Measurement of electricity distribution overhead wire tension

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Introduction

Conductor tension is a fundamental parameter for overhead line design calculations. However in practice installed line tension is difficult and expensive to measure. For this reason it is very common for distribution line designers to base their calculations on assumed tensions, which can be significantly different from actual installed tension.

This paper introduces a novel method for accurately measuring overhead line tension, which has substantial advantages over established techniques. The method employs a laser range finder device and a consumer grade tablet device running a purpose-built software application.

The paper will review those elements of line design for which line tension is a necessary input and discuss the significance of accurate information. It will summarise the tension measurement methods currently used in New Zealand, identifying strengths and weaknesses. The paper will then describe the new tension measurement technology and discuss its potential applications.

Why tension is important

Conductor tension is arguably the most fundamental and important parameter for the design of overhead lines. Discrepancy between installed line tensions and the tension used for calculation leads to errors which touch on almost every facet of line design, including:

- Support design - longitudinal, transverse and vertical loads on poles, stay and footing loads
- Conductor and fittings mechanical design – design for fatigue endurance and strength under extreme loading events
- Electrical design – phase to phase and circuit to circuit internal clearances, ground clearances and blow-out clearances to buildings, trees and easement boundaries
- Maintenance and construction design – for hazard identification and the specification of appropriate methods and equipment

For many aspects of line design the tension correlates directly with utilisation or efficacy. In some instances, such as in short spans or at section structures, designs can be even more sensitive to the conductor tension.

A prudent designer will allow an appropriate tolerance for variation in conductor tension. If the designer does not have a basis from which to establish a probable range of conductor tensions, the design tension adopted is inevitably a compromise between reducing risk and avoiding overly conservative design. A paucity of conductor tension information affects the ability of the designer to deliver reliable and economic designs.

Established tension measurement methods

Designers have a wide range of methods at their disposal with which to establish conductor tensions. However all of them have significant disadvantages which variously include:

- High cost
- Long lead times

- Associated hazards
- Poor accuracy
- Requirements for special equipment or training
- Limits to application

Table 1 describes the various tension measurement methods that are currently used in the distribution industry and lists some key pros and cons for each method.

Judged on evidence of current practice from a survey of 10 New Zealand distribution utilities the available techniques are, arguably, not practical for general use in the distribution industry. Figure 1 shows that 30% of utilities do not perform tension measurements during construction. Most utilities reported that they do not perform tension measurements during the construction of smaller lines.

In the absence of tension measurement during the construction process it cannot be established whether the installed tensions accord with those specified in the design. This undermines the legitimacy of the line design.

