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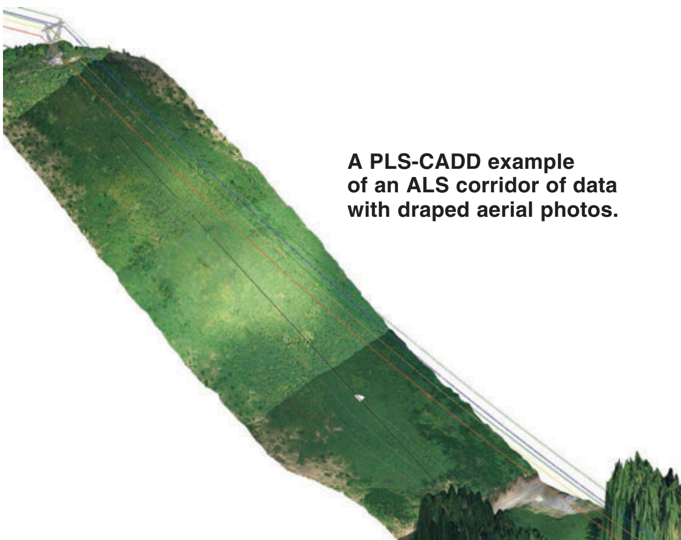
Design Tool Reduces Line-Uprating Costs

Careful analysis enables Transpower New Zealand to more accurately locate potential clearance violations and minimize rectification works.

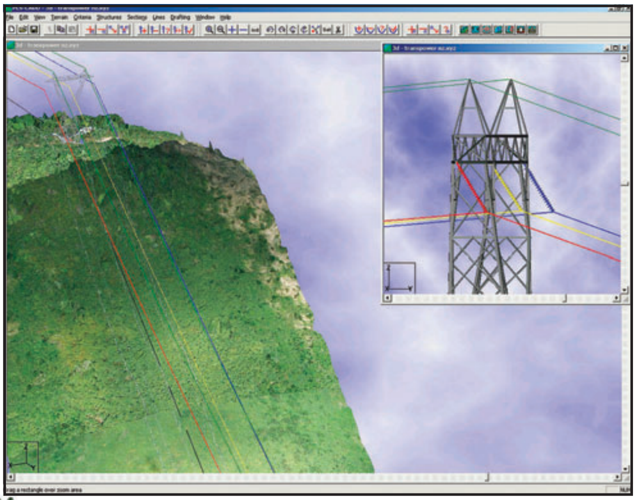
By Trevor E. Jacobs, formerly of Transpower New Zealand Ltd., and Robert Lake, Meritec Ltd.

The Network Group of Transpower New Zealand Ltd. (TPNZ; Wellington, New Zealand) conducted an investigation to find a cost-effective way to partially relieve a transmission line thermal rating constraint on part of its central North Island core grid. It explored the benefits derived from the newly developed finite element (FE) capability within PLS-CADD, overhead line design and analysis engineering software developed by Power Line Systems Inc. (Madison, Wisconsin, U.S.).

Adopting the results obtained from the FE analysis enabled TPNZ to increase the maximum operational thermal limit from 50°C to 60°C (122°F to 140°F), resulting in a 20% capacity increase. This analysis provided a real-dollar savings over those predicted using the ruling span (RS) analysis with 15 fewer clearance violations. The use of FE analysis resulted in an overall project implementation cost saving of about 34%, or about NZ$200,000. Apart from this cost saving, the FE analysis also generated a high degree of



A PLS-CADD example of an ALS corridor of data with draped aerial photos.



Longitudinal movement can occur by the mere swinging of a suspension insulator as well as deflection of the structures.

confidence that the derived clearance violations at the higher thermal limit were legitimate. The reduced rectification work also minimized the circuit outage time necessary to implement the uprating work. This latter benefit could have considerable impact potential on the electricity wholesale market in New Zealand, where spot prices may be significantly influenced by the unavailability of core grid circuits.

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Background

To protect the population from energized lines, most national safety codes specify the minimum conductor clearance of lines from ground, roads, railway tracks and other lines under the most critical loading combinations, including temperature, wind and ice.

Using the RS design method, the traditional approach delivers acceptable results. This method assumes the insulator strings are infinitely long and do not attract any horizontal load component due to longitudinal movement of the suspension clamp, and they remain vertical under all loading conditions. This approach provides reasonable results with small errors where the line traverses flat terrain with spans of relatively equal length. However, as this is not always the case, it is common to allow for some safety margin on the sag, typically ±0.5 m [±1.6 ft] when designing new lines, to offset the impact of these variances, as well as those resulting from possible survey and sagging errors, and conductor creep assumptions. While the traditional buffer may have been satisfactory for the operating temperatures of the line expected when constructed, it may not be sufficient for the operating temperatures to which in-service transmission line conductors may now be subjected.

