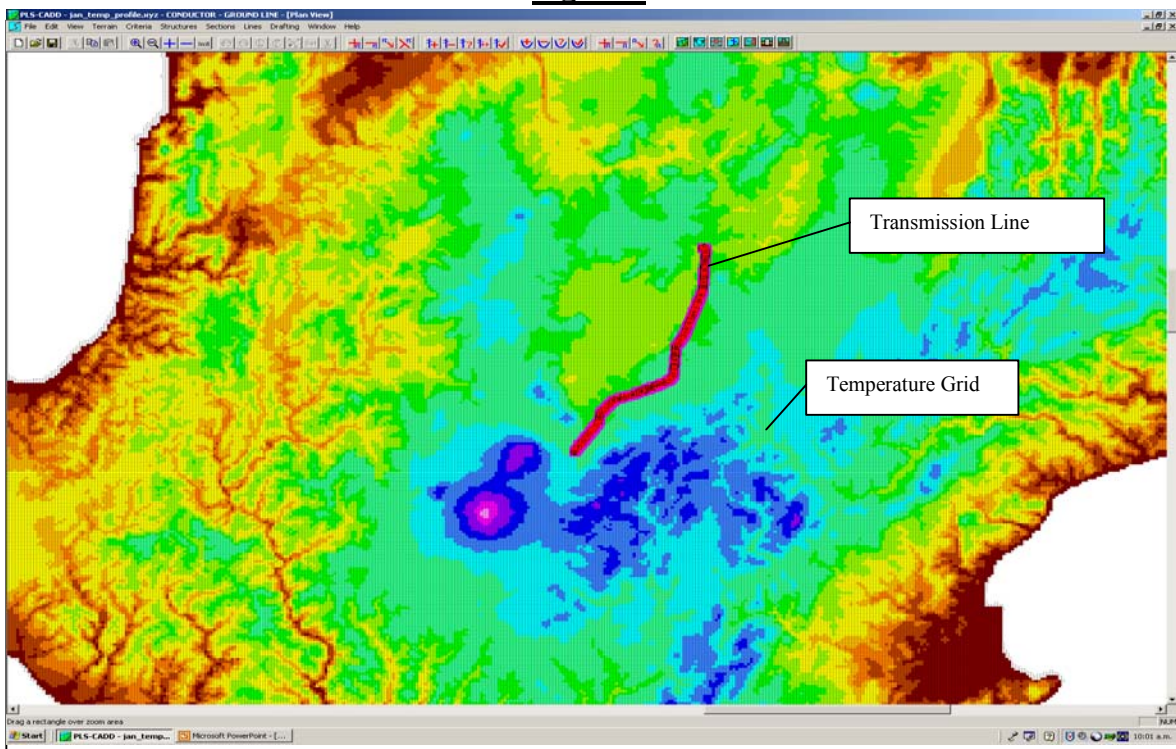
Note: The NZ map is made up entirely of temperature grid points and does not have an outline

Figure 1



**Zoomed-in view of the 500m temperature grid with a transmission line superimposed
(Temperature zones colour coded)**

Figure 2



Zoomed-in view of the transmission line, the temperature grid and the ‘closest distance’ markers to the conductor