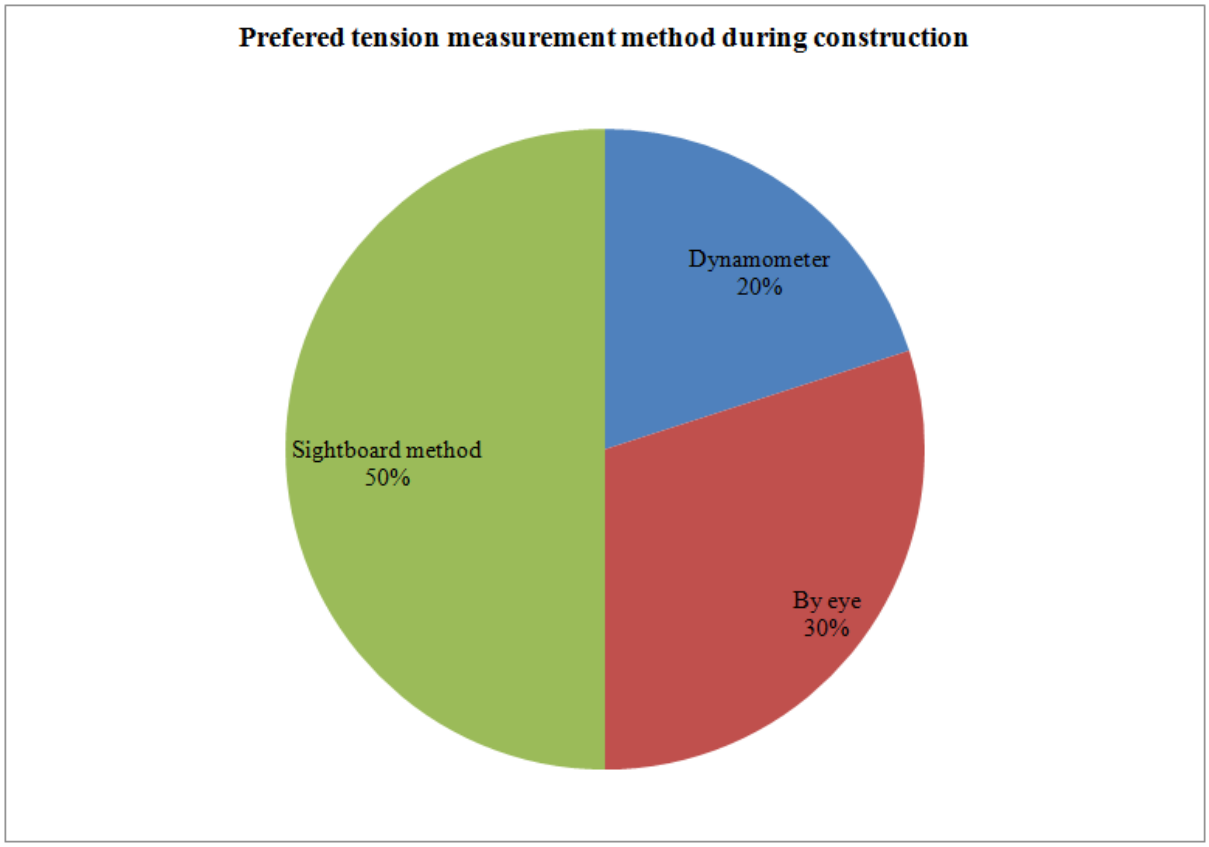

Figure 1: Most common method use to assess tension during construction

Table 1: Established tension measurement methods

Method	Description	Pros	Cons
Dynamometer	Directly measures axial tension. Can be measured directly as the conductor is being run out or parallel to the conductor before termination	• Direct measurement	• High cost • Hazards - Working at height, working in line environment, mechanical interference with assets • Only possible to measure at end spans, limiting accuracy for other spans
Lidar	Uses a laser survey point cloud, generally collected aerially, to model support positions and the conductor sags	• High accuracy	• Extremely high cost of data capture and processing • Hazards - Working at height and in aerial environment • Long lead time, requirements for specialised external services • Not economic for small projects
Sightboard method	Uses sightboards fitted to opposing structures such that the direct line of sight between them aligns with the belly of the conductor	• Low/ Medium cost	• Hazards - Working at height • Not suitable for long spans
Tangent method	Uses conventional survey equipment to establish support and conductor geometry from which the tension can be calculated	• High accuracy	• Requires specialist equipment and operators, potentially engagement of external services
Offset method	Uses conventional survey equipment to establish three points on a conductor, from which the tension can be calculated	• High accuracy	• Requires specialist equipment and operators, potentially engagement of external services
Clino method	Uses measurements for the span and the wire gradients at the supports to calculate the wire tension	• Low/ Medium cost	• Poor accuracy
Wave return method	Infers the tension based on measurement of the speed at which a mechanical pulse propagates along a conductor	• Low/ Medium cost	• Impractical for some spans • Variable accuracy
Tension Meter	A device that mechanically deflects the conductor a measured distance with a measured force. Uses that information to calculate tension. Can be deployed directly to the line or using a hotstick	• Low/ Medium cost	• Hazards - Working at height, working in line environment, mechanical interference with assets
Hot stick or laser range finder	Measurement of attachment height and the conductor at mid-span, from which the sag and tension can be calculated. Generally relies on the assumption that the ground is flat	• Low/ Medium cost	• Poor accuracy
By eye	Assessment of tension based on visual estimate of sag	• Low cost	• Extremely poor accuracy

Figure 2 shows that most utilities do not typically measure tensions to provide accurate input information for line upgrade, refurbishment, or modification designs. 30% of the organisations that do not typically measure tension stated that they might assess line tension in special situations. Where organisations do perform measurements they typically rely on using hotsticks, a relatively poor accuracy method.

