Evaluation of Instrumentation and Dynamic Thermal Ratings for Overhead Lines

Interim Report, August 2011

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CONTENTS

LIST OF FIGURES

LIST OF TABLES

1
INTRODUCTION AND BACKGROUND

Introduction

The demand for electric power over transmission circuits is increasing at a faster rate than the construction of new transmission facilities. This trend is pushing the capacity of many transmission circuits to their design limits. The power capacity (i.e., the rating) of most overhead transmission lines is prescribed by the so-called “static rating” based on both the conductor configurations and the environmental conditions. Typically, very conservative worst-case assumptions about environmental conditions were used when developing these “static ratings”. Due to this conservative approach, significant extra power capacity exists beyond the design margin on most lines most of the time.

As part of its on-going research in this area, EPRI has developed monitors, rating calculation methodologies, the Dynamic Thermal Circuit Rating (DTCR) software, workshops, and other products for the purpose of gaining access to extra power capacity. All the related EPRI research results and products are referred to at EPRI as DTCR Technologies. Prior to undertaking capital intensive activities—such as building new lines, reconductoring, raising structure heights, replacing transformers, putting lines underground, etc.—utilities can use these technologies to maximize power throughput of existing assets, defer capital expenditures, and simultaneously increase safe and reliable operation of their assets.

In 2010, a project was initiated between NYPA and EPRI to evaluate EPRI’s Dynamic Thermal Circuit Rating (DTCR) software, along with instrumentation that can be used to monitor the thermal states of transmission lines and provide the required real-time data needed for the DTCR calculations. The main objective of the project is to demonstrate how DTCR Technologies can be effectively deployed, and practically integrated, into transmission system engineering, operations, and planning of the New York Power Authority (NYPA).

Background

There are several instrumentation packages commercially available, or being developed, that can be used to provide the required real-time data for DTCR calculations. It was decided during the formative stages of the project, based on NYPA’s initial review and suggestions, that the focus would be on the following four technologies;

1. EPRI’s Conductor Temperature and Load Sensors (EPRI Sensors) for measuring conductor temperature and current,

2. ThermalRate systems to provide calculated conductor temperature and effective perpendicular wind speed,
3. Video Sagometers® to monitor the conductor position (sag), and
4. Weather stations to monitor the relevant weather variables.

Three 230 kV line sites were fully instrumented. Line current measurements need to be provided to DTCR from NYPA's EMS system, although the EPRI Sensors are capable of providing this data if calibrated. All these units come with their own power supplies, data logging, communications, and electronics.

All the instrumentation and associated equipment was delivered to the EPRI High Voltage Laboratory in Lenox, MA (Lenox). The first set of instruments were fully configured and installed on a test line at Lenox for testing. The hardware and programming for data logging, power supply operation, and communications necessary for the various instruments to work together went through their final design and testing stages. The data link to DTCR was tested, and DTCR was tested to verify that it could work with the incoming data stream. NYPA field crew members and engineering staff witnessed and participated in the installation in order to provide training for the final field installations.

The second and third sets of instruments were also delivered to Lenox, and some basic tests were performed to verify operation. The instruments were shipped to the line sites. Each instrumentation vendor provided their own on-site assistance during installation, and EPRI coordinated the activities. NYPA provided bucket trucks and line crews as needed, along with the capability to perform basic span surveys. The NYPA line crew performed the actual hands-on installation of all on-site materials, and personnel from EPRI or equipment vendors provided technical direction.

Overview of Project Activities

Field instrumentation occasionally (sometimes frequently), needs some type of troubleshooting and/or maintenance. EPRI provides ongoing technical support of instrumentation as needed. In some cases, the hardware vendor is directly involved. During on-site maintenance activities NYPA provides bucket trucks and line crew support. There have been several such site visits.

A server was provided for DTCR and other related software. The DTCR software and other associated programs presently reside at EPRI, and continue to run in real-time. This includes the retrieving and archiving of the raw field data, and real-time computations of line ratings. Ultimately, the server will be shipped to a NYPA location.

To perform rating calculations, the average temperature of the conductor must be known. In some cases, such as with a weather station alone, the temperature is calculated. For instruments such as the EPRI Sensors, the temperature is measured directly, but only at discreet points along the line. Sag monitoring instruments determine the average conductor temperature along an entire line section, however, it requires that the mathematical relationship between sag and average conductor temperature be determined. This requires a physical modeling of the line (using, for instance, SAG10 or PLSCAD), and some upfront data analysis. It is important that this be done correctly, and that the mathematical relationship, Tc(sag), be monitored and refined. An initial determination of Tc(sag) was made, and this is in the process of being refined.

It continues to be important for the success of the project for a NYPA engineer(s) to be assigned to take the lead role of overseeing the DTCR setup, operation, and integration at NYPA. This person(s) would be provided training on the use of the software, and on the significance and use of the incoming data and computed results. As a first step, DTCR will run on a stand-alone server away from the operations center and separate from the EMS (except for the possibility of procuring real-time load data). DTCR operation, and the I/O data integrity, will be verified, and training will be provided to the NYPA engineer(s). As a second step, the DTCR server will be moved to an operations environment where further testing can be performed, and where training will be provided to engineering and operations personnel. EPRI will provide ongoing support as needed.

Throughout the course of the project, a large amount of data and other information is being gathered, and will be processed and analyzed to achieve the greatest payback for the effort. The output and operational performance of the different types of instrumentation is being documented and analyzed over the project to document an assessment of the field technologies with respect to costs, ease of installation and use, accuracy, maintenance issues, and reliability. Also, the weather and rating data is being analyzed to understand the statistical distributions of these data. This effort will provide insight into the causes and effects of line rating variations and distributions, and is expected to provide very valuable insight into the behavior of ratings during high wind-power periods. It is anticipated that significant extra power capacity will be found on the transmission lines during these periods, when and where it is most needed.

The field installations were documented as will the instrumentation and DTCR integration with SCADA and the EMS system. Reliability issues that occur are being documented to be included in the final report.

The raw data from the field instruments and weather data are being collected and plotted on weekly graphs. This process is important for the following reasons:

- To directly observe the integrity and completeness of the data.
- To verify field equipment operation.
- To provide a direct comparison between field instrument measurements.
- To help identify and explain trends, in the instrument performance, and in the measured data.
- To provide a reference for analysis.

The data stream from the field includes the primary measurements that are to be studied as part of this project, and a large amount of secondary measurements used for diagnostic and other purposes, such as battery voltage, etc.

The rating data, similar to the raw field data, will be plotted on weekly graphs of ratings versus time for the purposes of:

- Directly observing the integrity and completeness of the data.
- To verify the rating calculation process.
- To provide a direct comparison between ratings computed by different means.
- To help identify and explain trends.
- To provide a reference for analysis.

This project was launched in mid-2010 and is planned to continue through late 2012. At this point in time the project is on schedule.

2
TRANSMISSION LINE RATINGS; PRINCIPLES AND PRACTICES

Introduction

The electric power industry worldwide is experiencing a need to push more power through existing assets. This is a result of the ever growing demand for electric power, and the cost and permitting hurdles of constructing new assets. This is all particularly true for overhead transmission lines, which are the limiting circuit components in most cases, and the most expensive and difficult to replace or upgrade.

However, the industry is recognizing that for almost all cases, transmission lines have significant extra capacity. When transmission lines were originally designed, very conservative design criteria were used, but with the increasing power demand, utilities are now reaching the original design limits, and there is a need to take advantage of the extra, "hidden" capacity. This hidden capacity can be tapped by maximizing a line's rating, either statically or dynamically.

Ratings

The rating of an overhead transmission line is the specified upper limit of amperage that the conductors are allowed to carry. The amperage must be limited in order to limit the operating temperatures of the conductors. In turn, the temperature of an overhead conductor must be limited to some upper value for either one of two reasons (or both), 1) to limit the sag of a conductor (clearance limited), or 2) to prevent loss of conductor strength (thermal limited).

The temperature of a given overhead conductor depends on the load it is carrying (amperage), and the ambient conditions (ambient temperature, wind speed, wind direction, solar intensity, and rain rate). The thermal energy input to a conductor comes from the resistive losses and solar input, and the thermal energy dissipation is in the form of heat convection, radiation, cooling by rain, and also in raising the conductor's temperature.

These thermal energy transfers are depicted in Figure 2-1 below (note that the effect of rain is not considered because its cooling effect cannot be well modeled, and the presence of rain cannot be accurately determined).

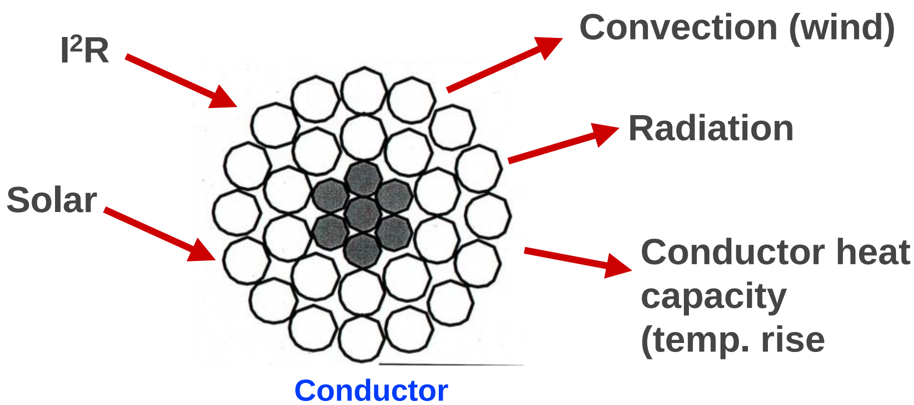


Figure 2-1 Depiction of the thermal energy input and output of an overhead line conductor.

The temperature of the conductor is calculated by equating the thermal energy input to the output via the following mathematical relationship.

$$I^2R + Q_S = mC\frac{dT}{dt} + Q_R + Q_C$$ **Equation 1**

where:

I = current (amps)

R = conductor resistance (ohms per meter)

Qs = solar input (watts per meter)

mC dT/dt = conductor heat storage

m = conductor mass (kilograms per meter)

C = conductor heat capacity (Joule/kg·degC)

T = conductor temperature (degC)

t = time (seconds) Qr = radiated energy (watts per meter)

Qc = convected energy (watts per meter)

The solar energy input, Qs, depends on the intensity of solar energy and the absorptivity of the conductor's surface. The radiated energy, Qr, depends on the temperature of the conductor and the emissivity of the conductor's surface. The convected energy, Qc, depends on the wind speed and direction and the conductor and ambient temperatures.

Static Rating

Traditionally, and almost universally still, utilities rate their overhead transmission lines with a ***static rating***. In this case, the current (conductor rating) that yields maximum allowable conductor temperature is calculated by assuming conservative values for the variables in the above equation. The advantages of using a static rating include the simplicity to calculate, and the fact that the rating is constant. In some cases the static rating is changed to reflect the differences in ambient conditions between night and day, or seasonal variations.

The disadvantage is that the actual power capacity of a line is usually significantly greater than dictated by the static rating due to the overly conservative assumptions required, and for some periods of time the actual capacity is less than the static rating. This situation is depicted in Figure 2-2.

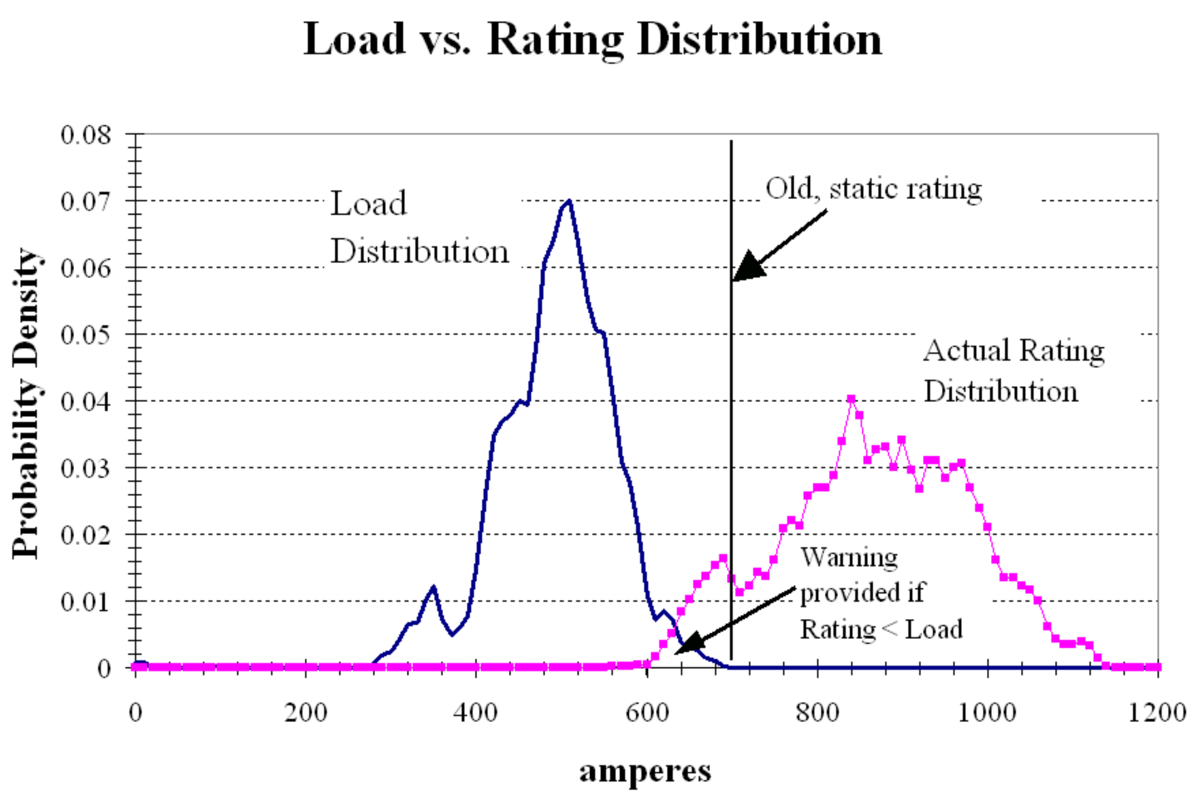


Figure 2-2 Load and rating probability distribution example for a transmission line.

In Figure 2-2, the static rating is fixed at about 700A, the load distribution is to the left of the static rating, and goes to zero at the static rating (the operator purposely keeps the load below the static rating). However, the actual line rating distribution is significantly higher than the static rating – with an average of over 20% greater. Also, there is some small part of the actual rating distribution that falls below the static rating.

Dynamic Rating

A concept which is gaining a foothold in the power industry is the use of ***real-time rating***, referred to as ***dynamic thermal circuit rating***. In this case, actual real-time field measurements are made of the variables needed in the rating equation, and the rating is calculated continuously – typically at ten minute intervals.

The advantage of using dynamic rating is that it provides a better knowledge of the actual line rating, which is significantly greater than the static rating most of the time. The disadvantage is that the dynamic rating is a varying quantity. In many cases, the thermal inertia of a conductor, due to its heat capacity, can be used to rate a conductor even much higher for a short period of time – referred to as an emergency rating. These concepts are illustrated in Figure 2-3.