Figure 3

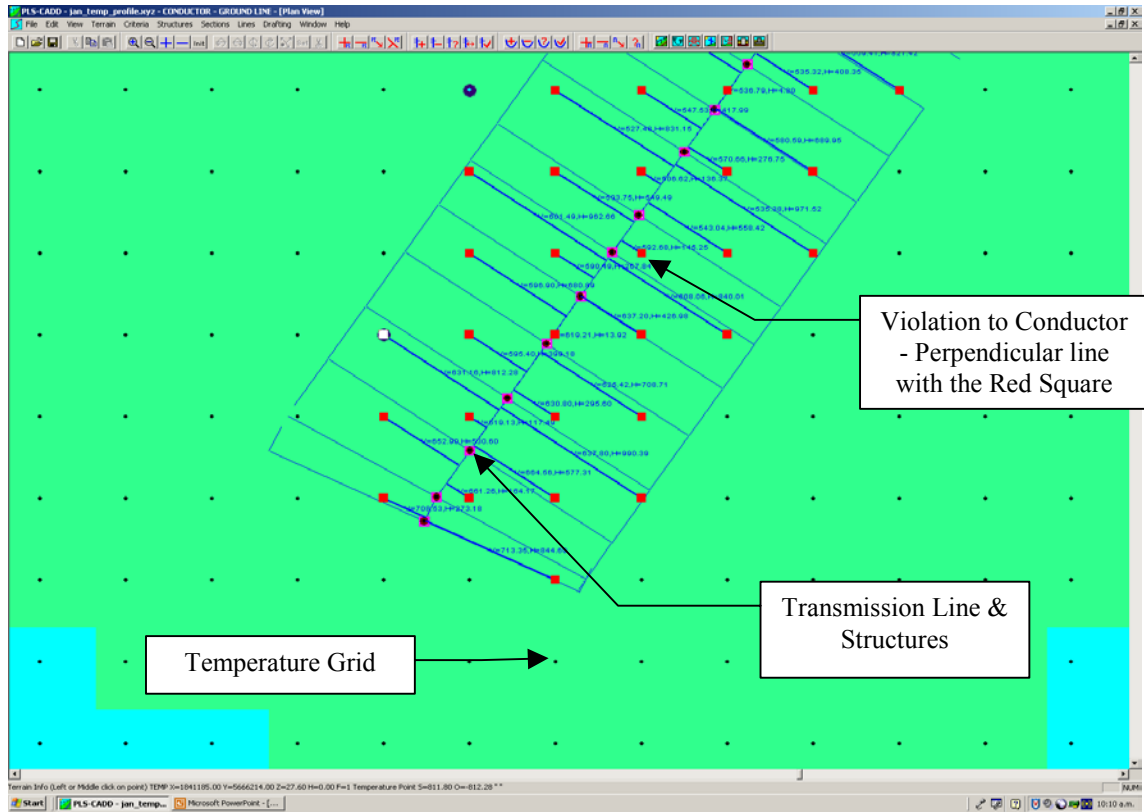


Table 1

A sample PLS-CADD generated ‘Terrain Clearance to Survey Point’ report

Note: The numbers highlighted in yellow indicate temperatures displayed as ‘elevation’; numbers highlighted in green indicate the closest temperature point distances to the conductor within the span

Point ID	Feature Description	Station	Offset	Elevation	Height	Ok
		(m)	(m)	(m)	(m)	
1	Tower Base Point	0	0	67	0	NG
2	Tower Base Point	75.17	0	69	0	NG
	Temperature Points	171.67	75.94	17.2	0	NG
3	Tower Base Point	271.64	0	65	0	NG
	Temperature Points	342.39	744.82	17.2	0	NG
	Temperature Points	413.62	-370.94	17.2	0	NG
	Temperature Points	594.03	312.76	17.2	0	NG
	Temperature Points	665.27	-803	17.2	0	NG
4	Tower Base Point	714.32	0.93	74	0	NG
	Temperature Points	774.45	996.46	17.1	0	NG
	Temperature Points	845.68	-119.3	17.2	0	NG
5	Tower Base Point	1008.94	-2.22	84	0	NG
	Temperature Points	1026.09	564.41	17.1	0	NG
	Temperature Points	1097.33	-551.36	17.2	0	NG
	Temperature Points	1277.74	132.35	17.1	0	NG
	Temperature Points	1348.97	-983.41	17.2	0	NG
6	Tower Base Point	1382.02	0.98	87	0	NG
	Temperature Points	1458.15	816.05	17.1	0	NG
	Temperature Points	1529.38	-299.71	17.1	0	NG
	Temperature Points	1709.8	383.99	17.1	0	NG
	Temperature Points	1781.03	-731.77	17.1	0	NG
7	Tower Base Point	1803.76	0.13	97	0	NG
	Temperature Points	1961.44	-48.06	17.1	0	NG
8	Tower Base Point	2113.36	1.07	102	0	NG
	Temperature Points	2141.85	635.64	17	0	NG
	Temperature Points	2213.09	-480.12	17.1	0	NG
9	Tower Base Point	2367.38	2.05	104	0	NG
	Temperature Points	2393.5	203.58	17	0	NG
	Temperature Points	2464.74	-912.18	17.1	0	NG
	Temperature Points	2573.91	887.29	16.9	0	NG
	Temperature Points	2645.15	-228.47	17	0	NG
10	Tower Base Point	2764.57	-0.37	108	0	NG
	Temperature Points	2825.56	455.23	16.9	0	NG
	Temperature Points	2896.79	-660.53	17	0	NG
11	Tower Base Point	2959.93	0	112	0	NG
	Temperature Points	3041.05	87.81	17	0	NG