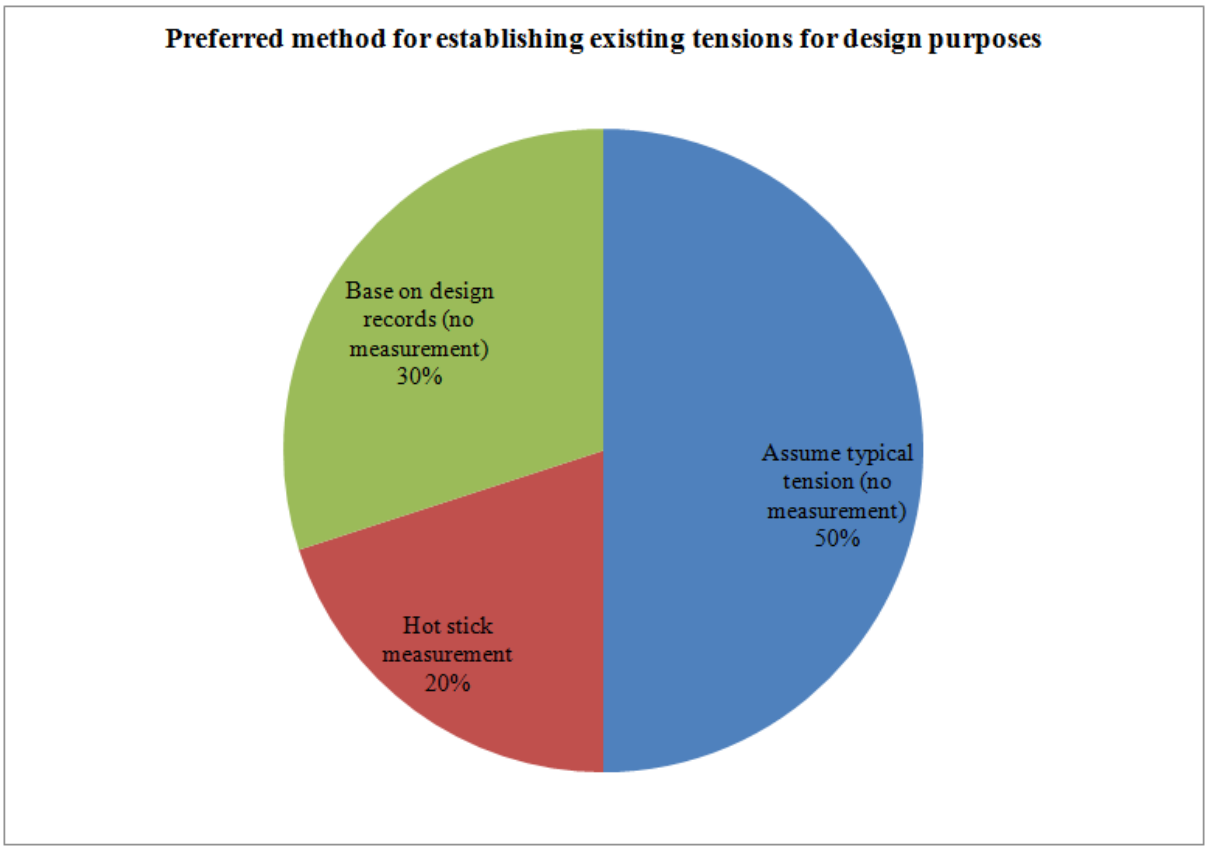

Figure 2: Most common method used to establish existing tension

In the absence of measured tensions designers rely on assumed tensions and tensions taken from design records. However there is good reason to be wary of relying on legacy design records to establish original design tensions. Unless the specific line design record is found, assuming it exists, a generic legacy design reference such as a sag chart or sag table must be used. This presumes that consistent design practice has been sustained over the history of the network. Another issue is that years of service will have modified line tensions from those originally installed. Specifically:

- Network tension specifications may have varied over and through network management change
- Designers and contractors engaged for specific projects can introduce external design specifications and practices
- Lines or sections of line may have been installed below standard tension
- Tensions may not have been measured during installation
- Tensions may have changed since installation as a result of:
    - Creep
    - Permanent elongation from a high loading event (eg snow, wind, impact)
    - Conductor repairs or insulator change
    - Support modification or movement

The decisions New Zealand engineers have made not to measure tension demonstrate that the perceived advantages of measuring tension are overwhelmed by the limitations of the available methods. Other evidence of this from the survey includes:

- Only 20% of organisations verify conductor tensions are correctly installed after construction
- No organisations check conductor tensions as part of regular condition assessment
- Most organisations have a programme to check conductor ground clearances but none of them perform calculations to verify line height at a maximum operating temperature or under mechanical loading as would be necessary to verify compliance with ECP34 and AS/NZS7000.