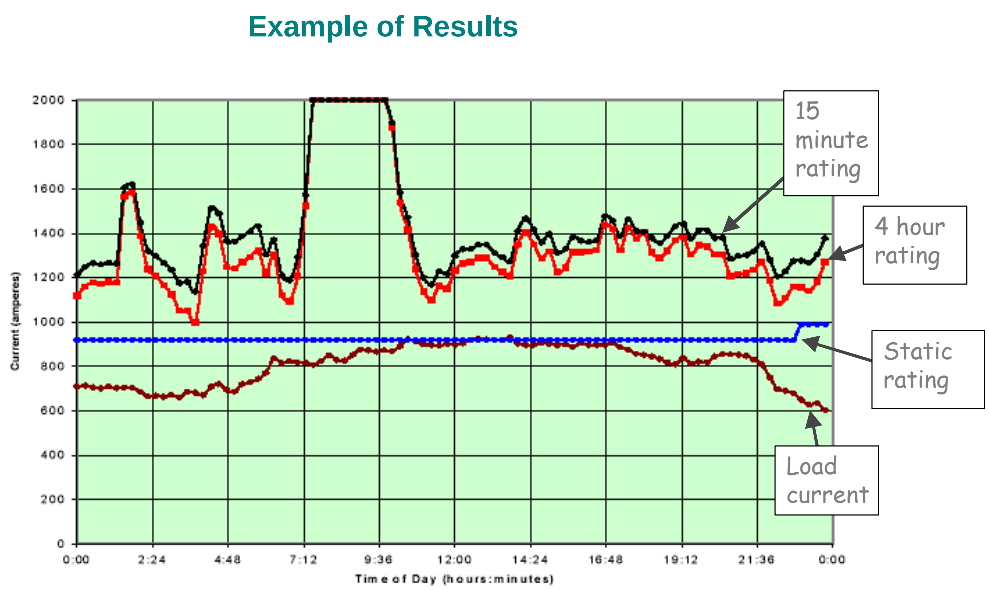


Figure 2-3 Example of dynamic rating, static rating, and load for a 24-hour period for a particular transmission line.

Figure 2-3 shows an example of the ratings for an operating 161 kV line over a 24-hour period. Plotted are the static rating, the line's load, and the dynamic ratings (4-hour "normal", and 15-minute emergency). The 4-hour rating is the amount of current that a conductor can pass for the next 4 hours without exceeding a predefined maximum allowed operating temperature – if conditions were to remain constant. For all practical purposes, this is equal to the "normal" rating, which is the magnitude of current that can be passed indefinitely, without exceeding a predefined maximum allowed operating temperature – if conditions remained constant.

Note that during the middle of this particular day the utility was bumping into its static rating when, according to the DTCR results, there was a significant margin to work with. Also note that a light rain that morning sent the actual ratings to very high levels.

Rating Studies

A methodology being developed by EPRI, and others, is to use the results of dynamic rating calculations as a basis for statistical analyses to optimize a modified approach to static ratings. These rating studies involve gathering a large amount of field data (typically one year of data), executing dynamic rating calculations on the field data, and performing statistical analyses of both the field data and the dynamic rating calculation results. This process can provide insight into the associated risk-of-exceedance a utility takes when setting a static-type rating for a given line. Such a risk always accompanies the setting of a static rating (see Figure 2-2), but the methodology provides a scientifically based process for making risk-informed decisions.

One of the features of this methodology is the statistical analysis of the DTCR results, as opposed to the statistical analysis of the field data alone. The DTCR computations naturally account for correlations among the field variables that would be missed if the field variables were analyzed separately.

For example, it has been observed that higher winds statistically accompany higher ambient temperatures. This statistical correlation would be missed if the wind speeds and ambient temperatures were analyzed separately, but the DTCR computations automatically account for their correlated impact on the ratings.

Field Data and Instruments for Real-Time Rating

Referring to Equation 1 above, it can be seen that for any given transmission line, the rating at any point in time depends on the ambient weather conditions, i.e. ambient temperature, wind speed, wind direction, and solar intensity. To calculate a line rating with Equation 1, the line parameters (constants), weather variables, and the maximum permissible conductor operating temperature are used as inputs, and the equation is solved for the current, I (i.e. the rating). In other words, the rating is the current, I, that causes the conductor to reach its maximum allowed temperature.

In the first term of Equation 1, I^2R, R is the conductor resistance (ohms per meter). These resistance values are well known, and are provided in manufacturers' tables. The DTCR software has a built-in database of the values for most conductor types.

The second term in Equation 1 is the solar input, Qs (watts per meter). The magnitude of Qs depends on the solar intensity at the field site, and is measured by the weather station in real-time with a device called a ***pyranometer***. The magnitude of Qs also depends on line direction and the value of the conductor's absorptivity, which are both of fixed value for a given line.

The third term in Equation 1 (mC dT/dt) is the heat storage term. The "m" and "C" are the mass and heat capacity of the conductor, respectively, which are fixed for any given conductor type, and are provided in manufacturers' tables and in the DTCR software conductor database. "T" is the conductor temperature, and "t" is time. The derivative, dT/dt, is the rate of change of conductor temperature with time, and accounts for heat storage and the changing conductor temperature when the thermal energy of the conductor is not in a steady state. This term is useful during contingency situations when the conductor can pass more current than its normal rating because the conductor temperature has not yet reached its maximum value due to the heat storage (thermal inertia). In cases where the current, I, is known, Equation 1 can be solved for T (conductor temperature). When Equation 1 is used to calculate a rating, T is assigned the maximum conductor temperature and Equation 1 is solved for I.

The fourth term in Equation 1, Qr, is the amount of power (watts per meter) dissipated to the environment by radiation. This depends on the conductor temperature, T, and the conductor emissivity, which is assigned a constant value.

The fifth term in Equation 1, Qc, is the amount of power (watts per meter) dissipated to the environment by convection. This term depends on the conductor temperature, T, the ambient temperature, Ta, and on the wind speed and wind direction relative to the conductor. Ta is measured in the field by the weather station's temperature sensor. The wind speed and direction are measured by the weather station's anemometer.

As shown in Figure 2-4, changes in wind speed and direction relative to the line, have a much larger impact on the line rating than changes in air temperature and solar heating.

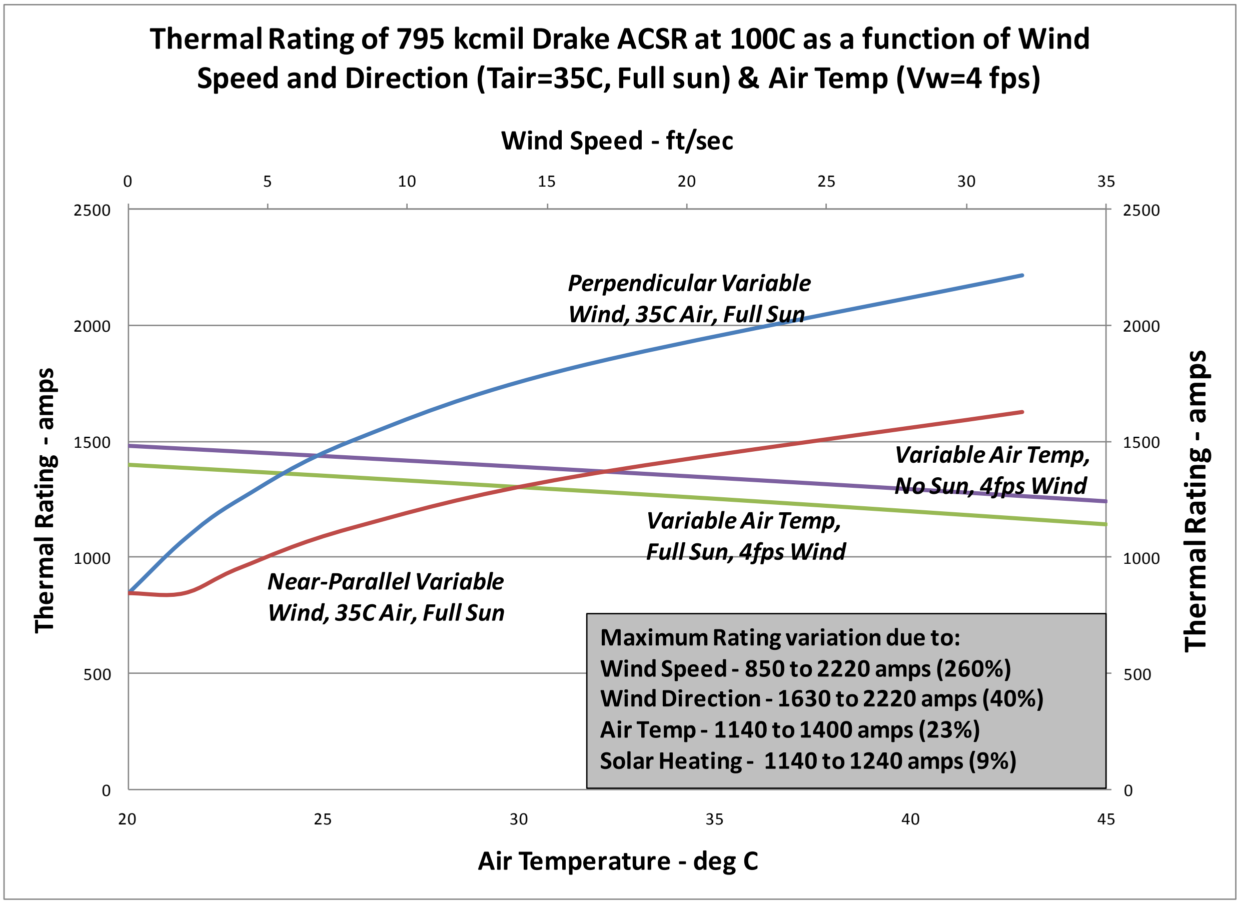


Figure 2-4
Impact of changes in air temperature, solar heating, and wind speed and direction on line ratings

Also, solar heating and air temperature are typically similar from span to span in most transmission lines. This is shown in Figure 2-5 where the air temperature at two locations over a mile apart along a transmission line right-of-way, are shown to be highly correlated over a week of measurements.

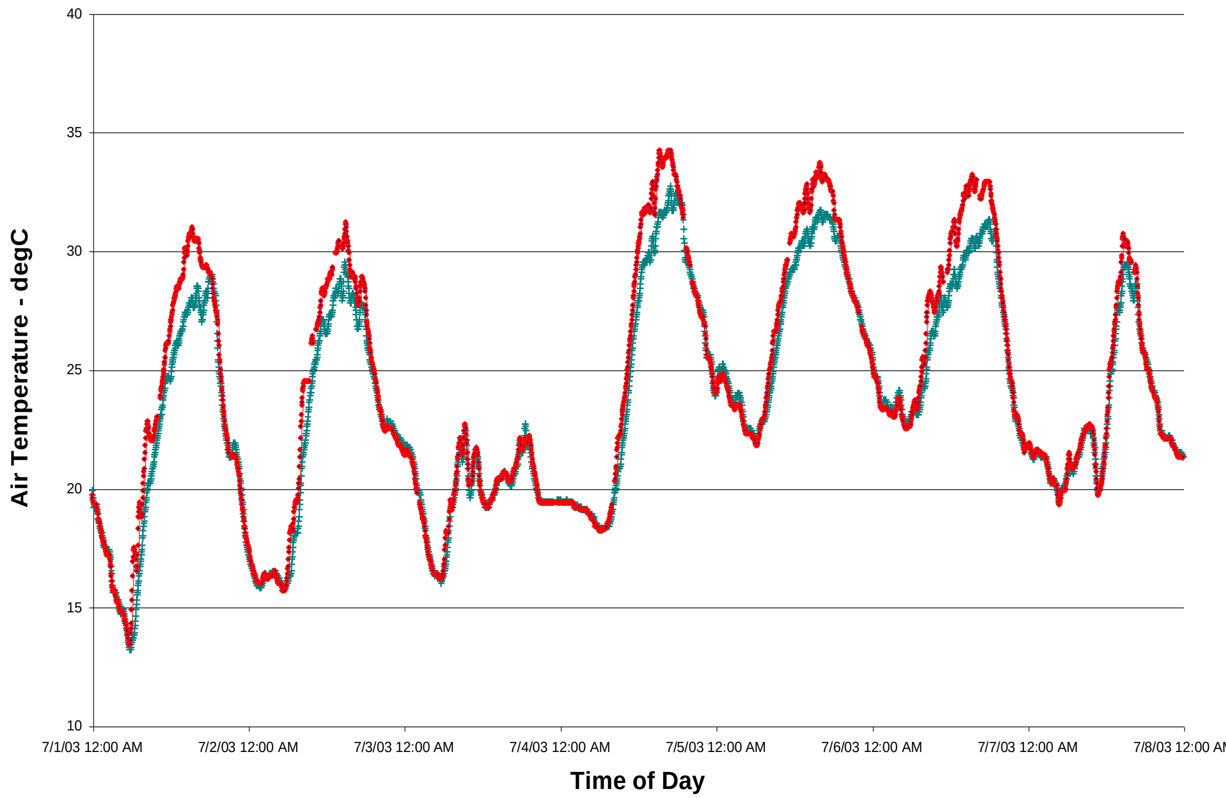


Figure 2-5 Variation in air temperature between two spans approximately 1.5 miles apart in a typical transmission line.

On the other hand, wind speed and wind direction typically vary widely from span to span, especially at low wind speeds that are of primary interest in thermal rating calculations. Figure 2-6 is a scatter plot of simultaneous 10-minute average wind speeds at two locations less than 2 miles apart. Notice that the wind speed can be nearly zero a one location and between 5 and 10 fps at the other location.

This illustrates the need to measure the wind speed and direction at multiple locations along the line in order to be sure to use the minimum wind cooling for dynamic rating calculations. As explained in this section, this can be done by installing multiple wind anemometers, multiple temperature monitors, or multiple sag-tension monitors.

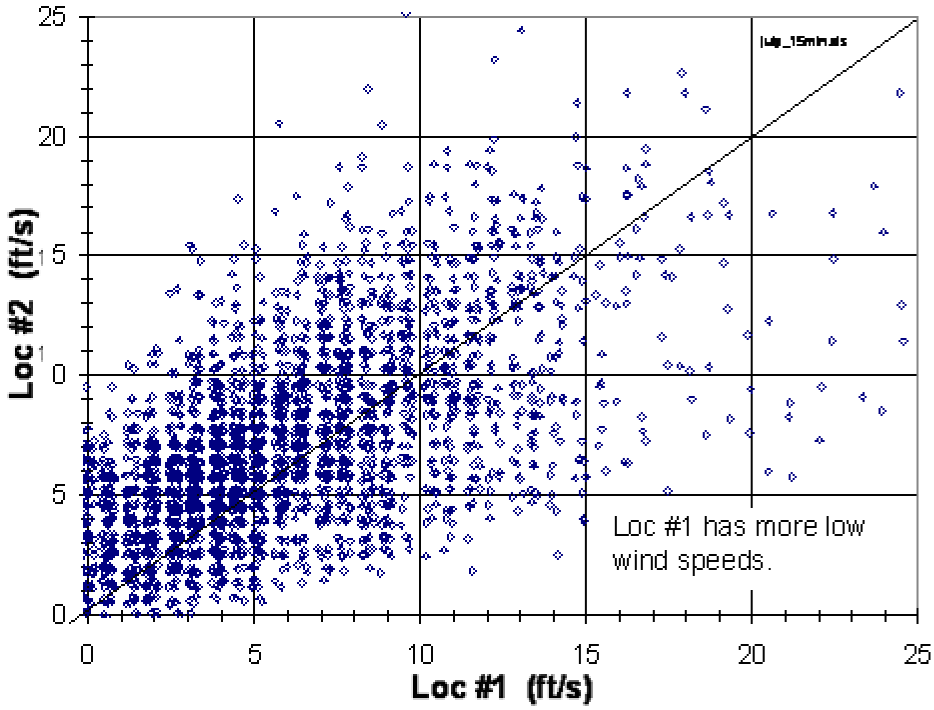


Figure 2-6 Comparison of simultaneous 10-min average wind speeds at two locations about 2 km apart along a transmission line.