Practically, longitudinal movement occurs between spans of different lengths as the operating temperatures fluctuate and the corresponding differential expansion lengths balance out. This longitudinal movement can occur by the mere swinging of a suspension insulator as well as small deflections of the structures themselves. The extent of these longitudinal movements varies greatly with respect to the relationship of shorter spans and longer spans, and how they are sequenced in the line. However, generally the FE approach results in longer spans having less sag (more ground clearance), while shorter spans have more sag (less ground clearance) than those calculated using the traditional RS method.

Ground clearance violations typically occur on longer spans. By accounting for the actual movements of the conductors and insulators as the operating temperatures increase, substantial savings can be realized if FE analysis negates the need for modifications where the RS method indicated that there would have been clearance violations. Conversely, there may be ground clearance problems on shorter spans, which over highways or other clearance sensitive elevated areas are most critical for maintaining proper safety clearances, where the RS method indicated that no problems exist.

Those who measure the actual sags in the three of four spans of a strain section and then try to fit a ruling span profile to that section observe this phenomenon frequently. When a catenary curve fit is found for one measured point, the other measured sag points usually cannot be matched; it is then the engineer's decision, usually following a few trials, to select the best curve fit approximation. This is also observed easily with data collected from aerial laser surveys, complete with conductor positions along the spans and insulator swings.

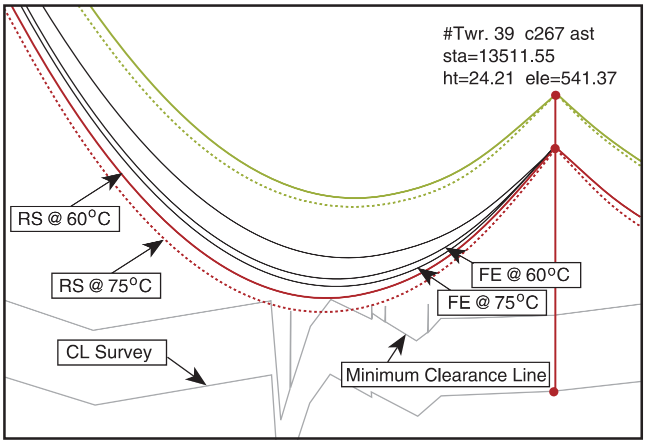
With the advent of high-speed computers and easy-to-use line design and analysis software, it now has become practical and cost effective to analyze transmission lines using more sophisticated techniques, such as FE. This takes into account the conductor sag resulting from all longitudinal suspension clamp movements, since insulator strings have a finite length and operate at temperatures other than that at the time of construction. This longitudinal movement and resulting sag change, which varies with changes in line loading, is particularly noticeable on lines in hilly to mountainous terrain as found in New Zealand, and needs to be taken into account.

FE analysis is enhanced if conductor sag and insulator swing anomalies can be modeled using data established by accurate survey, such as aerial laser survey, where the effect of conductor creep and sagging/construction errors are effectively captured. The impact of sagging/construction was found to be noticeable in New Zealand following the completion of an aerial laser survey (ALS) project where approximately 80% of the core grid has now been surveyed.

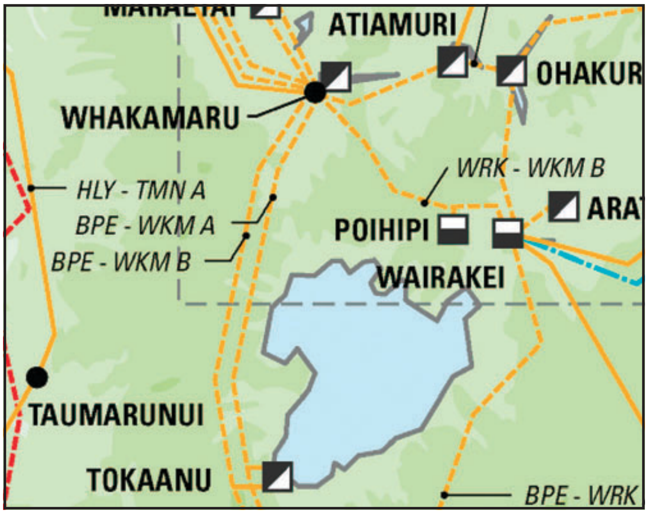
Long tension sections strung using a series of artificial snub or termination points over several successive days also can cause sag errors. Accumulated sag discrepancies may result from sagging errors and conductor loading variances, especially with ambient air temperature variations on the successive days. Discrepancies of up to 1.5 m [4.9 ft] have been recorded on very long tension sections (±30 km [±18.6 miles]) based on a review of the ALS data. Coincidentally, this is three times higher than the traditionally