Distribution utility assets are numerous, widely spread, sometimes difficult to access and generally are long lived. Individually assets are worth relatively little, so maintenance and management activities applied across a network will tend to add up to incur significant cost relative to the value of the network.

The industry is funded such that the income is effectively fixed and business margin is dependent on the ability of the network to minimise its maintenance and management costs. Some relatively expensive practices that are common in other industries that deal with higher value assets, have historically been viewed as uneconomic for distribution network assets, though the same rationale for those practices might exist. Examples include not undertaking soil investigations or detailed design. Conductor tension measurement is another such example. However, increasing regulatory pressures on organisations to demonstrate asset safety and compliance with standards means that the case for implementing these practices is becoming more compelling.

If a truly practical method for measuring tension existed it could be used on a regular basis to:

- Construct lines
- Verify construction quality
- Acquire design input information
- Identify line damage or issues
- Identify conductor tensions and structure loads for maintenance and construction purposes

For tension measurement to be adopted into industry practice in such ubiquitous way it would need to overcome several barriers by being:

- at negligible cost,
- generally applicable, anywhere, under any circumstances
- generally accessible, not requiring special training or equipment that was not commonly available
- accurate and reliable
- avoiding the hazards of working at height or in proximity to the line

The following section describes such a practical tension measurement solution.

Measurement solution description

This section describes a new tension measurement method. The method uses a photograph of the span targeted for measurement to establish the shape of the wire, from which the wire tension can be determined. For correct calculation this Image Based Tension Assessment (IBTA) method requires information that defines the orientation of the camera device with respect to gravity and the target span.

To acquire the orientation information, the photograph is captured using a consumer grade tablet or smartphone device, because they contain integrated accelerometers. The accelerometers allow the orientation of the device to be established with respect to gravity. The orientation of the device with respect to the target span can be established by measuring the distance to the structures at either end. This information is most easily and accurately captured using a laser range finder.

Tablets, smartphones and laser rangefinders share the following merits:

- relative inexpense
- common availability within modern utilities
- potential usefulness for a range of other industry applications
- portability
- good durability

Tablets and smartphones also come with the following benefits:

- highly capable processors
- established highly efficient channels for distributing software and software updates
- easy to read screens
- simple, intuitive Graphical User Interface (GUI)
- integrated gyroscopes, gps hardware, compasses and in many cases barometers, which could be used to improve accuracy or facilitate other lines of analysis

To implement the IBTA method the authors have developed a mobile application that workflows and integrates the photo capture, data input, calculation and graphical and numerical reporting of results.

Figure 3 shows the steps involved in accurately calculating tension using the IBTA method.

1. The app captures the accelerometer measurements at the instant the photo is taken and stores them with the image meta-data.

2. As illustrated in Figure 4 the GUI allows the user to identify the support positions in the photograph.

3. The user measures the distance to the supports. This measurement can be performed using any preferred method, however using a laser range finder is recommended for accuracy and efficiency.