When using high quality anemometers to determine line rating in real-time, ambient temperature and solar intensity must also be measured in real-time and the heat balance equation solved for conductor rating, I, for an assigned maximum conductor temperature, $T_{C,}$ at each anemometer location. A sufficient number of anemometers must be located along the line to be sure that sheltered spans are included and the average conductor temperature within the sag-section can be calculated.

A positive feature of using weather stations is that they are relatively inexpensive, are very durable, easy to setup and use, and don't require any special calibrations. They can also be located in sheltered spans to be sure that the maximum conductor temperature (used for annealing calculations) is calculated as well as the average conductor temperature (used for sag clearance calculations).

Another way of determining the local wind cooling is to measure the conductor temperature with a monitor. There are commercially available devices for doing this, and EPRI is in the process of developing an instrument for this purpose, referred to in this report as the ***EPRI Sensor*** (EPRI Sensors are used in this NYPA project). The EPRI Sensor measures conductor temperature by a thermocouple pressed against the conductor. From conductor temperature, T_C, an effective perpendicular wind speed can be determined for the location along the line.

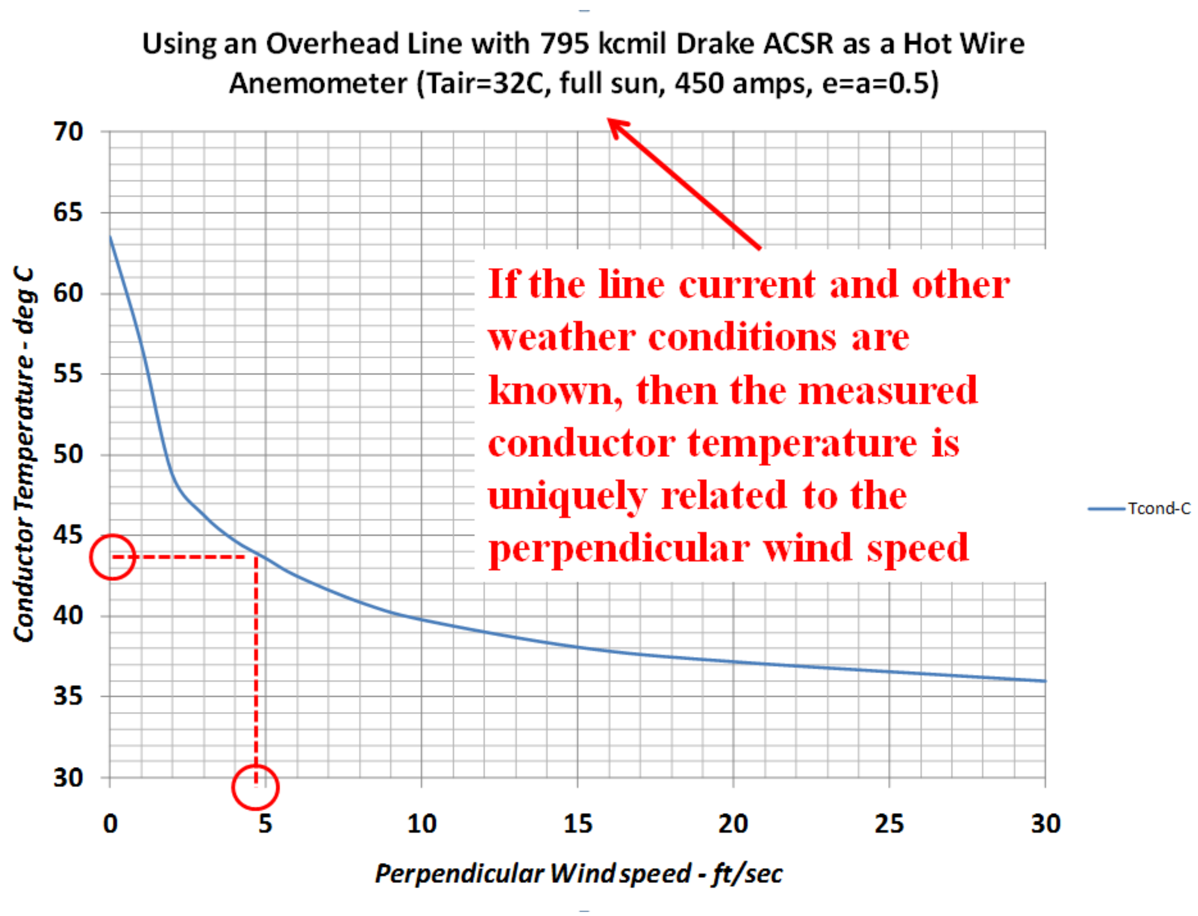


Figure 2-7
Given the conductor temperature, current, air temperature, and solar heating, the effective perpendicular wind speed can be determined.

Temperature monitors have several advantages over the use of wind anemometers, the largest of which is that they measure the effect of the wind at the surface of the energized conductor rather than some distance away. They also can be designed to measure line current which anemometers cannot. Also, the individual temperature sensors are relatively inexpensive.

Limitations are also significant. The most important limitations involve the possibility of heat sinking and flow disruption due to the presence of the monitor. Another is that the wind speed error can be large when the line current is so low that the conductor temperature is no more than one or two degrees higher than the conductor temperature without any current.

A limitation shared by both anemometers and conductor temperature monitors involves the thermal and mechanical behavior of overhead transmission lines. Most lines are constructed with periodic “dead-end” structures which are designed to stop cascade structure failures. Between dead-ends, suspension structures are used where the conductors are supported vertically but are free to move axially. The suspension spans between each pair of dead-ends is called a “sag-section”. Because the conductor supports are axially flexible, any variations in tension from span to span, due to variations in load and temperature, are equalized. In this case, the sag in any suspension span depends on the average load and temperature of the line section rather than the load and temperature of that span alone.

At the same time, bare overhead stranded conductors are very poor axial heat conductors and there can be significant differences in the conductor temperature span to span due to wind speed and direction variations along the line. This temperature variation typically increases with line current as shown in Figure 2-8.

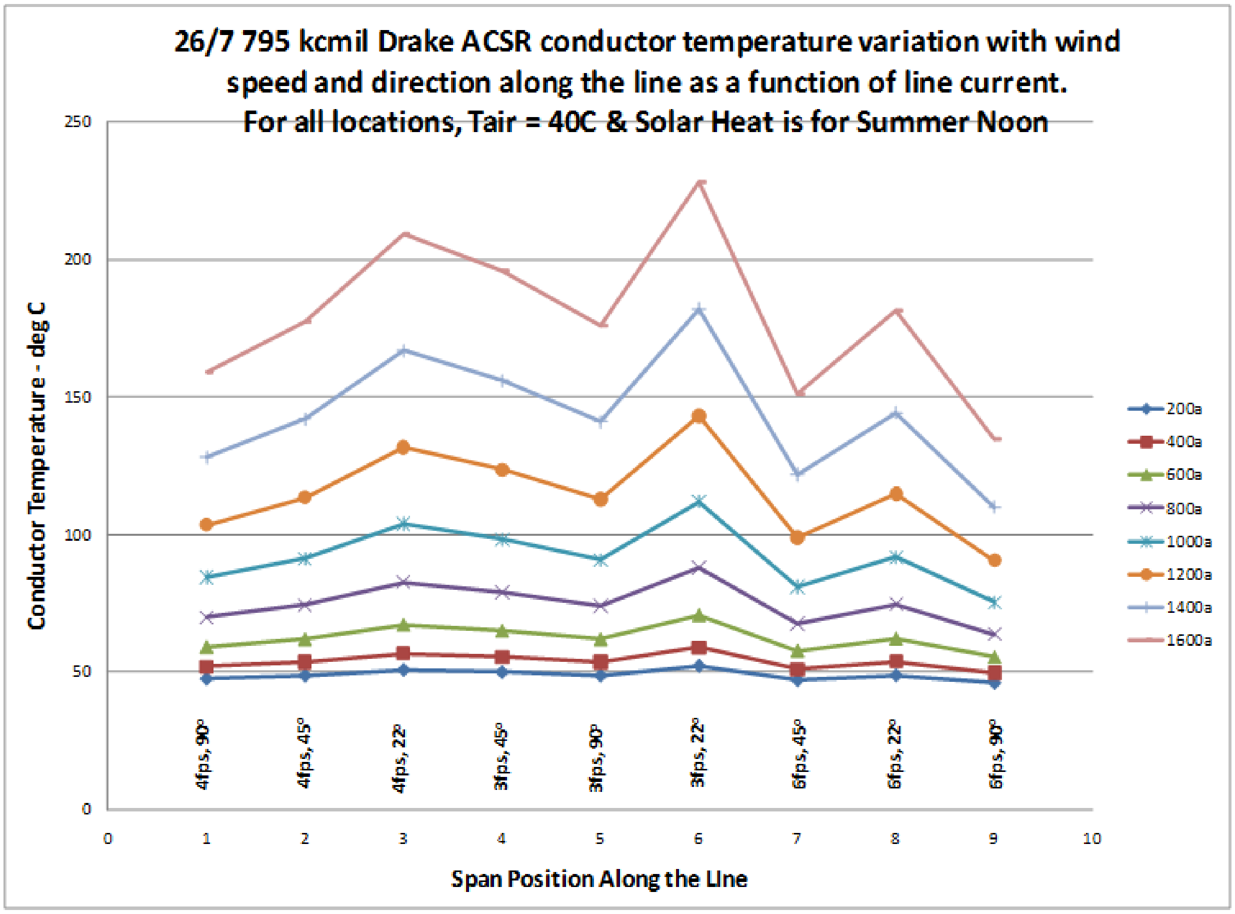


Figure 2-8
Span to span variation in conductor temperature due to wind speed and direction variations along a line.

The use of temperature monitors on the conductor or anemometers adjacent to it, at a limited number of locations along the line may not give a good indication of the "average" temperature in the sag-section.

Instead of using many monitors or anemometers, a different type of conductor monitor, called a sag-tension monitor can be used. These devices do not measure temperature or wind speed and direction but rather either the conductor tension or the conductor sag which reflects the average temperature of the sag-section. Theoretically, at least, one such monitor can replace multiple temperature or wind monitors, and they measure the actual behavior of the line sag-tension change as a function of line current and weather.

As with anemometers and temperature monitors, calculation of the dynamic line rating also requires real-time air temperature, line current, and solar heat intensity but sag-tension monitors also require the experimental derivation of a calibration equation which relates the sag-tension parameter to the average sag-section conductor temperature which is then related to the effective perpendicular wind speed for the sag-section. This additional step is demonstrated in Figure 2-9.

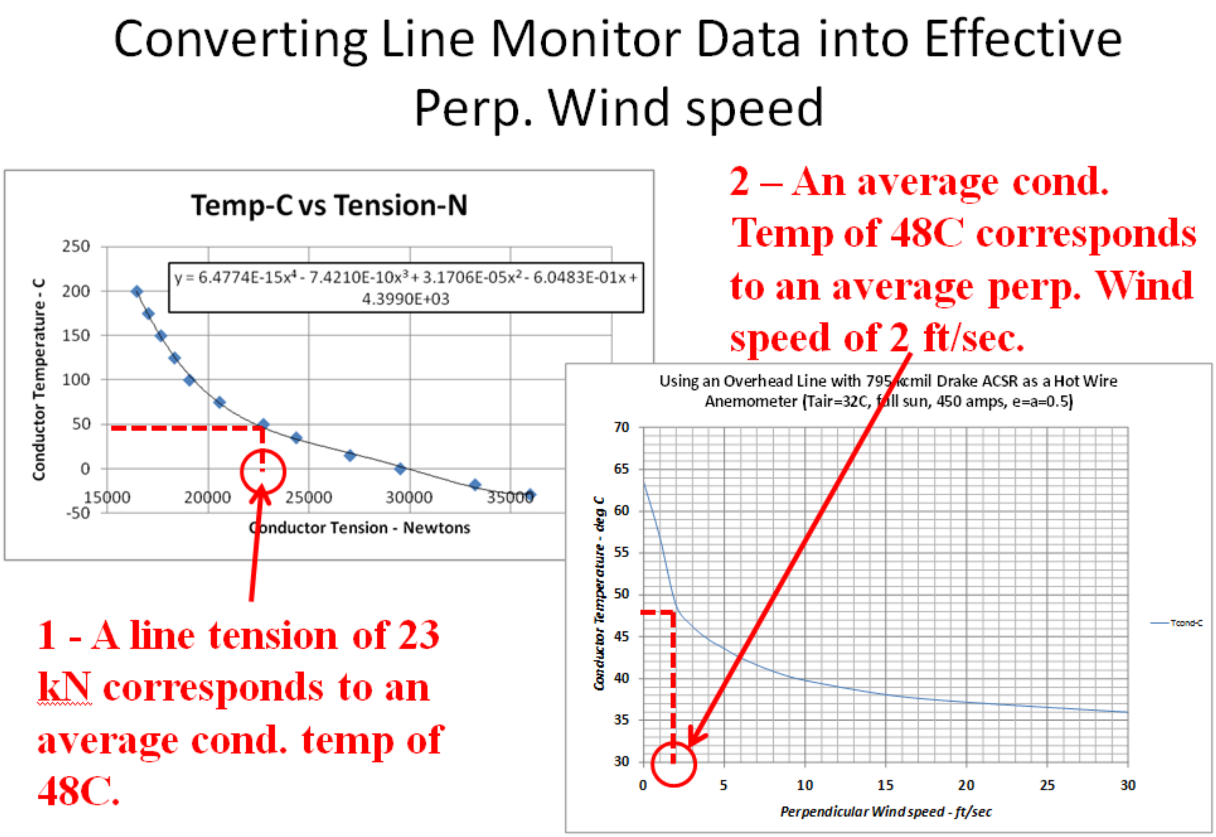


Figure 2-9
A demonstration of the two-step process for converting tension or sag or tension into an average sag-section perpendicular wind speed.

The disadvantage of this type of monitor is that, as is true of conductor temperature monitors, the line current has to be at least 0.25 to 0.5 amps/kcmil for the line rating to be reasonably accurate and the process of determining the calibration equation and verifying it can take a month or more. For instance, for the Video Sagometers installed in this NYPA project, the average conductor temperature as a function of sag, i.e. T(sag), must be defined (typically as a polynomial) in a process that involves modeling the physical construction of the line with a program such as SAG10 or PLSCAD, and then adjusting the model for as-built conditions by calibrating the model with samples of field data where the current is very low at night. This model must be checked and refined occasionally. The calibration equation T(sag) is sometimes referred to in the industry as a ***state-change equation***.

Finally, there is a controversial idea in the industry that perhaps wind measurements provided by on-line weather services could be used for line ratings instead of installing dedicated monitors in the transmission line right-of-way. The problem with this approach is that the online weather services data may not accurately represent, or even be correlated with, the weather in a line's corridor. It may be that for some sites this approach would work, and for others it will not work. This idea is being explored as part of the NYPA project.

3
INSTRUMENTATION, COMMUNICATIONS, SOFTWARE

Weather Station Air Temperature

Figure 3-1 Weather station array highlighting the temperature sensor

Air temperature and relative humidity probes typically consist of two separate sensors packaged in the same housing. Often relative humidity is measured with a capacitive RH sensor, while air temperature is measured by a PRT. Solar radiation shields are required for any of the sensors if they will be exposed to sunlight.

Perhaps the most common type of resistance temperature detector (RTD) is the platinum resistance thermometer (PRT), the practical operating range of which is -250 to 850 °C. Depending on type, RTDs have an accuracy of between 0.03 and 0.3 °C. The most frequently used PRT is the Pt100 — so called because it has a resistance of 100 Ω at 0 °C.