Typical Comparison of Identified Clearance Violations for One of the Circuits

Span Ahead	Tower	Ground Violation for 60°C meter (feet)		LV Crossing Violation for 60°C meter (feet)	
At Tower	Type	RS	FE	RS	FE
3	Standard Suspension	Nil	Nil	Nil	0.7 (2.3)
10	Standard Suspension	1.0 (3.3)	Nil	Nil	Nil
11	Standard Suspension	0.5 (1.6)	Nil	Nil	Nil
17	Standard Suspension	Nil	Nil	1.0 (3.3)	0.8 (2.6)
38	Angle Suspension	0.6 (2.0)	Nil	Nil	Nil
57	Angle Suspension	0.8 (2.6)	Nil	Nil	Nil
58	Angle Suspension	1.8 (5.9)	Nil	Nil	Nil
64	Heavy Suspension	0.1 (0.3)	Nil	Nil	Nil



Difference in sags obtained between FE and RS for 60°C and 75°C operation.



WRK-WKM A & B and BPE-WKM A & B lines.

assumed conservative 0.5-m [1.6-ft] buffer.

As transmission lines are costly to replace or re-conductor with high-capacity modern conductors, a cost-effective capacity increase solution remains a "quick fix" thermal uprating. Where conductors have been in service for a long time, and conductor clearances are established by accounting for full mechanical and material creep, accurate modeling and sag determination becomes paramount.

Using FE over RS analysis in PLS-CADD is beneficial for deriving accurate conductor placement under varied loading conditions, thus ensuring safe statutory clearance management and compliance. It also has led to building confidence with the line maintenance personnel in terms of accurate work scope outcomes.

Ground Violation Differences.

The transmission lines investigated in this project for increasing the maximum thermal operating limit (originally 50°C), were analyzed for 60°C operation, thus effecting partial constraint relief. However, clearance remedial work was performed to achieve future operation at 75°C (167°F) to minimize future cost and circuit outage time, as a thermal limit of 75°C is likely to be considered in the future.

The difference in sags obtained from the FE and RS analysis methods are illustrated by the span (in the figure), where the extent of sag is shown for operation at 60°C and 75°C for both methods of analysis. No remedial action was required for the sag resulting from the FE analysis for operation at 75°C. Consequently, this resulted in a cost saving compared to the RS output that otherwise identified a clearance violation that required attention. On other spans the converse may be true, where the violation extent may increase or appear; however, for this particular line, an overall reduction in violations was realized.

The Project

TPNZ's overall project covered the survey, clearance review and thermal uprating of four transmission lines in the central North Island section of the transmission system.

Two of the transmission lines, BPE-WKM A and B, each approximately 70 km (43 miles) in length, are parallel to each other simplifying the uprating construction access, while the other two lines, WRK-WKM A and B approximately 56 and 40 km (35 and 25 miles) in length, respectively, are on different alignments. The lines are all single-circuit construction, using horizontal or flat-topped configuration steel towers. Three of the lines have Goat ACSR/GZ, while the third has Zebra ACSR/GZ conductor.

The traditional survey work included centerline, offset ground-based surveys and isolated point surveys for individual spans, where existing survey data was available. The clearance issues dealt with included under-crossing lines and ground violations. Any identified vegetation clearance issues were managed through the normal maintenance processes. As the conductor was not being changed or re-tensioned, existing swing clearances were not influential; therefore, only the vertical and relatively small lateral offset clearances were corrected.

Options considered to increase clearances include:

- Relocation or modification of under-crossing lines
- Earthworks where practical and minor in extent
- Removal of standard phase to structure clearance enhancing components, such as hanger brackets, where not required for specific structures
- Insulation replacement with composite and shorter insulators
- Removal of existing conductor from selected spans
- Shifting of conductor from critical spans to other spans and re-clamping
- Conversion from I-string to V-string insulators
- Conversion from suspension to a floating-strain assembly
- Tower raising or relocation onto new foundations with or without longer leg extensions
- Insertion of additional structures.

In one case, time restrictions required the construction of a temporary tower to relieve the constraint over the critical summer period. The following winter an existing tower was relocated onto new higher foundations.