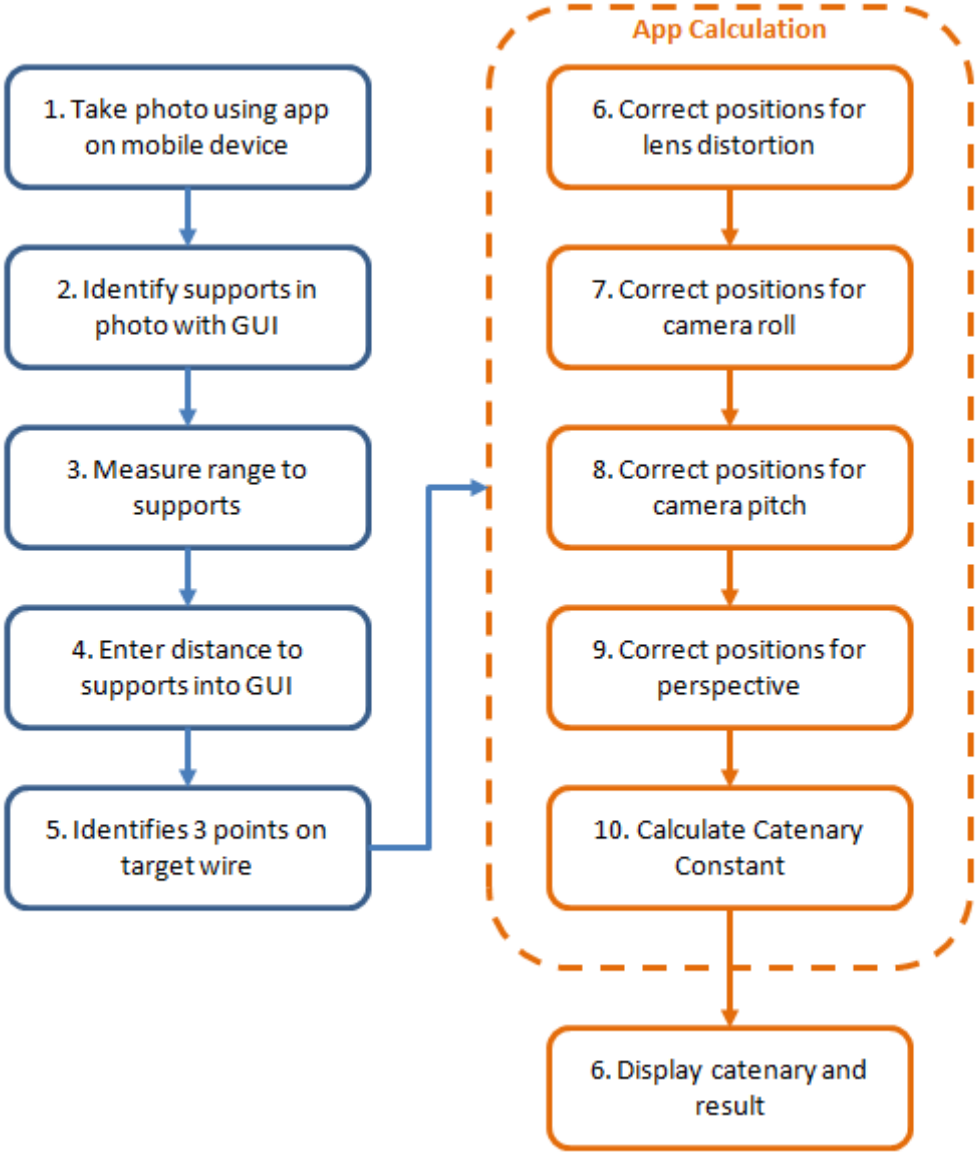

Figure 3: IBTA process

4. The measured distances are entered against the applicable supports via the GUI. With this information, together with the angle between the supports in the image, it is possible to establish the plane of the span and the supported wires, with respect to the device position.

5. The user establishes the position of the target wire in the GUI by identifying any three points that the wire passes through. Practically the three points selected to define the curve should be as far apart as possible so as to minimise the effect of any errors in the measurement of the coordinates. If the three points are close together the measurement errors will be proportionally greater in comparison to the delta between the coordinate positions.