PRTs are either wire-wound or metal film resistors. Of these, the latter exhibits the faster response time. As a Pt100 sensor is basically a resistor, its value can be measured with an Ohmmeter. However, the low resistance of the sensor and its low sensitivity (0.385 Ω/°C) make accurate measurements difficult due to lead resistance. A 1 Ω resistance in each lead connecting the Pt100 to the meter will cause an error of more than 5 °C.

To avoid the problem of lead resistance errors, most Pt100 measurements are made using a 4-wire configuration. Here, two of the wires are used to provide an excitation current and the other two connect a voltmeter over the PRT. Provided the impedance of the voltmeter is high then a few Ohms of resistance in the cables will not cause an error.

The HMP60 probe measures temperature for the range of -40° to 60°C, and relative humidity for the range of 0 to 100% RH. It is suitable for long-term, unattended monitoring, and is compatible with all Campbell Scientific dataloggers.

Make and model number: Vaisala HMP60

Data should reported in degrees C

Figure 3-2 Temperature sensor removed from housing, housing shown to the right of the sensor

Weather Station Humidity

Figure 3-3 Weather station array highlighting the humidity sensor

SHT7x (including SHT71 and SHT75) is Sensirion's family of relative humidity and temperature sensors with pins. The sensors integrate sensor elements plus signal

processing in compact format and provide a fully calibrated digital output. A unique capacitive sensor element is used for measuring relative humidity while temperature is measured by a band-gap sensor. The applied CMOSens® technology guarantees excellent reliability and long term stability. Both sensors are seamlessly coupled to a 14bit analog to digital converter and a serial interface circuit. This results in superior signal quality, a fast response time and insensitivity to external disturbances (EMC).

Humidity and temperature sensors have been put together in one unit, the Vaisala HMP60 sensor.

Data should be reported in terms of a percent relative humidity.

Figure 3-4 Temperature sensor removed from housing, temperature and humidity sensors are combined into one unit

Weather Station UV

Figure 3-5 Weather station array highlighting the solar radiation sensor

The CS300 measures total sun and sky solar radiation for solar, agricultural, meteorological, and hydrological applications. Its spectral range of 300 to 1000 nanometers encompasses most of the shortwave radiation that reaches the Earth's surface. This pyranometer connects directly to the dataloggers which measure its output.

Photosynthetically active radiation, often abbreviated PAR, designates the spectral range (wave band) of solar radiation from 400 to 700 nanometers that photosynthetic organisms are able to use in the process of photosynthesis. This spectral region corresponds more or less with the range of light visible to the human eye. Photons at shorter wavelengths tend to be so energetic that they can be damaging to cells and tissues, but are mostly filtered out by the ozone layer in the stratosphere. Photons at longer wavelengths do not carry enough energy to allow photosynthesis to take place.

PAR measurement is used in agriculture, forestry and oceanography. One of the requirements for productive farmland is adequate PAR, so PAR is used to evaluate agricultural investment potential. PAR sensors stationed at various levels of the forest canopy measure the pattern of PAR availability and utilization. Photosynthetic rate and related parameters can be measured non-destructively using a photosynthesis system, and these instruments measure PAR and sometimes control PAR at set intensities. PAR measurements are also used to calculate the euphotic depth in the ocean. PAR is normally quantified as µmol photons/m^2/second, which is a measure of the photosynthetic photon flux (area) density, or PPFD. PAR can also be expressed in W/m^2. W/m^2 measurements are important in energy balance considerations for photosynthetic organisms. Because photosynthesis is a quantum process, PPFD is generally used by plant biologists.

Make and Model number: Apogee CS300

Data should be reported in Watts per meter squared.

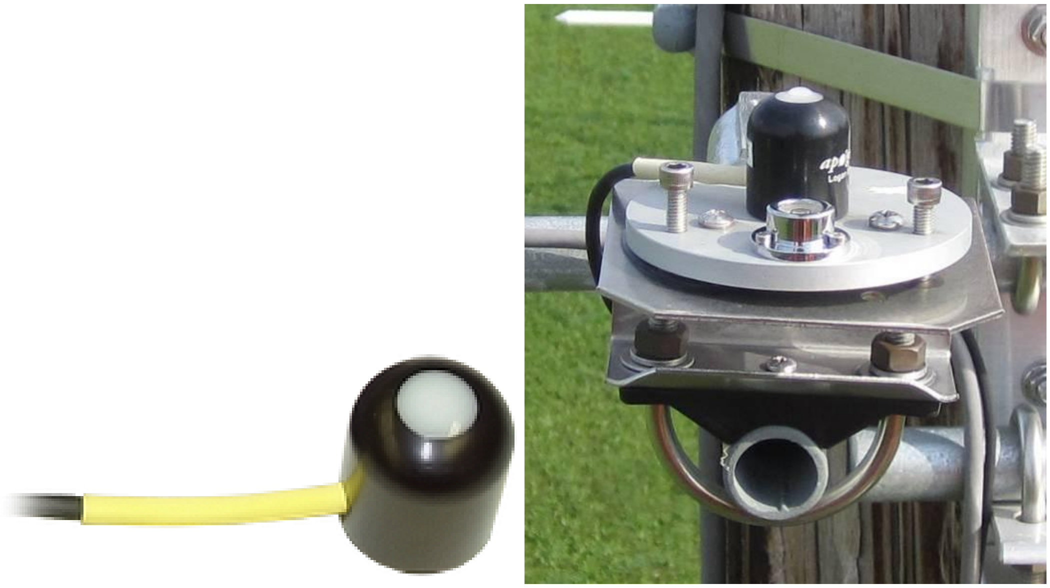


Figure 3-6 solar radiation sensor removed from mounting plate

Weather Station Rain

Figure 3-7 Weather station array highlighting the rain gauge sensor

The TE525 tipping bucket rain gage has a 6-in. orifice and measures rainfall in 0.01-in. increments. It is compatible with all Campbell Scientific dataloggers, and is widely used in environmental monitoring applications.

The tipping bucket rain gauge consists of a funnel that collects and channels the precipitation into a small seesaw-like container. After a pre-set amount of precipitation falls, the lever tips, dumping the collected water and sending an electrical signal.

The advantage of the tipping bucket rain gauge is that the character of the rain (light, medium, or heavy) may be easily obtained. Rainfall character is decided by the total amount of rain that has fallen in a set period (usually 1 hour) and by counting the number of 'clicks' in a 10 minute period the observer can decide the character of the rain.

The tipping bucket rain gauge is not as accurate as the standard rain gauge because the rainfall may stop before the lever has tipped. When the next period of rain begins it may take no more than one or two drops to tip the lever. This would then indicate that pre-set amount has fallen when in fact only a fraction of that amount has actually fallen. Tipping buckets also tend to underestimate the amount of rainfall, particularly in snowfall and heavy rainfall events

Make and Model number: Texas Electronics TE525

Figure 3-8 Tipping bucket rain gauge mounted on a aluminum tube

Weather Station Wind Speed and Wind Direction

Figure 3-9 Weather station array highlighting the three axis sonic wind sensor

The RM Young Model 81000 Ultrasonic Anemometer is a 3-axis, no-moving-parts wind sensor. It is ideal for applications requiring fast response, high resolution and three-dimensional wind measurement.

The sensor features durable corrosion-resistant construction with 3 opposing pairs of ultrasonic transducers supported by stainless steel members. Each 81000 is individually wind-tunnel calibrated. Wind and sonic temperature data is available on four voltage output channels

Sonic anemometers, first developed in the 1970s, use ultrasonic sound waves to measure wind velocity. They measure wind speed based on the time of flight of sonic pulses between pairs of transducers. Measurements from pairs of transducers can be combined to yield a measurement of velocity in 1-, 2-, or 3-dimensional flow. The spatial resolution is given by the path length between transducers, which is typically 10 to 20 cm. Sonic anemometers can take measurements with very fine temporal resolution, 20 Hz or better, which makes them well suited for turbulence measurements. The lack of moving parts makes them appropriate for long term use in exposed automated weather stations and weather buoys where the accuracy and reliability of traditional cup-and-vane anemometers is adversely affected by salty air or large amounts of dust. Their main disadvantage is the distortion of the flow itself by the structure supporting the transducers, which requires a correction based upon wind tunnel measurements to minimize the effect.

Make and Model number: RM Young 81000

Units are reported in feet per second.

Figure 3-10 3 axis wind speed and direction sensor. Note the wire junction box should always point south. This keeps the wind direction aligned to a known compass heading.

Sagometer Camera Unit

Figure 3-11 Side view of the Sagometer

To measure sag a camera is used to detect the position of a target that is mounted on the transmission line 150 feet away from the face of the camera. The camera has an image of the target stored in memory it then compares this image with the one it is currently seeing. Once the pattern of the target is identified in the image the camera locates the target in the image. It does this by counting pixels. Each pixel has been calibrated to equal a distance at 150 feet. In this way the camera can be used to determine the location of the target within its field of view. The camera also has tilt sensors, accelerometers that can help correct for small variation of camera movement that may be a result of solar heating of a steel pole.

Figure 3-12 Camera unit installed showing the front of the camera. The laser target illumination is mounted inside the camera unit.

EPRI Sensors Conductor temperature

On board thermally isolated thermocouples are used to determine conductor temperature. Significant RD has gone into making this device to ensure accurate conductor temperature. The device was originally designed to measure spice temperatures.

EPRI Sensors Line inclination

Line inclination sensor is experimental at this stage. Fundamentally it is a 3 axis accelerometer. There is a unique relationship between line inclination and the temperature of the conductor. From line inclination sag can be determined. Once sag has been determined line temperature can be determined. Once line temperature has been determined and if the current is high enough, effective perpendicular wind speed can be determined. The advantage of using line inclination is that the entire ruling span section can be rated as opposed to rating only one point along the line.

EPRI Sensors Current

Perhaps the most valuable sensor in the EPRI sensor is the current sensor. This sensor serves two functions. Fundamentally the sensor is a coil of wire that is in close proximity to the conductor. This coil is magnetically coupled to the conductor. This coupling allows the sensor to charge the on board batteries. It also functions as a CT to determine the amount of current flowing down the line. Because the coil is in close proximity to, but not looped around the conductor, it is highly sensitive to small position changes. Consequently the sensor must be calibrated after it is installed.

Figure 3-13 EPRI sensor mounted to the conductor.

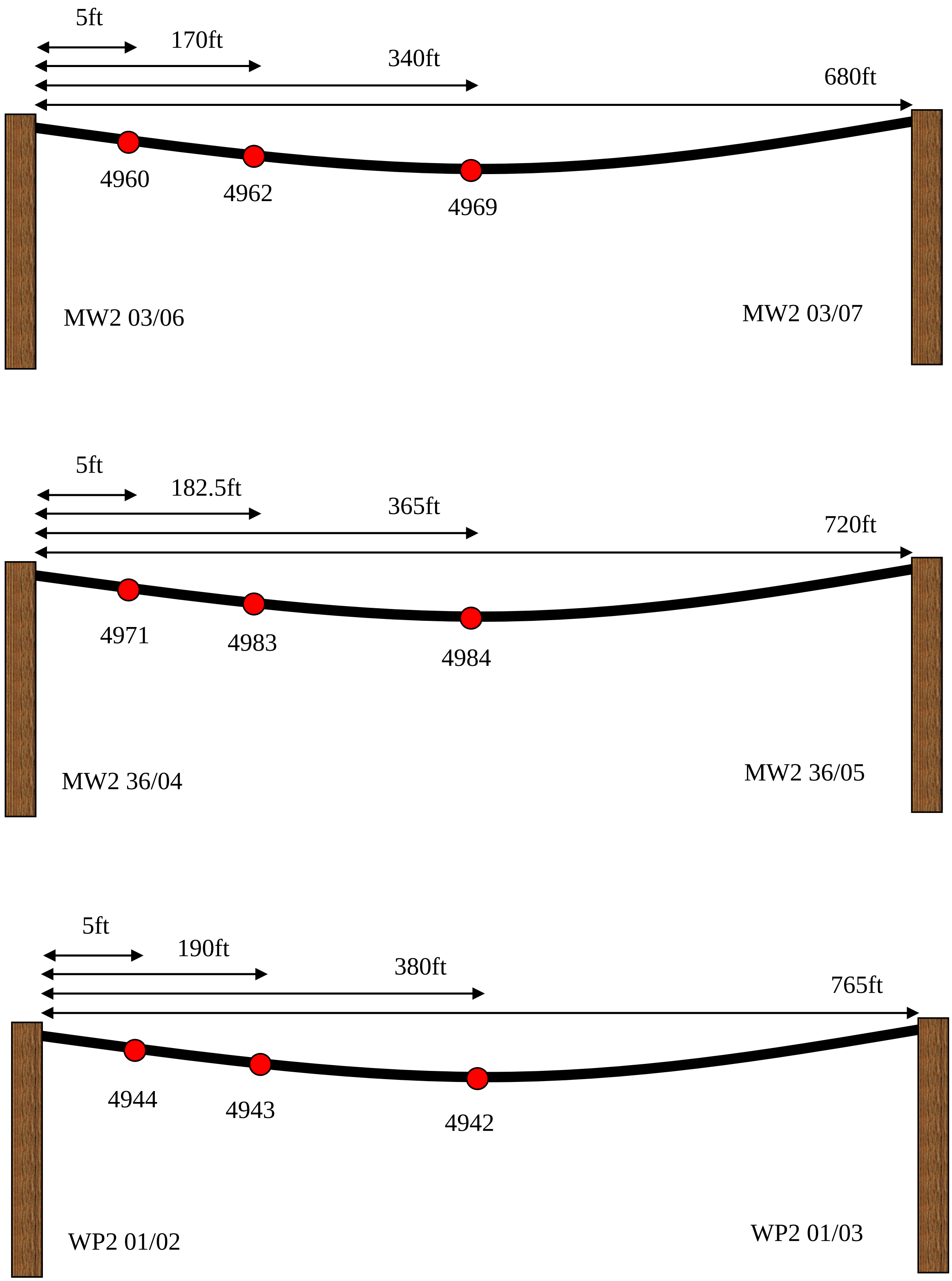


Figure 3-14 Positions of EPRI sensors

ThermalRate Effective perpendicular wind speed

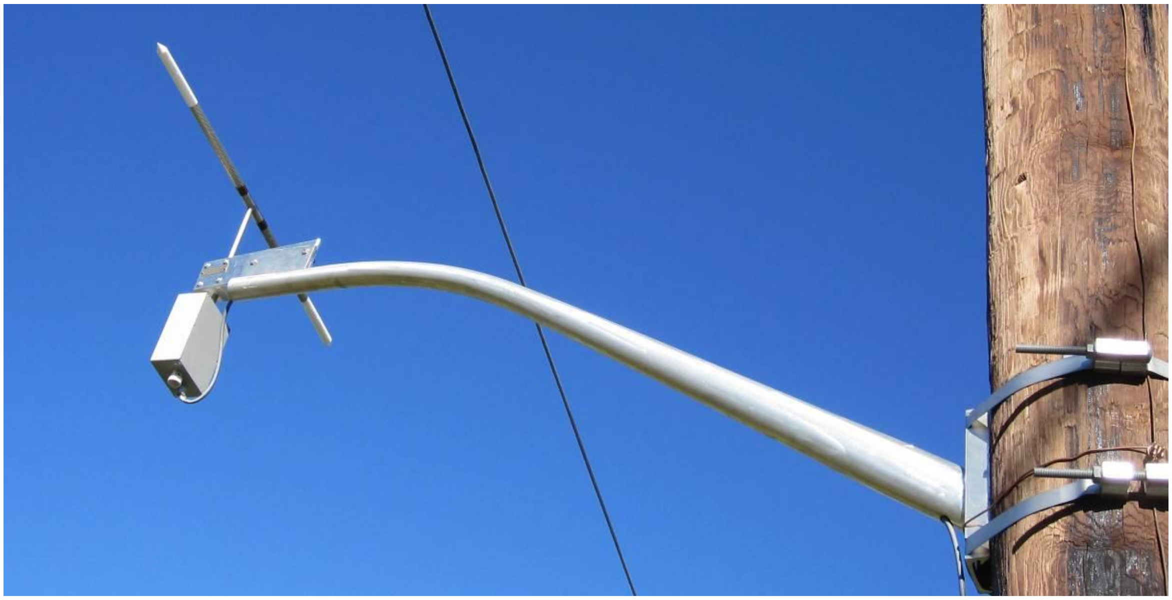


Figure 3-15 ThermalRate sensor. One side of this sensor is heated and the other side is cold.