Table 2

The Output of the VB Program “Current Rating”

Current rating profile for 25 spans of a sample line

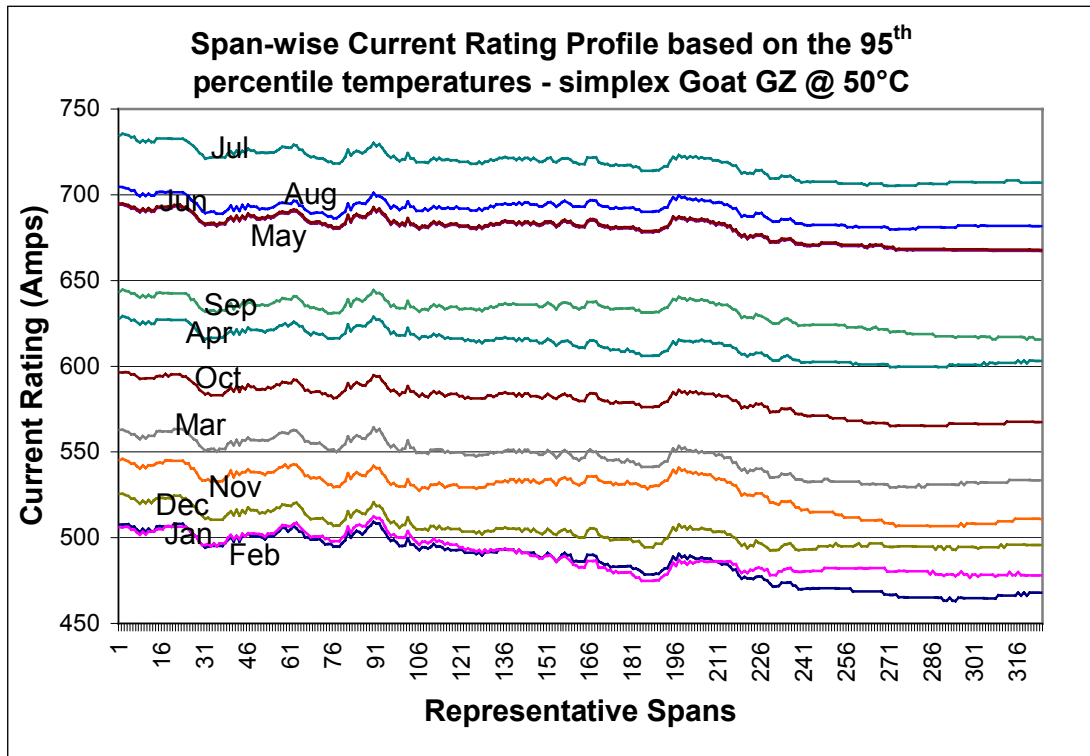
Case: Varied Ambient, Varied Maximum Temperature