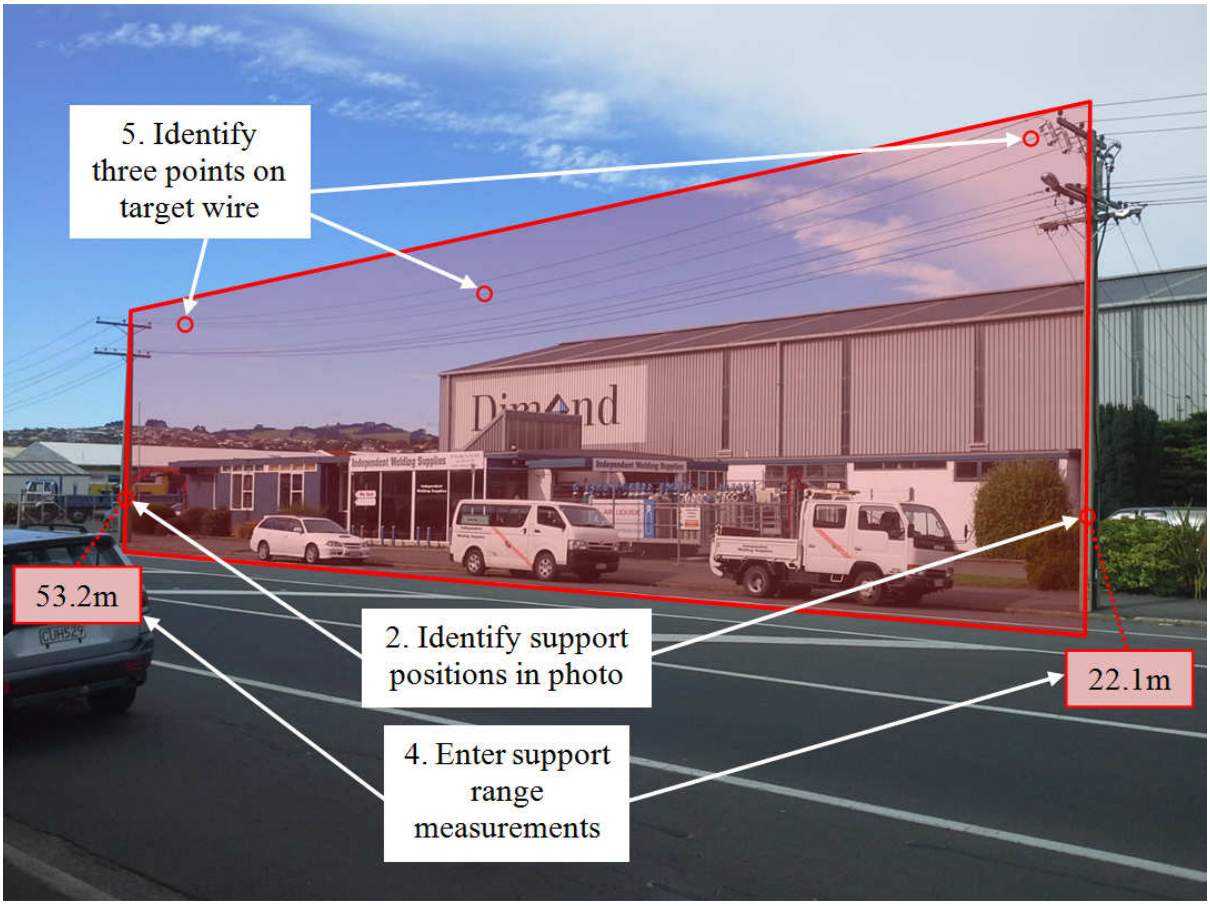

Figure 4: Data entered by the user

6. Lens distortion is an effect caused by camera optics. The application corrects the selected positions for lens distortion by applying a correction algorithm which is calibrated to the individual camera during the software setup process. Figure 5 provides an illustration of lens distortion correction.

Figure 5: Correction for lens distortion

7. Camera roll occurs when the photograph is not taken while the camera is level. The degree to which the camera is off horizontal is calculated by the software using the device accelerometer measurements which indicate the direction of gravity. The roll correction

adjusts the selected positions to rotate them back to a horizontal system of reference, as shown in Figure 6.

Figure 6: Correction for camera roll

8. Camera pitch occurs when the photograph is taken while the camera is aimed above or below the horizontal. The degree to which the camera is above or below the horizon is calculated based on the accelerometer readings. The pitch correction adjusts the selected positions to account for the perspective error as shown in Figure 7.

Figure 7: Correction for camera pitch

Using the corrected input data the software can adjust for the photo perspective in three dimensions to establish positions for the supports and target wire in a local coordinate system. This requires the correlation of image pixels to incident light angles, which is established by a calibration exercise during software setup. The software can then use the three wire coordinates to establish the shape of the wire and therefore the catenary constant of the wire.

The catenary constant is a ratio that normalises for different conductor types so their sags can be compared. The catenary constant is defined by the following equation:

$$C = H / w$$

Where:

C = Catenary constant (m)
H = Horizontal tension (N)
w = Linear weight (N/m)

The Catenary constant is referred to as a constant because conductors of equal catenary constant, irrespective of size or length, will have the same sag curvature. Catenary constants are the basis for sag curves or sag templates which were the traditional graphical method for drawing line profiles when designing for line clearance. The solution proposed in this section essentially operates like a sag curve in reverse. It uses the shape of the wire to establish the catenary constant.