Converting I-Strings to "Floating" Strains

This solution involves replacing the suspension assembly, with a relatively short suspended steel strap, that in turn supports a "special" yoke plate, connecting the two strain assemblies. Increasing the conductor height by some 2 m [6.6 ft] was possible with this method, and it provided the most significant improvement in conductor clearance relief.

The "special" yoke plate, connecting the two strain assemblies.

The strap must be long enough to limit any differential longitudinal loading of the suspension tower to within the structure's performance capacity, which the PLS-CADD software analyzes.

PLS-CADD Enhancements

Since the completion of this project, Power Line Systems has further improved the FE capabilities of PLS-CADD. The most significant improvement is automatic regression fitting of the conductors, insulators and structures to accurately model the line for true as-built conditions. Again, using the FE capabilities in PLS-CADD, the true effects of marker balls, spacers and spacer dampers can be taken into account and accurately calculated. Differential icing within individual spans also can be investigated, as well as any other point loads such as conductor trolleys. Sections of wire can be removed or even shifted to other spans, with the appropriate sags, structure loads and a detailed FE structure analysis (using the companion TOWER program by Power Line Systems), performed all in one operation.

Proven Results

This project has shown that it is technically and economically feasible to routinely investigate the behavior of transmission line models employing the FE method, allowing more accurate conductor behavior modeling, and therefore clearance checks, to minimize any rectification work required for either the review of existing lines or, in particular, the uprating of lines.

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FE over RS modeling has proven its use for transmission line investigation within the Transpower New Zealand Ltd. network and will be used for all future uprating investigations. With the recently obtained aerial laser survey data, Transpower is now confidently analyzing the subject lines for possible further uprating from 60°C to 90°C.