Conductor	Wind Speed	Wind Angle	Emiss	Absorb	Max Temp.	Cond Dirn	Sun Time	Latitude
GoatAC	0.61	90	0.5	0.5	-	E - W	11	39°

Span	Time	T-amb	Max Temp for span	Q-convect	Q-radiative	Q-solar	Res Loss	Current Rating	Elevation
1	hr:min	°C	°C	W/m	W/m	W/m	W/m	Amps	m
2	11	14	75	79.92	18.24	13.41	84.75	915.87	250
3	11	14.2	78	83.65	19.38	13.34	89.7	937.57	200
4	11	14.6	85	92.35	22.18	13.27	101.27	985.02	150
5	11	14.2	76	81.04	18.59	13.34	86.29	922.61	200
6	11	14.5	90	99.02	24.37	13.27	110.12	1019.08	150
7	11	14	85	92.97	22.32	13.41	101.87	987.97	250
8	11	14.4	100	112.21	29.01	13.27	127.95	1081.61	150
9	11	14.5	85	92.53	22.21	13.23	101.5	986.15	125
10	11	14.6	90	99.02	24.35	13.16	110.22	1019.51	75
11	11	14.2	77	82.35	18.99	13.34	87.99	930.14	200
12	11	14.5	78	83.45	19.32	13.16	89.61	937.11	75
13	11	14	82	89.14	21.06	13.34	96.86	967.97	200
14	11	14.4	86	93.92	22.65	13.27	103.31	993.31	150
15	11	14.5	95	105.6	26.64	13.23	119	1051.13	125
16	11	14.6	102	114.71	29.94	13.16	131.49	1093.15	75
17	11	14.2	84	91.57	21.85	13.27	100.15	981.15	150
18	11	14.5	79	84.76	19.72	13.16	91.32	944.48	75
19	11	14	87	95.76	23.17	13.27	105.66	1002.95	150
20	11	14.4	92	101.76	25.29	13.27	113.78	1032.63	150
21	11	14.6	85	92.44	22.18	13.2	101.43	985.78	100
22	11	14.6	87	95.05	23.04	13.2	104.9	999.33	100
23	11	14.2	78	83.73	19.38	13.27	89.85	938.35	150
24	11	14.5	86	93.83	22.63	13.23	103.23	992.95	125
25	11	14	95	106.16	26.74	13.3	119.6	1053.77	175
26	11	14.2	100	112.47	29.06	13.27	128.26	1082.91	150

Figure 4

Charted Output of "Current Rating"