If the type of wire, and therefore its linear weight, is known, the linear weight can be multiplied with the catenary constant to establish the horizontal component of the wire tension. Using the position of the supports, the slope of the wire, and therefore the tangential tension of the wire at the supports, can be calculated by the software.

Measurement solution applications

While the IBTA method has been specifically developed to make the measurement of tension efficient it establishes a basis from which many types of analysis can be performed, for a range of applications and users.

It facilitates the development of a universal tool for the remote measurement and analysis of overhead lines and structures.

Analyses that can be performed using the IBTA method include:

- Measurement of wire tensions, sags and catenary constants
- Measurement of structure dimensions
- Measurement of span lengths
- Measurement of conductor heights above ground
- Measurement of structure loads
- Calculation of conductor tensions and sags under design load cases or for alternative supports or conductor systems
- Calculation of conductor blow-out under design load cases or for alternative supports or conductor systems
- Calculation of conductor height above ground under design load cases or for alternative supports or conductor systems
- Calculation of structure loads under design load cases
- Assessment of phase to phase spacing

There are many potential ways to apply the results of these analyses and a range of users who could benefit from those applications. Table 2 provides an indication of who might use the analyses and how their results might be applied. For example the installed tension might be used by designers as a design input, by an asset manager to confirm installation at the correct tension, or by a linesman to select appropriate methods or equipment for maintenance activity. It might be especially important for linesmen to establish existing tensions and loads

as part of a site safety meeting where a structure has been displaced or it is apparent that a structure may be subject to significant wire tension imbalances or high tensile loads.

Table 2: IBTA applications

Application	Designers	Condition assessors	Asset managers	Linesmen	Manufac-turers
Establish current conductor tension.	X		X	X	
Calculate conductor tensions for multiple load cases.	X		X	X	
Establish current structure loading	X			X	
Calculate structure loads for multiple load cases	X				
Calculate electrical clearances for multiple load cases (to ground, roads, buildings etc)	X		X	X	
Record evidence of line characteristics at high risk locations (eg clearances)			X		
Establish conductor creep performance based on observation of installed conductor	X				X
Identify conductor stretch after a major loading event		X	X	X	
Confirm component sizes on existing assets	X	X	X		
Establish conductor blow out	X	X	X	X	
Assess susceptibility of conductors to vibration damage	X		X		
Perform phase to phase and circuit to circuit clearance checks		X		X	

This is especially the case because so many of the barriers to the adoption of more conventional methods are overcome by IBTA:

- Safety – IBTA does not require operation at heights, operation in the vicinity of electrified wires, the operation of heavy equipment or the proximity to or disturbance of mechanically loaded assets.
- Ease of use – IBTA takes advantage of the usability of modern consumer tablets. The software is simple and intuitive so requires no special training.
- Efficiency – All calculations are performed within the software so the user need only take a photo and enter a few details. In some locations it is not necessary for a user to leave the vehicle to complete a measurement. The results can be viewed in the field without requirement for post-processing or additional analysis.
- Low cost – The equipment required to take IBTA measurements will already be available at many utility organisations. Both pieces of equipment can be purchased relatively cheaply.
- Accuracy – IBTA is a highly accurate method for measuring overhead line wire tensions. Typically tensions can be measured to a precision of less than 2%.
- Quality assurance and records – The raw output from the IBTA software is a photo that is overlaid with the measurement result. The image can be stored as a permanent

record of the asset condition at the time of measurement. The image also graphically shows the measurement quality.

- Communication – Because the tablet devices used for the IBTA method are designed for use on the internet it becomes easy to transfer measurements to external parties or storage.

Summary

Existing tension measurement methods have been shown to be inadequate with the consequence being that important engineering work is systematically being left undone. Conventional tension measurement methods are simply not practical for the distribution utility industry. They are variously too expensive, too complex, too labour intensive, too time consuming, too hazardous and in some cases too inaccurate.

The IBTA method overcomes these issues and presents an opportunity for the industry to realise engineering efficiency and quality improvements.