The Sensor consists of two parallel replicas of line conductor and mimics how the line behaves in the given weather conditions. The replicas have the same material, diameter, and surface as the line and are each approximately one foot in length. The Sensor is installed in the vicinity of the line. It is mounted at the average conductor height and oriented parallel to the line in order to see the same weather conditions as the line itself. Units are reported in feet per second perpendicular to the line.

Thermal Rate Current from EMS

Spread spectrum radio connects the ThermalRate system to the utility EMS system. This requires the utility make changes to an RTU so that it can send data to the ThermalRate system.

Data Loggers

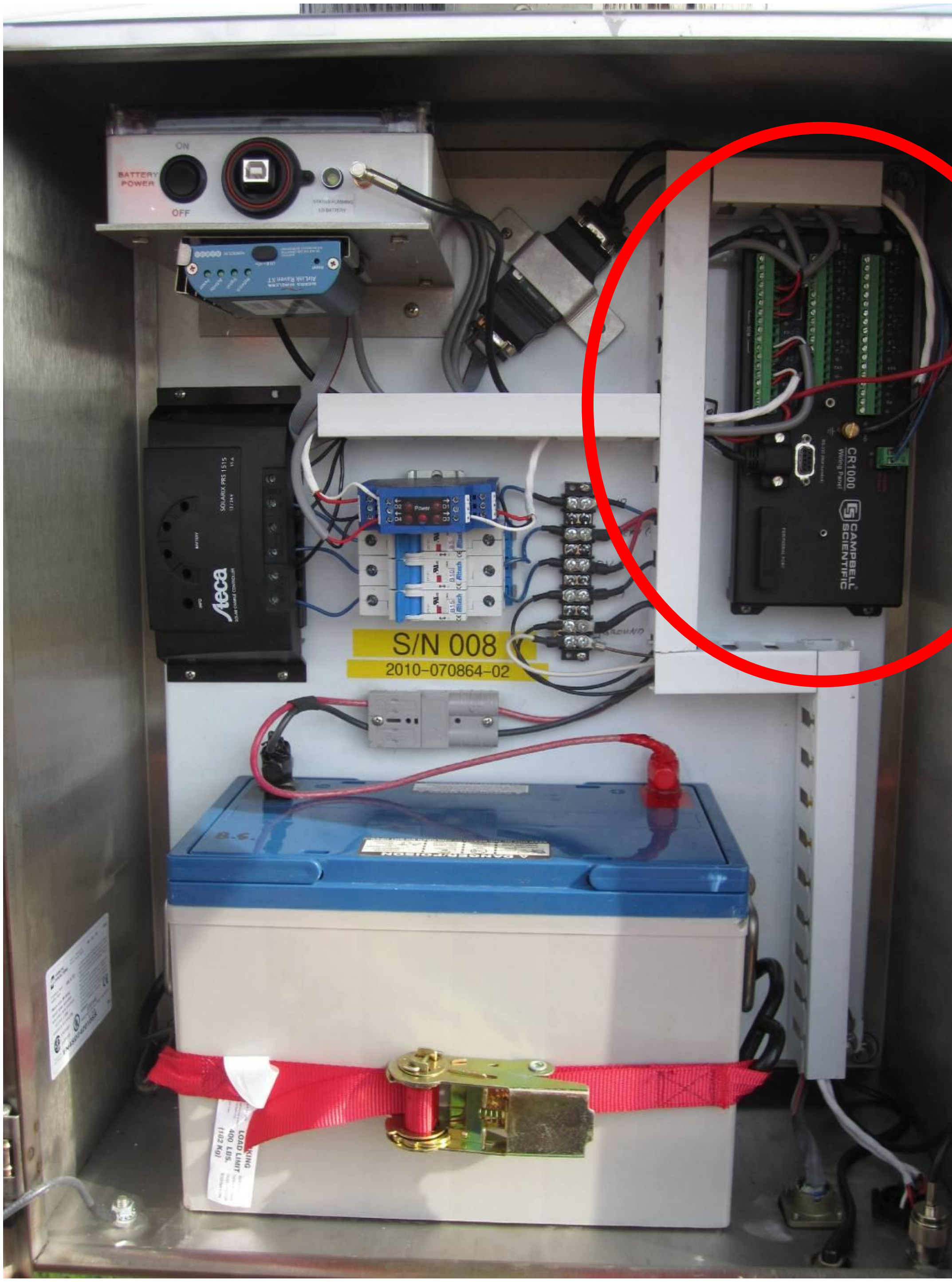


Figure 3-16 EPRI sensor electronics box. Highlighted item shown here is the Campbell Scientific CR1000 data logger

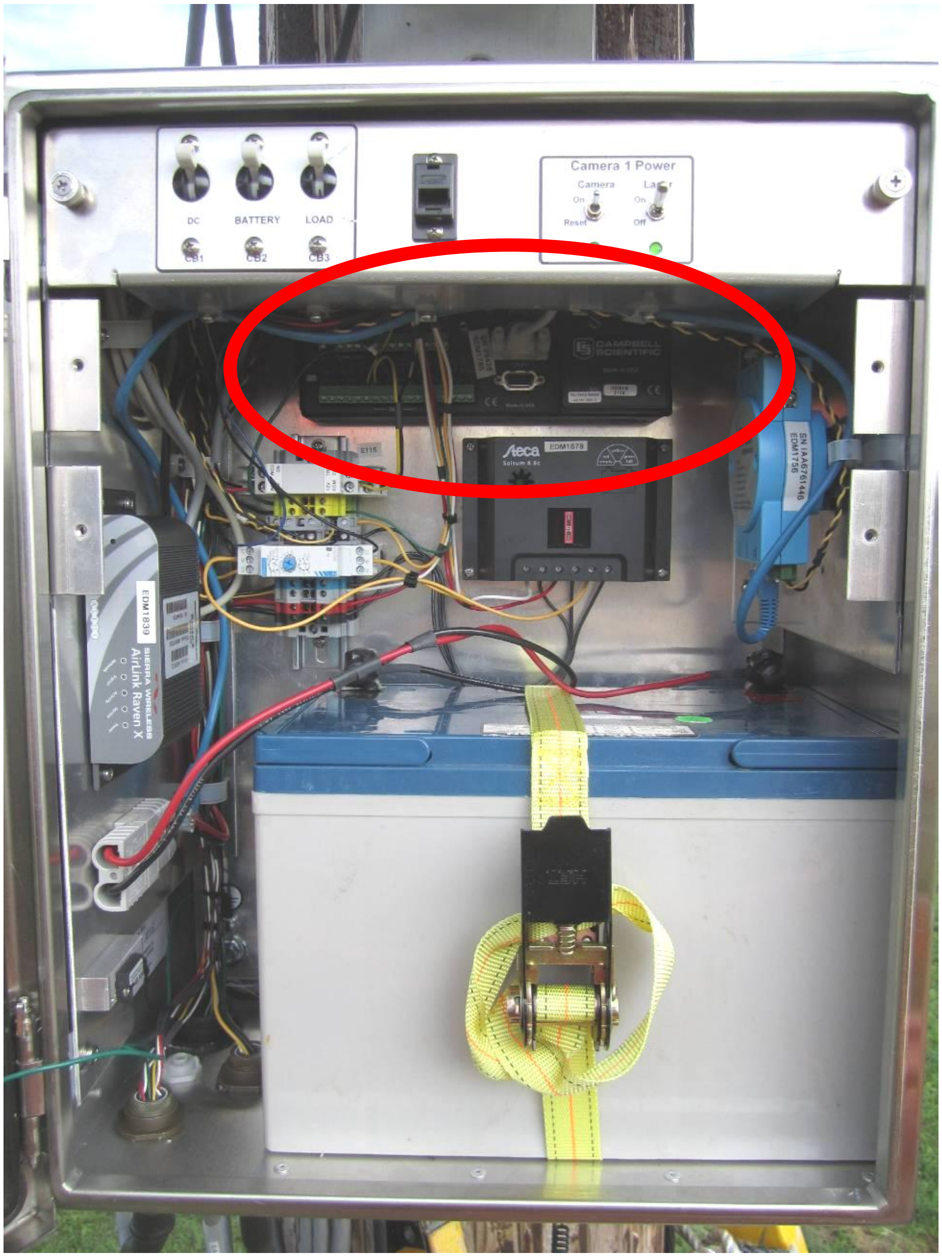


Figure 3-17 Sagometer electronics box. Highlighted item shown here is the Campbell Scientific CR1000 data logger

Sensors communicate with data loggers. These can be digital or analog signals. The signal can be directly wired into the logger or wireless. The loggers can store the data for long periods of time between download. However, eventually, if the data is not retrieved, the data starts to get overwritten. The loggers used for this project are Campbell Scientific CR1000.

Specifications for the CR1000

4 Mbyte memory

Program execution rate of up to 100 Hz

CS I/O and RS-232 serial ports

13-bit analog to digital conversions

16-bit H8S Renesas Microcontroller with 32-bit internal CPU architecture

Temperature compensated real-time clock

Background system calibration for accurate measurements over time and temperature changes

Single DAC used for excitation and measurements to give ratio metric measurements

Gas Discharge Tube (GDT) protected inputs

Data values stored in tables with a time stamp and record number

Battery-backed SRAM memory and clock ensuring data, programs, and accurate time are maintained while the CR1000 is disconnected from its main power source

Serial communications with serial sensors and devices supported via I/O port pairs

PakBus®, Modbus, DNP3, TCP/IP, FTP, and SMTP protocols supported

Figure 3-18 Isolated view of the Campbell Scientific Data logger

Communications Layout diagrams

These diagrams were made during the design stage of this project. The purpose of these simple diagrams is to show the data flow along with the mode of communications.