Current rating profile of 25 sample spans shows the possible increase

Figure 5

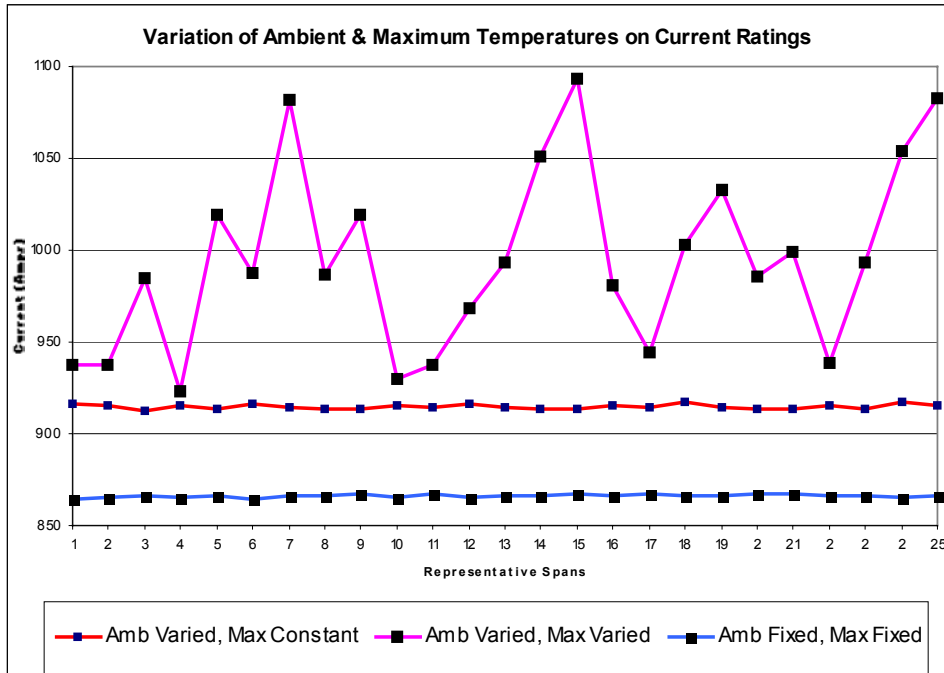
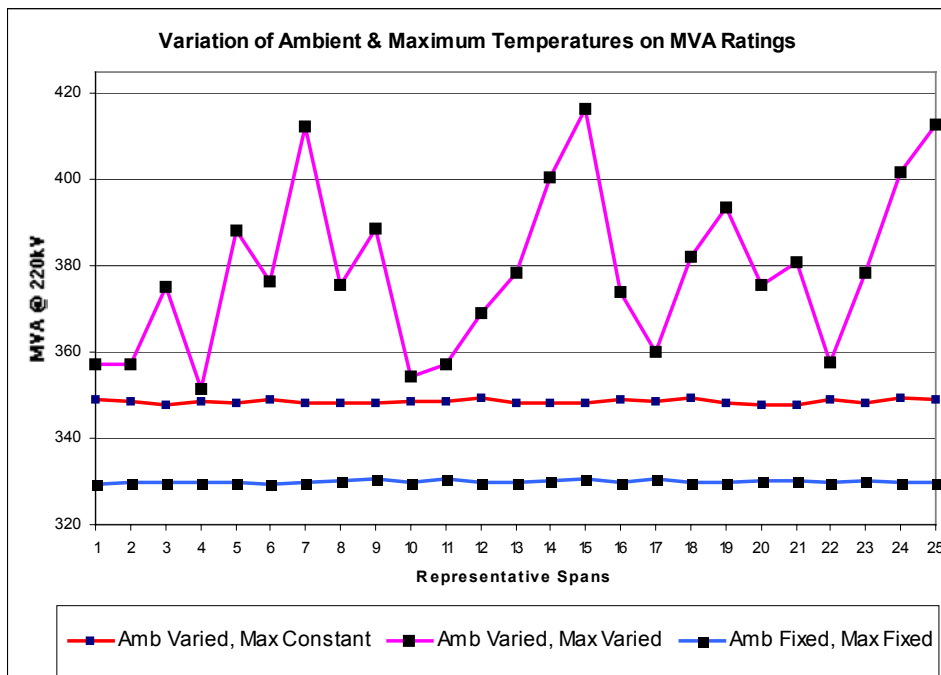


Figure 6



Milind Khot - Biographical Profile

Milind is currently a Senior Development Engineer at Transpower NZ in Wellington.

Milind is an Electrical Engineer with 25 years of experience in engineering of rotating machines, design of transmission lines, electrical consulting, software engineering and Total Quality. He is an electrical engineer from the University of Pune India, a Member of the Institution of Engineers, a Chartered Engineer and a Microsoft Certified Software Developer (MCSD).

He started his career with Crompton Greaves India, manufacturing HT motors and generators, later became the Manufacturing Manager and the Corporate Improvement manager. After 17 years with Crompton Greaves, Milind started 'Electromech' a consulting firm, and designed two of Asia's largest lift irrigation schemes. He then started the software firm 'Electrologic Solutions', and developed 11 electrical software products.

Milind is also a recognised expert on Total Quality, the ex-Secretary General of the National HRD Network India, a member of the Indian Society for Applied Behavioural Sciences and a professor of Total Quality, Organisational Behaviour and Organisational Development.