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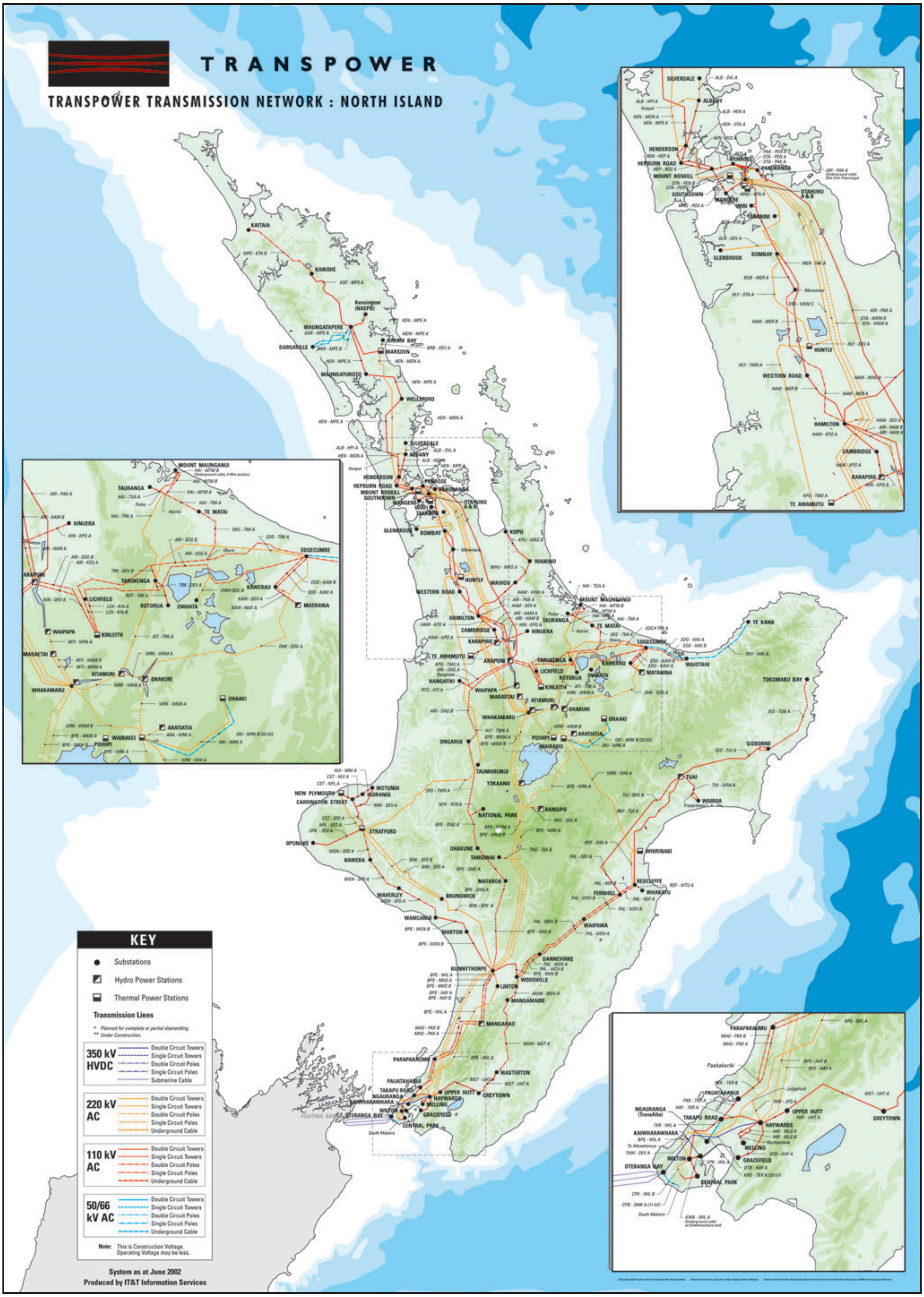
Robert Lake holds BECE and MSCE degrees, and is the technical manager of transmission lines with Meritec Ltd., a multidiscipline consulting firm (an AECOM company). He is responsible for transmission line projects and related structure/foundation design/analysis for the company.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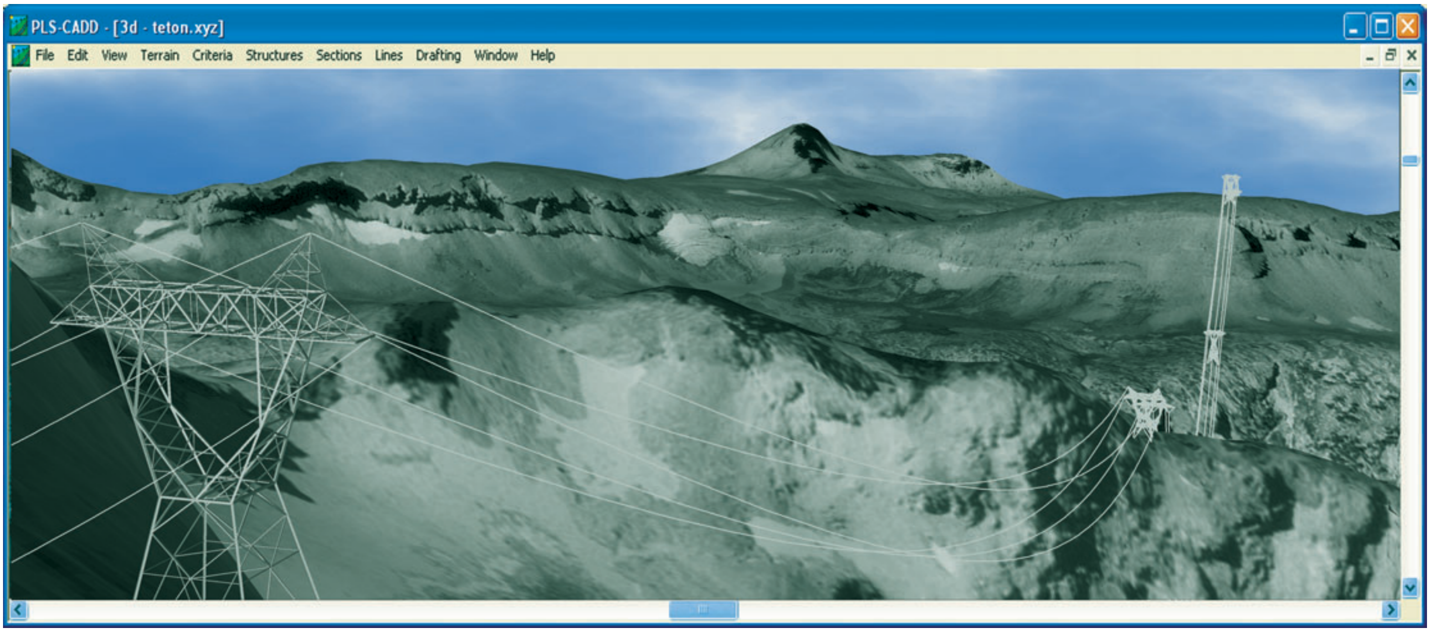

Do you own transmission lines?

Do you ***know*** what your line ratings are? Do you really ***know***? Do you ***know*** how to increase them? Do you ***know*** how much it will cost? Do you ***know*** what the best tools for the job are?

PLS-CADD is used in more than sixty countries by utilities, consultants, fabricators, and contractors. Twenty-one of the twenty-five largest transmission owners in the United States use **PLS-CADD**. Our ability to quickly produce answers has made Power Line Systems the industry standard for overhead line design and analysis.

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