

Conductor tension in overhead line designs

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

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 common for distribution line designers to base their calculations on assumed tensions, which can be significantly different from actual installed tension.

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.
- *Mechanical design of conductor, insulators and fittings:* 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.

A prudent designer will allow for an appropriate amount of tolerance in conductor tension. If the designer does not have a basis from which to establish a probable range of conductor tensions, it becomes necessary to assume a conservative design tension, to manage the risk of underestimating loads or sag.

Established tension measurement methods

Designers have a wide range of established methods at their disposal with which to establish conductor tensions. However all of them have significant disadvantages which 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 which are currently used in the distribution industry and lists some key pros and cons for each method.

Despite all these methods being available some utilities do not ensure that design tensions are installed by performing conductor tension measurements during installation. Also many do not

measure the tension of existing lines before embarking on the design of line upgrades, refurbishment, or modification.

In the absence of measured tensions designers may rely on assumed tensions for existing lines, or tensions taken from design records. Assumed or estimated tensions are an obvious source of design uncertainty and potential inaccuracy. There is also good reason to be wary of relying on legacy design records to establish current design tensions:

- Network tension specifications may vary during a network's development meaning. An available set of historical tension records may not be relevant. For example foreign design specifications and practices might have been introduced by external designers and contractors.
- Lines or sections of line may not have been installed at the design tension, or they may not have even been measured.
- Tensions may have changed since installation as a result of:
 - Creep
 - Permanent elongation from a high loading event (e.g. snow, wind, impact)
 - Conductor repairs or insulator change
 - Support modification or movement

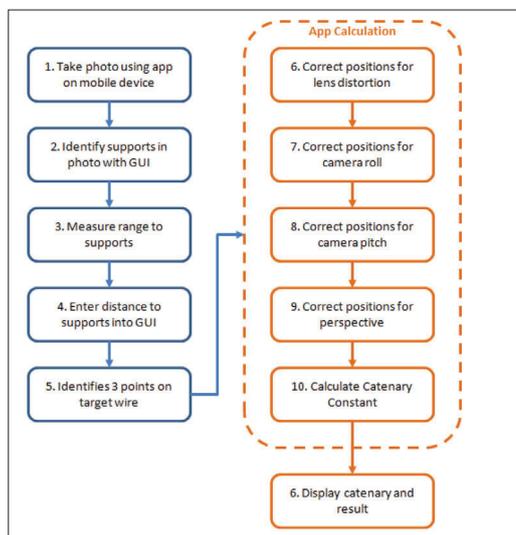


Fig. 1: The IBTA process.

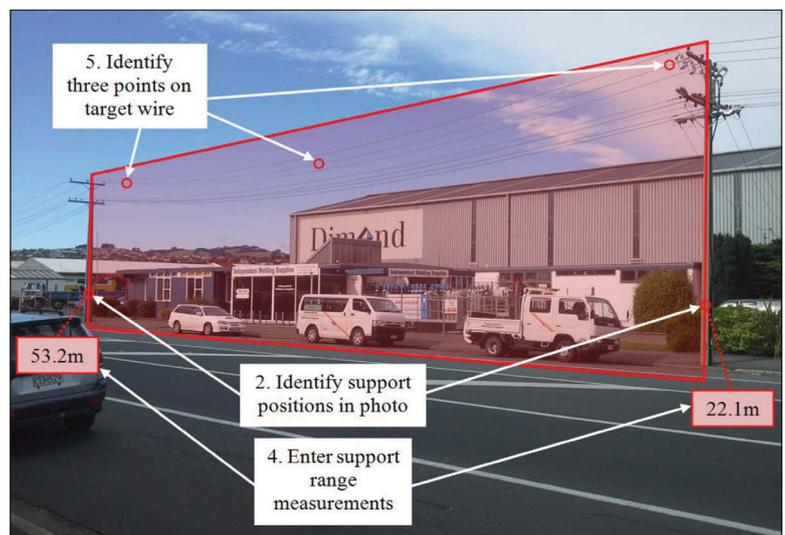


Fig. 2: Data entered by the user.

In the absence of tension measurement it cannot be established whether installed tensions accord with tensions used in the design. This undermines the legitimacy of the line design.

If a truly practical method for measuring tension existed it would be reasonable to expect to see it used routinely when knowledge of tension is important:

- Line construction
- Verification of construction quality
- Acquisition of design input information
- Assessment of line condition
- Identification of conductor tensions and structure loads for maintenance and construction purposes

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

- Of negligible cost
- Generally applicable
- Accessible, not requiring special training or equipment
- Accurate and reliable
- Safe, 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 method called Image Based Tension Assessment

(IBTA). The IBTA method uses a photograph of the span being measured to establish the catenary shape of the wire, from which the wire tension can be determined. Establishing wire shape from a photo 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 because they contain integrated accelerometers. Accelerometers allows device orientation 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 inexpensive
- Common availability within modern utilities
- Potential usefulness for a range of other industry applications
- Portability

Tablets and smartphones also include the following benefits:

- Contain 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.

Figs.1 and 2 show the steps involved in calculating tension using the IBTA method. By identifying the end supports in the image and specifying the distance to those supports, the plane of the span can be established with respect to the camera position and viewing angle. This knowledge of perspective provides a basis from which to transform the three user-defined wire positions on the image into three dimensional coordinates which can be used to establish the location and shape of the catenary, and therefore its catenary constant.

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:

$$C = H/w$$

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
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 in an aerial environment; Long lead time: requires specialised external services
Sightboard method	Uses sightboards fitted to opposing structures such as that direct line of sight between them aligns with the conductor belly.	Low to 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
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
Cliino method	Uses measurements of the span and wire gradients at the supports to calculate the wire tension.	Low to 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 to medium cost	Impractical for some spans; Variable accuracy; Mechanical interference with assets.
Tension meter	A device which mechanically deflects the conductor a measured distance with a measured force to calculate tension. Can be deployed directly to the line or using a hotstick.	Low to medium cost	Hazards: working at height; working in line environment; mechanical interference with assets
Not 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 to medium cost	Poor accuracy
By eye	Assessment of tension based on visual estimate of conductor sag.	Low cost	Extremely poor accuracy

Table 1: Established tension measurement methods



Fig. 3: Correction for lens distortion.



Fig. 4: Correction for camera roll.



Fig. 5: Correction for camera pitch.

where:

C = Catenary constant (m)

H = Horizontal tension (N)

w = Linear weight (N/m)

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 means for line profiling. The IBTA method 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.

For some devices, images taken will require correction for lens distortion, an effect caused by camera optics. A correction algorithm can be calibrated to the individual camera during the software setup process. Fig. 3 provides an illustration of lens distortion correction.

Camera roll occurs when a photograph is taken while the camera is not 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 Fig. 4.

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 Fig. 5.

Measurement solution applications

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

Analyses that could 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
- 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 or for alternative conductor systems
- Assessment of phase to phase spacing

IBTA is especially practical for these analyses because it overcomes the barriers to adoption faced by established methods:

- **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. 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.
- **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 can connect to the internet it becomes easy to transfer measurements to external parties or storage.

Conclusion

Established tension measurement methods are often not practical for the distribution utility industry. They are 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.

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