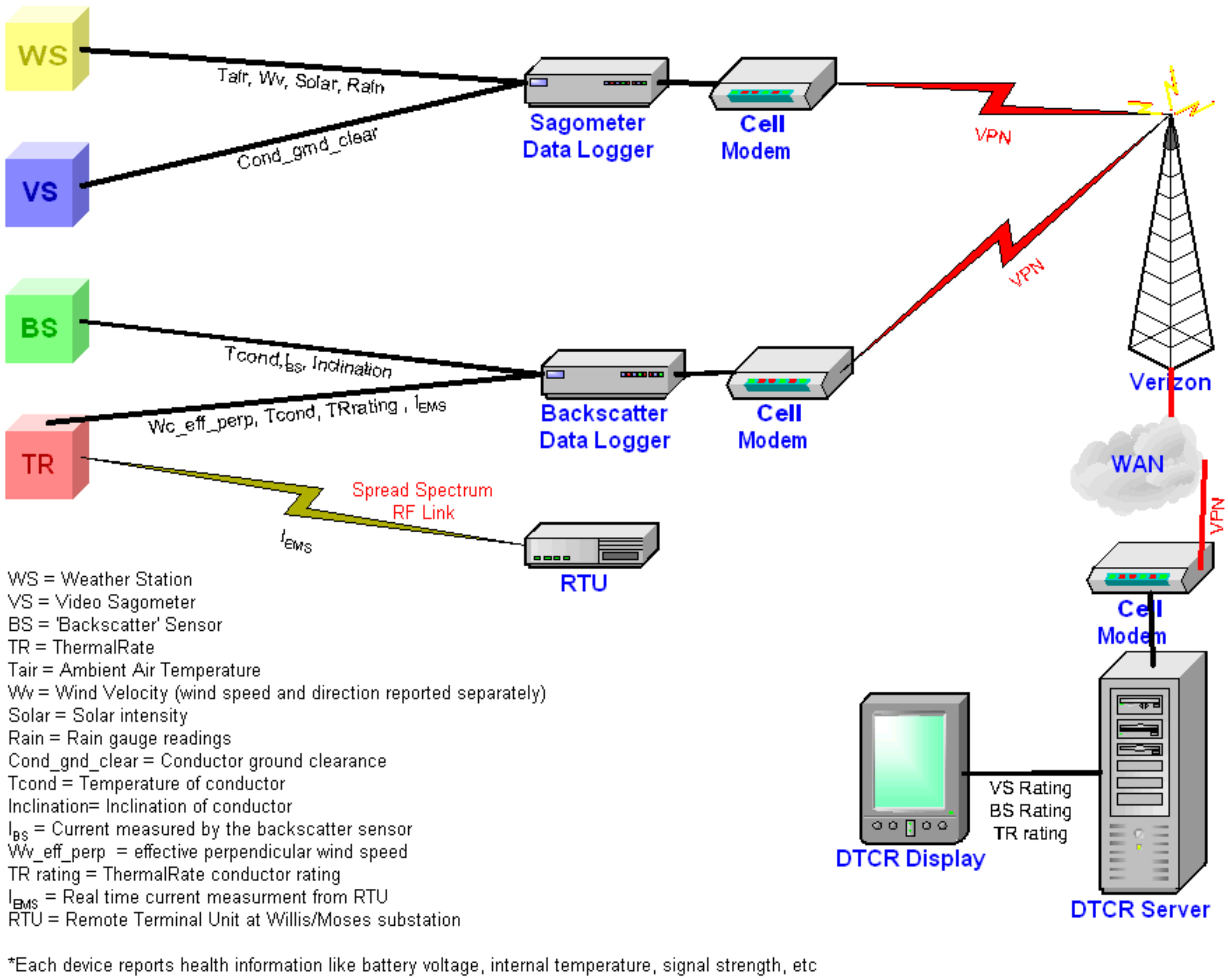


Figure 3-19 Overall communications layout

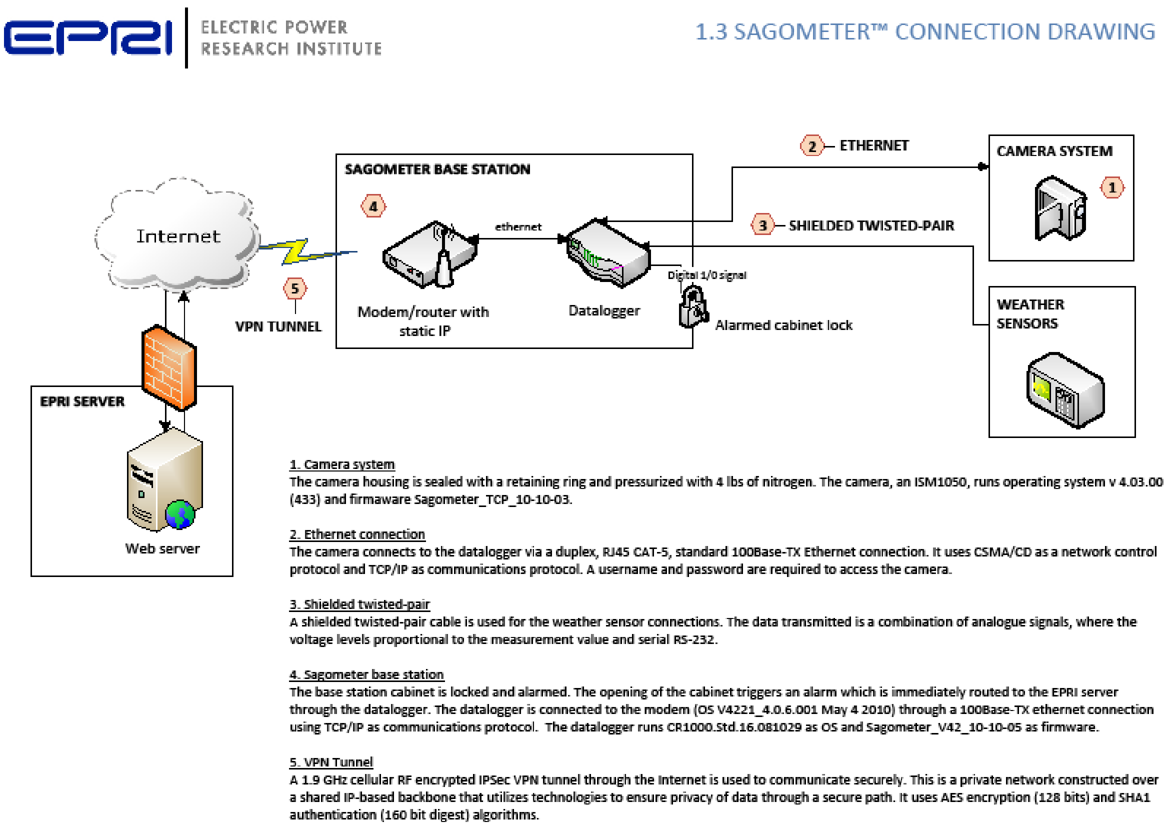


Figure 3-20 Detailed communications layout for Sagometer

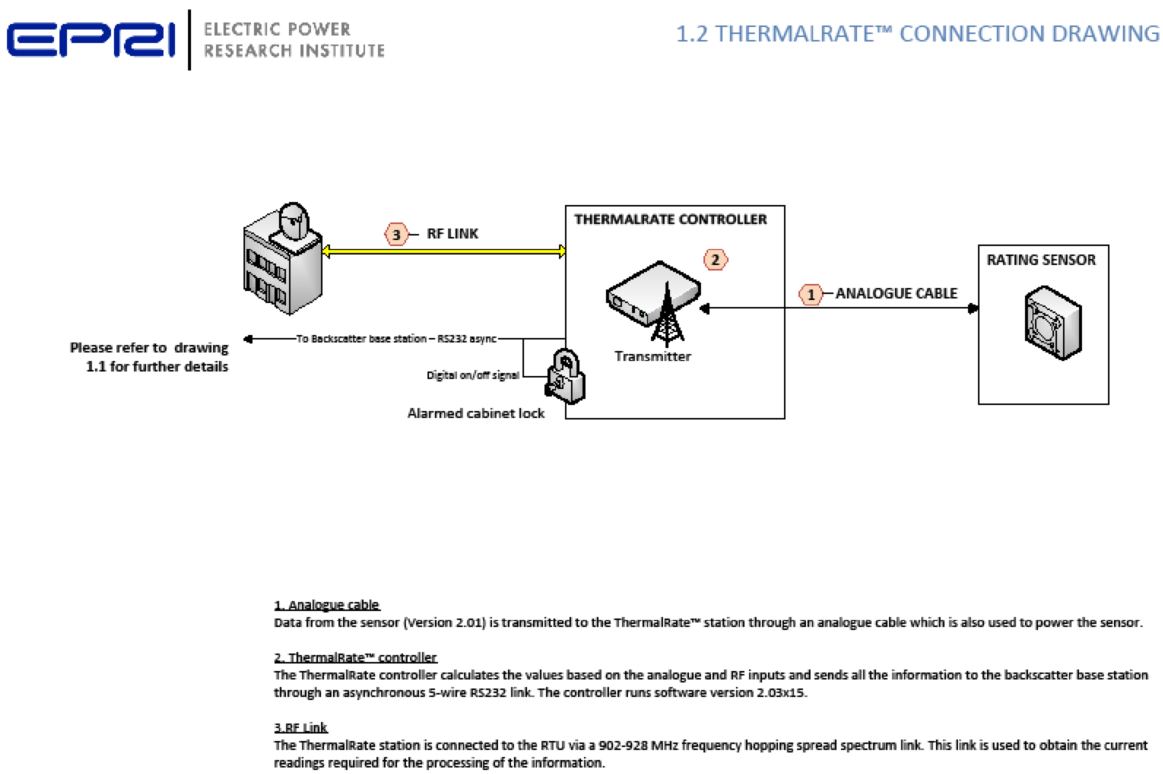


Figure 3-21 Detailed communications layout for ThermalRate

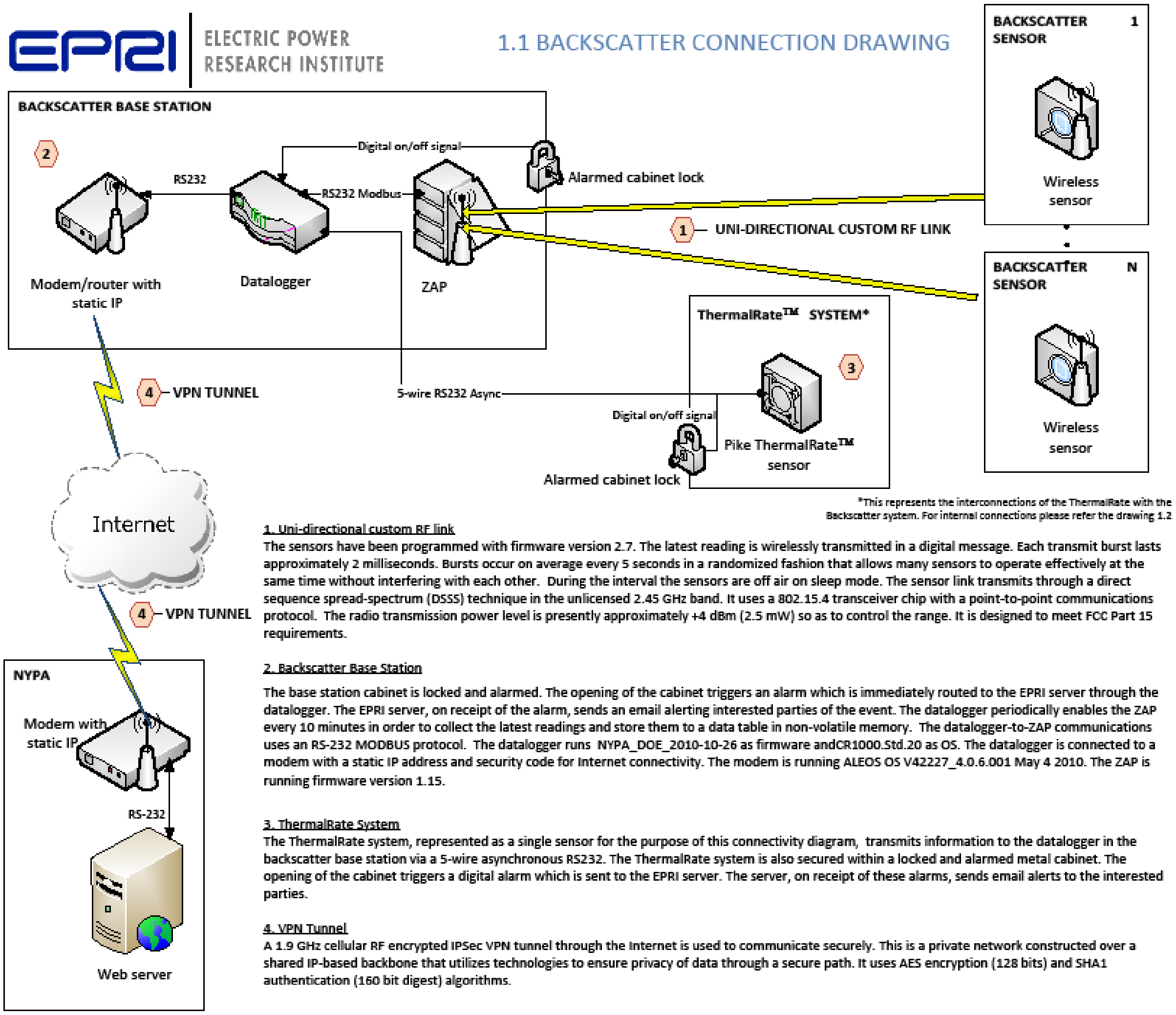


Figure 3-22 Detailed communications layout for EPRI Sensor system

Modems

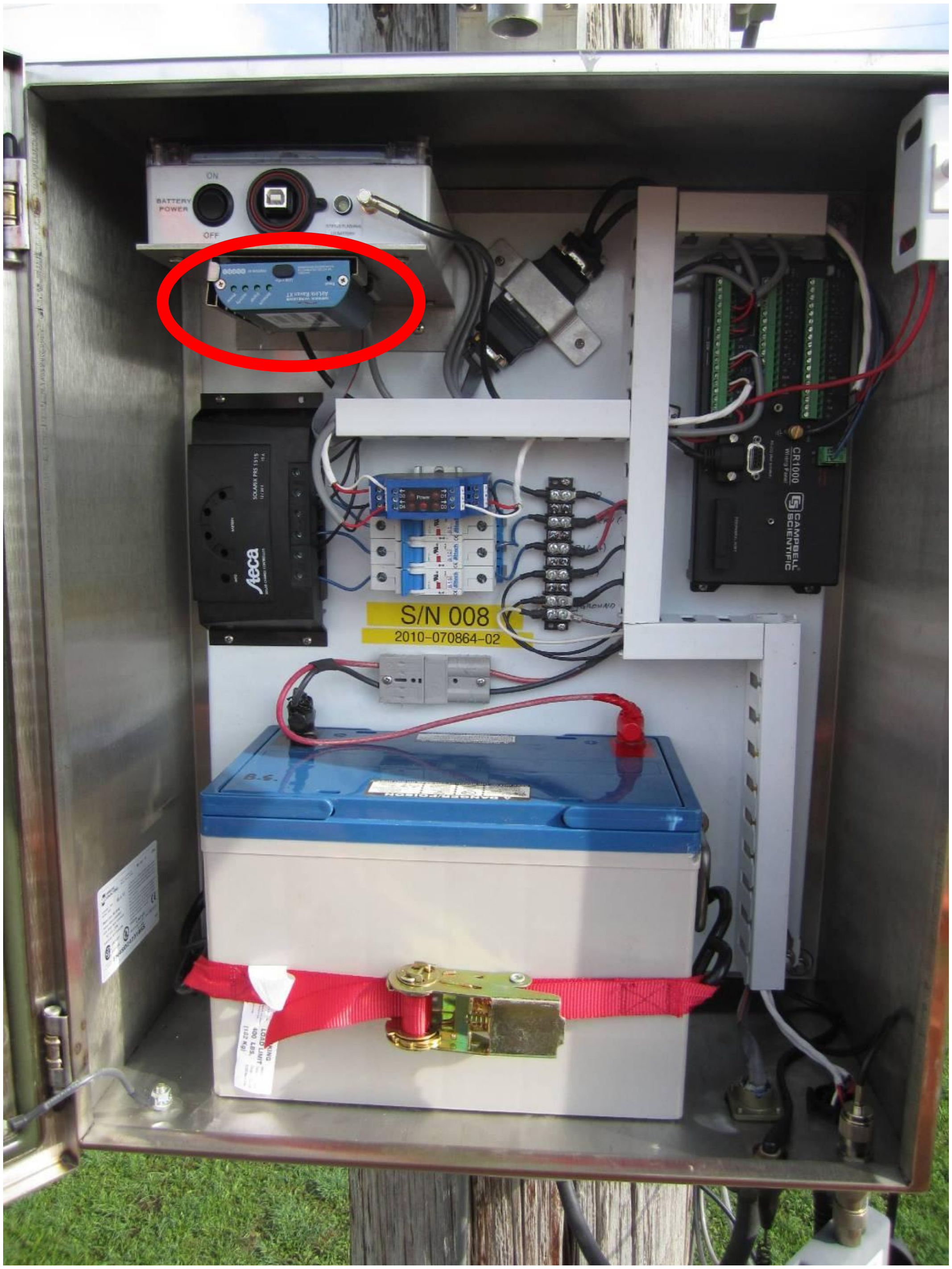


Figure 3-23 EPRI sensor electronics box. Highlighted item shown here is the Sierra wireless raven XT modem

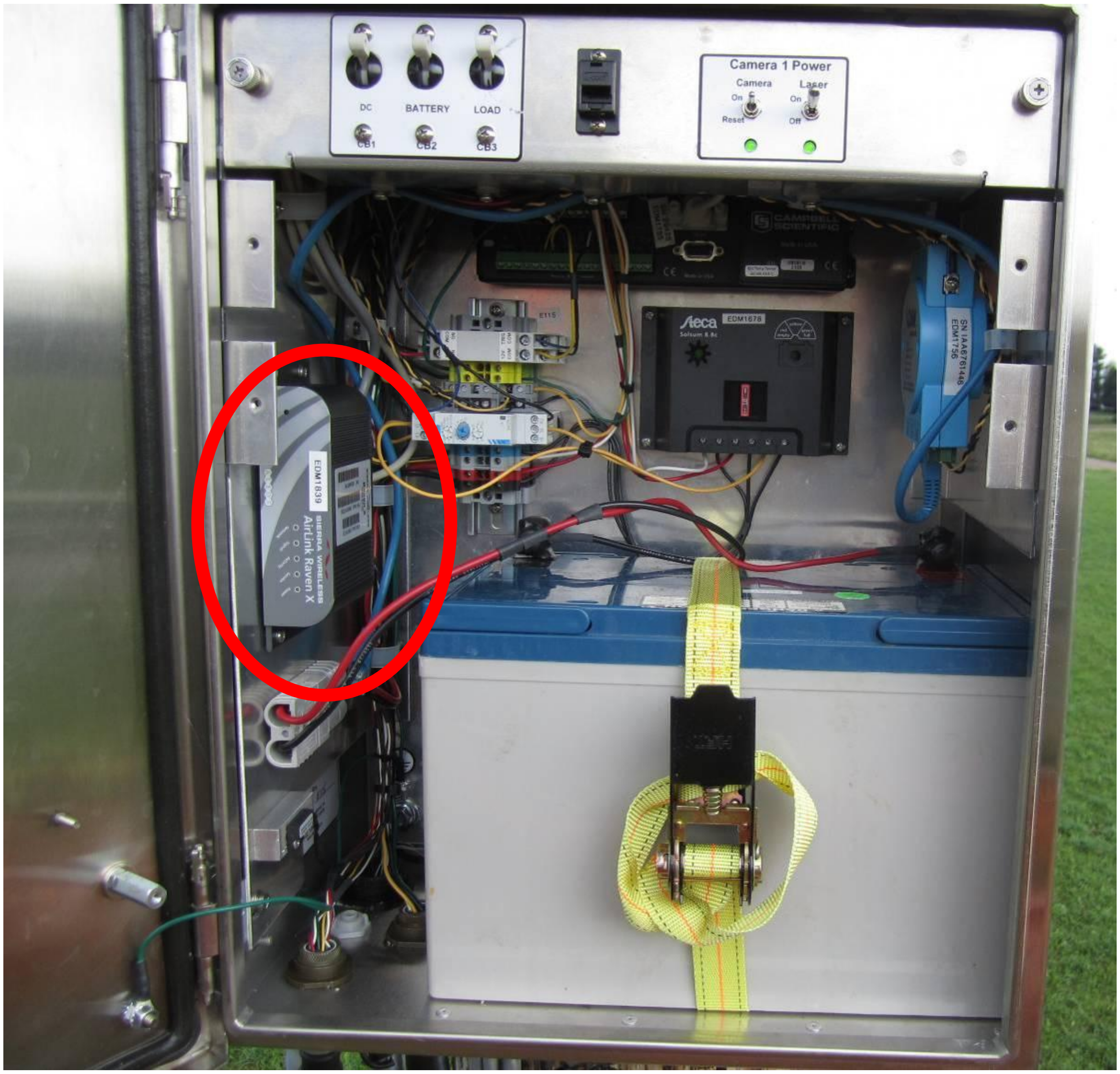


Figure 3-24 Sagometer electronics box. Highlighted item shown here is the Sierra wireless raven X modem

Cellular modems are used to move the data from the data loggers to the web. The Raven X is a wireless networking device designed to utilize 3G networks. Its Ethernet port makes the Raven X useful for enterprise applications, while the serial port and embedded machine protocols make it suited for industrial deployments. IPsec VPN provides security for the most sensitive data. In this case a VPN tunnel is established between the modem and the server downloading the data. Verizon is the cellular carrier for this project. The modems used are Sierra Wireless Raven X and Sierra Wireless Raven XT.

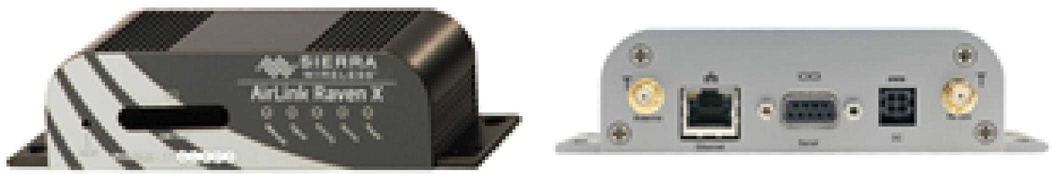


Figure 3-25 Isolated front and rear view of Raven X This modem is used by the Sagometer

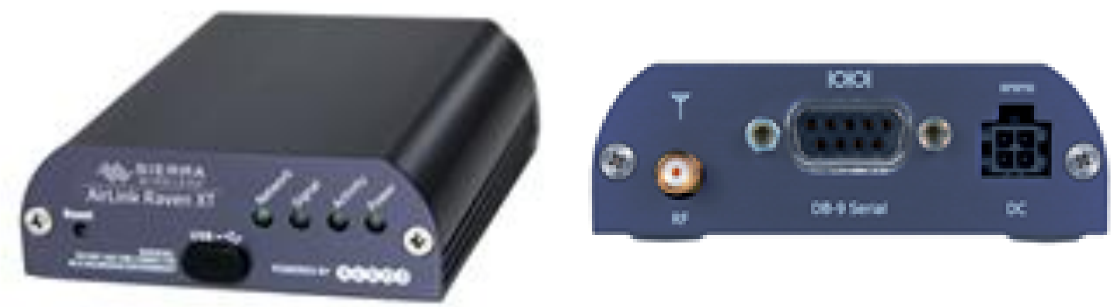


Figure 3-26 Isolated front and rear of view Raven XT This modem is used by the EPRI Sensor system and the server

IP Address information

Moses Substation is about 8 miles NW of Massena, NY (Harvestock Rd)
Willis Substation is in the Town of Chateauguay, NY (Willis and Hartnett Rd)

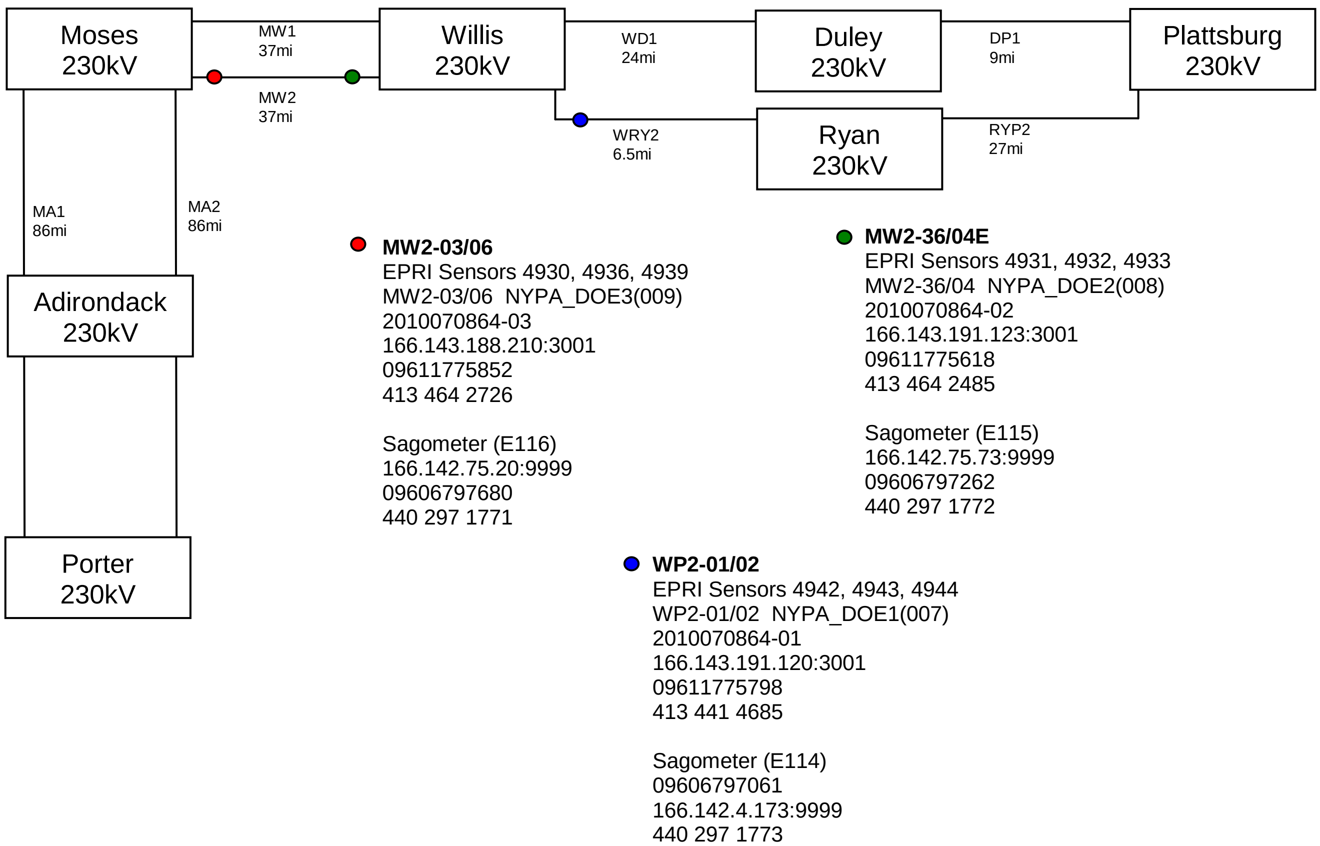


Figure 3-27 Modem Location and other critical information

VPN information

A virtual private network (VPN) is a mechanism for providing secure, reliable transport over Internet. The VPN uses authentication to deny access to unauthorized users, and encryption to prevent unauthorized users from reading the private network packets. The VPN can be used to send any kind of network traffic securely.

VPNs are frequently used by remote workers or companies with remote offices to share private data and network resources. VPNs may also allow users to bypass regional internet restrictions such as firewalls, and web filtering, by "tunneling" the network connection to a different region.

Technically, the VPN protocol encapsulates network data transfers using a secure cryptographic method between two or more networked devices which are not on the same private network, to keep the data private as it passes through the connecting nodes of a local or wide area network.

See appendix for details about setup. Note that some IP addresses may have changed.

Server

Server hardware specifications are shown below.

HP Prolient DL320 G6 Server

Quad-Core Intel Xeon processor E5520 2.26 Ghz 8M Cache

HP 6GB PC3-10600E 3x2GB 2Rank Memory

P410/256MB with Battery (SAS Array Controller)

HP 8-Bay Drive Cage

HP 9.5nm SATA DVD ROM Drive

Embedded NC326i Dual Port Gigabit Server Adapter

2 HP 400W power supplies

Integrated Lights Out 2 (proliant onboard administrator powered by integrated lights out -2)

HP 146GB Hot Plug 2.5 SAS Dual Port 10000 rpm hard drive

HP 1.83m 10A C13-UL US power cord

HP iLO Port option kit

The operating system on the computer is Windows Server 2003.

Software that runs on the NYPA DTCR server

EPRI DTCR

EPRI DAP

Campbell Scientific LoggerNET

Sierra Wireless software

Other EPRI experimental software

Two wireless modems are connected to the server because 1 modem can only handle 5 VPN connections and the system requires 6 VPN tunnels. The server has multiple drives so it is running RAID. Currently the data is FTPed to an internal EPRI server where it is backed up. EPRI is exploring this concept of a wireless secure FTP connection second server.

Figure 3-28 HP Prolient DL320 G6 Server

Campbell Scientific LoggerNet Software

LoggerNet is the Campbell Scientific datalogger support software package. It supports programming, communication, and data retrieval between dataloggers and a PC. LoggerNet consists of a server application and several client applications integrated into a single product. It can support connection to a single datalogger, but is adept in applications that require telecommunications or scheduled data retrieval used in large datalogger networks. Version 4 is the most recent version of LoggerNet that features a new tool for designing and configuring PakBus® networks, a more powerful file viewer, an upgrade to RTMC, a redesigned toolbar, and many updates to existing clients.

Static IP addresses are assigned to each modem in the system. Future systems may change this to dynamic allocation. However, for this system that utilizes a VPN link, EPRI elected to use static IP addresses. The data loggers run code that is developed by the vendors. That code produces data tables, much like an MS Excel spread sheet. These tables exist in the data loggers memory. The LoggerNet software then connects to the loggers via the wireless modems. LoggerNet compares the data in the server with the data on the logger, after determining what new data is available on the logger it downloads the information to the server. For overhead lines this download interval is typically 5 or 10 minutes. The data tables are saved as files on the server with the file extension of *.DAT. DTCR can directly read these *.DAT files.

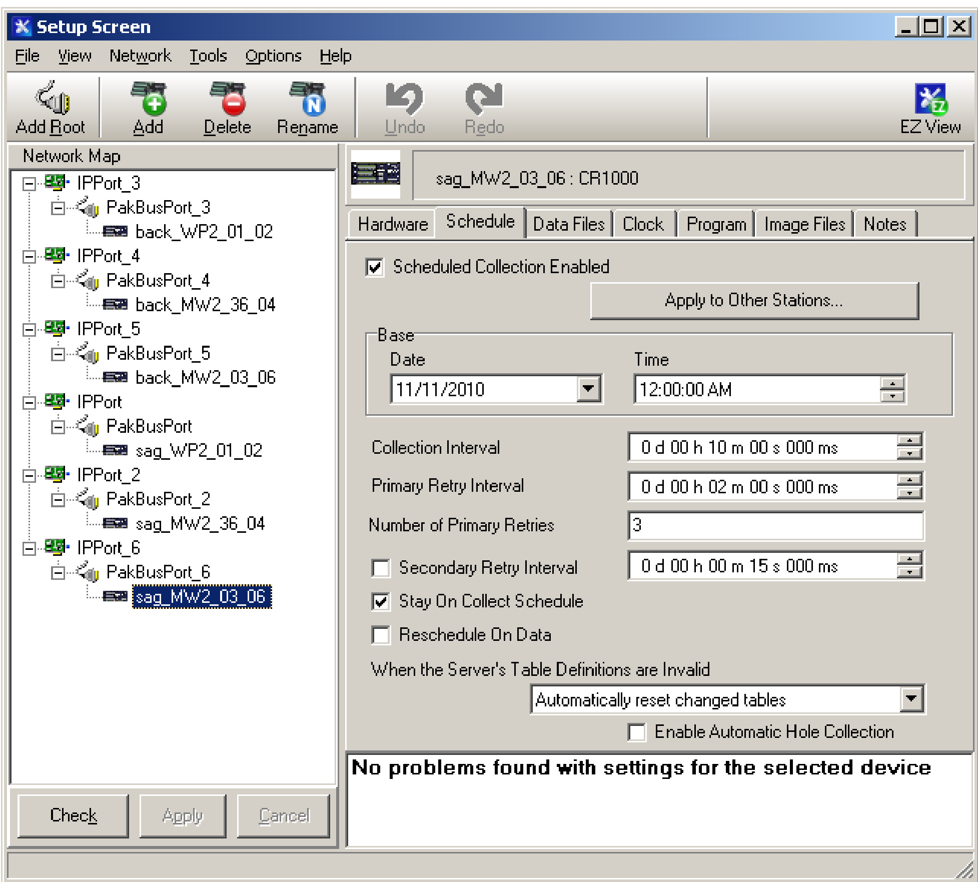


Figure 3-29 View of Campbell Scientific LoggerNet Software

DTCR Software

The DTCR software is designed to accept real-time or simulated real-time inputs from a number of field sensors, and computes the normal (and emergency) ratings for overhead line segments, and for entire circuits. The results can be made available to operators in real-time, or can be used in studies to evaluate a utility's approach to acceptable rating levels in general.

In 1993, EPRI initiated a project to develop and field test software which would allow the real-time thermal monitoring of transmission circuits. Certain existing thermal models for underground cables, overhead lines, power transformers, and substation equipment such as line traps, circuit breakers, bus, switches, and current transformers, were included in an integrated software model capable of calculating the dynamic thermal rating of transmission circuits which consist of one or more elements. Since that initial project, the software has gone through several fundamental revisions based on a series of field tests and installations at cooperating utilities. The latest version of the software was used during this project.

Dynamic (i.e. "real-time") thermal ratings are calculated based on actual weather conditions (e.g. air temperature, wind speed, etc.) and line monitoring equipment (such as the Video Sagometer) rather than using "worst-case" weather conditions as done for conventional static rating calculations. Also, simulations of dynamic operation based on archived data for an actual line can be useful in the evaluation of present rating methods, and can provide a database for making scientifically justified decisions about uprating methods.

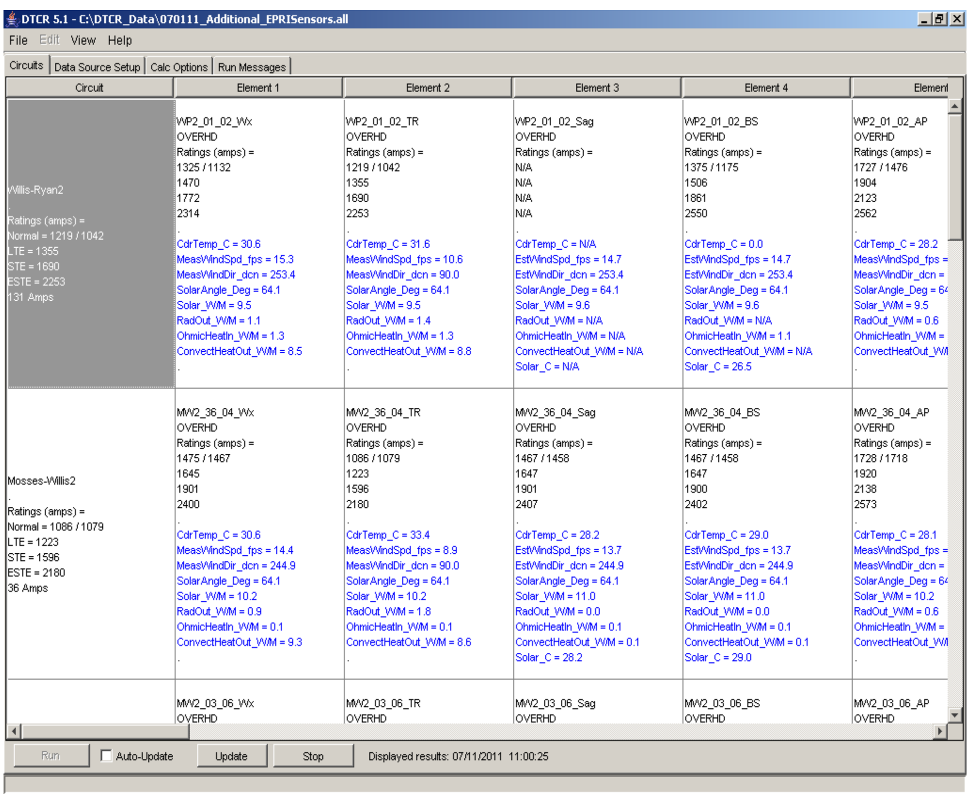


Figure 3-30 View of EPRI DTCR Software

Data Key Information

The output of the Campbell Scientific software is batch of data files. Included below are a number of data tables that will aid in decoding these files. These tables include the column header in the *.DAT file along with the description of that data. These files can be opened up in MS Excel using comas as the delimiter. Units can be difficult to manage in projects like this so it is important to keep tabs on this parameter. The Sagometer device will allow the end user to change the units without any additional data logger reprogramming.

Table 3-1 Thermal Rate data table structure

Thermal Rate		
Table column name	**Description**	**Units**
ThermalRateString(1)	Debug String	N/A
ThermalRateString(2)	Date	N/A
ThermalRateString(3)	Time	N/A
ThermalRateString(4)	Cold Rod Temperature	°C
ThermalRateString(5)	Hot Rod Temperature	°C
ThermalRateString(6)	Air Temperature	°C
ThermalRateString(7)	Heater Power	Watts
ThermalRateString(8)	Normal Rating	Amps
ThermalRateString(9)	1st Emergency Rating	Amps
ThermalRateString(10)	2nd Emergency Rating	Amps
ThermalRateString(11)	Conductor Temperature	°C
ThermalRateString(12)	Line Current	Amps
ThermalRateString(13)	Effective Wind Speed	ft/s

Table 3-2 Sagometer data table structure

Sagometer		
Variable Name	**Description**	**Units**
Sag_Avg(1,1)	Conductor clearance at target	ft
Sag_Avg(1,2)	Sag_Avg(1,1) corrected for twisting (rotating) of target from vertical	ft
Sag_Avg(1,3)	Sag_Avg(1,2) corrected for change in camera tilt	ft
Sag_Avg(1,4)	Conductor clearance at low-point on catenary, calculated from Sag_Avg(1,4) and low point parameters	ft
Sag_Avg(1,5)	Conductor Tension	ft
Sag_Avg(1,6)	Horizontal position of target Negative values = left of center Positive values = right of center	ft
Sag_Avg(1,7)	Twist (rotation) of target from vertical, caused by twisting of conductor	degrees
Sag_Avg(1,8)	Correlation/Score	n/a
Tilt_Avg(1)	Camera Tilt	degrees
Tilt_StdDev(1)	Camera Tilt, Standard Deviation	degrees
Sag_Avg(2,1)	Conductor clearance at target	ft
Sag_Avg(2,2)	Sag_Avg(2,1) corrected for twisting (rotating) of target from vertical	ft
Sag_Avg(2,3)	Sag_Avg(2,2) corrected for change in camera tilt	ft
Sag_Avg(2,4)	Conductor clearance at low-point on catenary, calculated from Sag_Avg(2,4) and low point parameters	ft
Sag_Avg(2,5)	Conductor Tension	lbs
Sag_Avg(2,6)	Horizontal position of target Negative values = left of center Positive values = right of center	ft
Sag_Avg(2,7)	Twist (rotation) of target from vertical, caused by twisting of conductor	degrees
Sag_Avg(2,8)	Correlation/Score	n/a
Tilt_Avg(2)	Camera Tilt	degrees
Tilt_StdDev(2)	Camera Tilt, Standard Deviation	degrees
AmbTemp_Avg	Ambient Temperature, Avg	C
Rad_Avg	Solar Radiation, Avg	W/m^2
Rain_Tot	Rain, Totalized	in
Humid_Avg	Relative Humidity, Avg	%
WSMax(1)	Wind Speed, Max, Anem #1	fps
WSAvg(1)	Wind Speed, Avg, Anem #1	
WDAvg(1)	Wind Direction, Avg, Anem #1	degrees
WDStdDev(1)	Wind Direction Standard Deviation, Anem #1	
WS3D_Avg	Wind Speed, 3D (includes vertical), Avg	fps
WDV_Avg	Wind Direction, Vertical Only, Avg	degrees
SOSAvg(1)	Speed of Sound, Anem #1	m/s
WSMax(2)	Wind Speed, Max, Anem #2	fps
WSAvg(2)	Wind Speed, Avg, Anem #2	
WDAvg(2)	Wind Direction, Avg, Anem #2	degrees
WDStdDev(2)	Wind Direction Standard Deviation, Anem #2	
SOSAvg(2)	Speed of Sound, Anem #2	m/s
BattVolt	Battery Voltage, Avg	volts
IntTemp	Internal Temperature, Avg	C

The data table below shows what units are available for on the fly adjustment within the Video Sagometer.

Table 3-3 Sagometer units table structure

Sagometer user adjustable settings		
Variable Name	**Description**	**Units**
SagCal(1,1)	Vertical Offset	ft or m
SagCal(1,2)	Tilt Offset	Degrees
SagCal(1,3)	Camera to Target Distance	ft or m
SagCal(1,4)	Target Twist Radius	ft or m
SagCal(1,5)	Low Point Constant L1	none
SagCal(1,6)	Low Point Constant L2	none
SagCal(1,7)	Tension Constant T1	none
SagCal(1,8)	Tension Constant T2	none
SagCal(2,1)	Vertical Offset	ft or m
SagCal(2,2)	Tilt Offset	Degrees
SagCal(2,3)	Camera to Target Distance	ft or m
SagCal(2,4)	Target Twist Radius	ft or m
SagCal(2,5)	Low Point Constant L1	none
SagCal(2,6)	Low Point Constant L2	none
SagCal(2,7)	Tension Constant T1	none
SagCal(2,8)	Tension Constant T2	none
Units(1)	Length/Distance Units	0 – ft
Units(2)	Tension Units	0 – lbs
Units(3)	Temperature Units	0 - °F
Units(4)	Wind Speed Units	0 – fps
Units(5)	Precipitation Units	0 – in
ModemPower(1)	Periodic interval when modem is turned ON	Min
ModemPower(2)	Duration modem remains ON after being turned ON	Min
RollWindow	length of rolling average window	Min

The video sagometer allows the user to change many parameters on the fly. The exact settings for the NYPA site have been captured here in this data table.

Table 3-4 Sagometer configuration table structure

User adjustable Setting in Sagometer as of 01/07/2011				
Variable Name	**WP2 01 02**	**MW2 36 04**	**MW2 03 06**	**Description**
SagCal(1,1)	32.39	36.99	37.25	Vertical Offset
SagCal(1,2)	-1.101	-1.47	1.41	Tilt Offset
SagCal(1,3)	147.058	148.56	147.07	Camera to Target Distance
SagCal(1,4)	1.1	1.1	1.1	Target Twist Radius
SagCal(1,5)	1.535	1.469	1.476	Low Point Constant L1
SagCal(1,6)	29.702	30.458	25.51	Low Point Constant L2
SagCal(1,7)	49673	47125	42883	Tension Constant T1
SagCal(1,8)	53.02	52.76	50.44	Tension Constant T2
SagCal(2,1)	0	0	0	Vertical Offset
SagCal(2,2)	0	0	0	Tilt Offset
SagCal(2,3)	150	150	150	Camera to Target Distance
SagCal(2,4)	0.75	0.75	0.75	Target Twist Radius
SagCal(2,5)	0	0	0	Low Point Constant L1
SagCal(2,6)	0	0	0	Low Point Constant L2
SagCal(2,7)	0	0	0	Tension Constant T1
SagCal(2,8)	0	0	0	Tension Constant T2

Table 3-5 EPRI Sensor table structure

EPRI Sensors

column heading	description	units
TIMESTAMP	timestamp when data was recorded	date hour:min:sec
RECORD	record number of data	integer
ETempSensorReading(1,1)	Id number of first sensor	integer
ETempSensorReading(1,2)	latest temp reading	Celsius
ETempSensorReading(1,3)	latest current reading	amps
ETempSensorReading(1,4)	peak temp reading	Celsius
ETempSensorReading(1,5)	current reading at peak temp	amps
ETempSensorReading(1,6)	battery voltage	volts
ETempSensorReading(1,7)	Max X acceleration	ADC counts
ETempSensorReading(1,8)	Min X acceleration	ADC counts
ETempSensorReading(1,9)	Max Y acceleration	ADC counts
ETempSensorReading(1,10)	Min Y acceleration	ADC counts
ETempSensorReading(1,11)	Max Z acceleration	ADC counts
ETempSensorReading(1,12)	Line inclination	1/100ths of a degree
ETempSensorReading(1,13)	X acceleration	1/1000th of a G
ETempSensorReading(1,14)	Y acceleration	1/1000th of a G
ETempSensorReading(1,15)	Z acceleration	1/1000th of a G
ETempSensorReading(1,16)	Stale Inclination Count	integer
ETempSensorReading(1,17)	Min Z acceleration	ADC counts
ETempSensorReading(1,18)	Average absolute deviation X acceleration	integer
ETempSensorReading(1,19)	Average absolute deviation Y acceleration	integer
ETempSensorReading(1,20)	Average absolute deviation Z acceleration	integer
ETempSensorReading(1,21)	latest on board temp	ADC counts
ETempSensorReading(1,22)	firmware version	8 bit number
ETempSensorReading(1,23)	latest on board temp	Celsius
ETempSensorReading(1,24)	RSSI value	dB
ETempSensorReading(1,25)	missed reading cycle count	integer
ETempSensorReading(1,26)	AAD threshold	integer
ETempSensorReading(1,27)	Inclination threshold	integer

Sagometer Power Systems

Sun Electronics
SUN-ES-C-110
110W

Werker
WKDC12-100PUS
100 A-hr @ 20Hr

Steca
Solsum 8.8F

Figure 3-31 Photo of solar System

EPRI Sensor Power System

Solar Cell – Sharp 80W Solar Panel, Eco Direct P/N: NE-80EJEA

Battery – Power Sonic 12VDC 100 Amp hour battery, Allied Electronics P/N: 621-9000

Charger – Steca 15 Amp Charger, Eco Direct P/N: PRS 1515

Figure 3-32 Photo of solar System

Thermal Rate Power System

Figure 3-33 Photo of solar System

Figure 3-34 Photo of Thermal Rate battery box

Figure 3-35 Photo of battery and charger

Figure 3-36 Radio communication link (MDS TransNet 900) for ThermalRate system

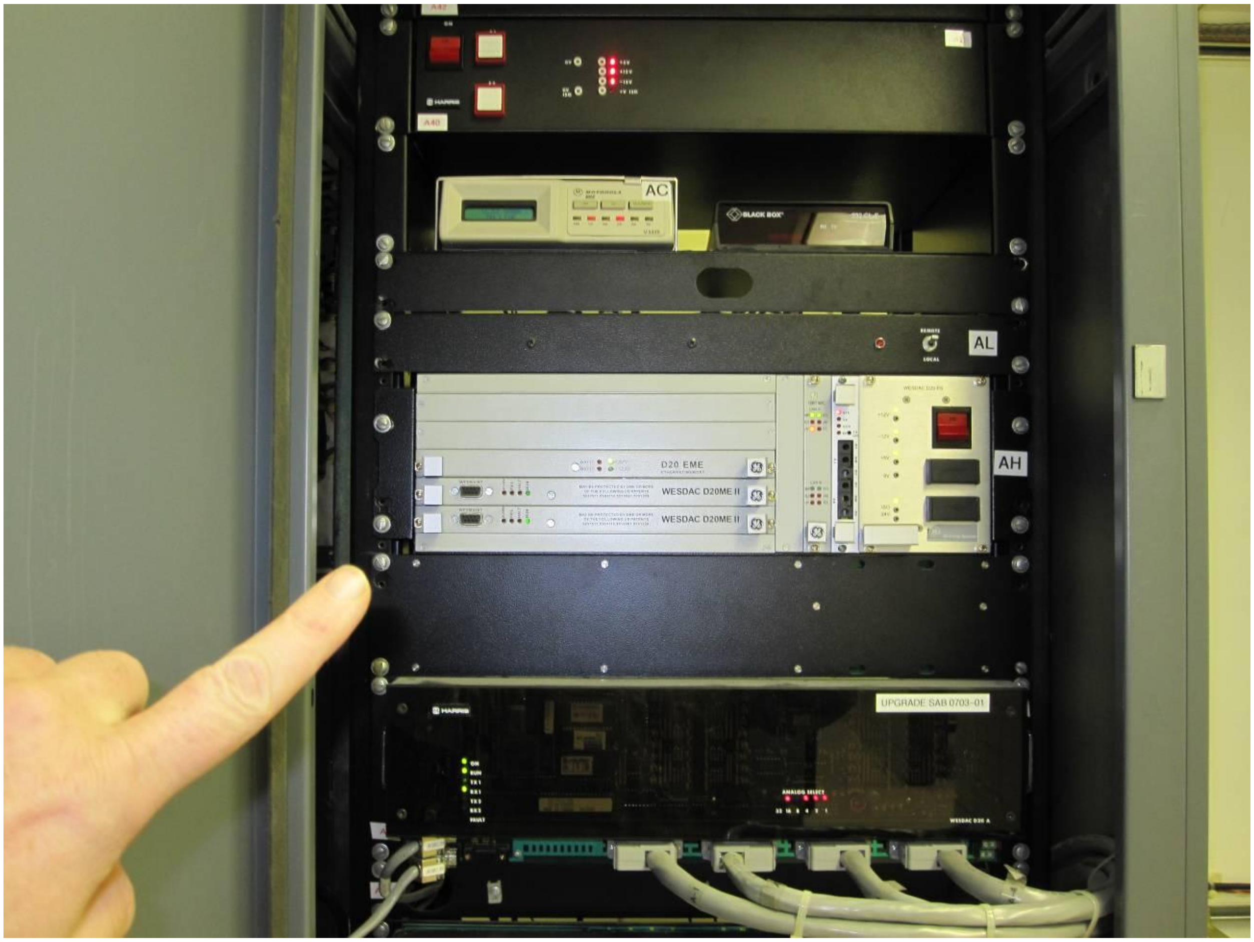


Figure 3-37 RTU at Willis Substation

4
FIELD INSTALLATIONS

Introduction

Side-by-side field trials and evaluations of three transmission line sensor systems that monitor an overhead transmission line's sag, temperature and local ambient weather conditions were initiated in November 2010. Note that the weather stations are part of the Sagometer System. Four installations were performed as part of this effort. The first installation was for practice, performed at EPRI's High-Voltage Laboratory in Lenox, MA under controlled conditions. This provided the project team and line crew an opportunity to familiarize themselves with the instruments and installation methods. The next three installations were at actual field sites on NYPA's 230 kV transmission system. NYPA refers to these sites as WP2 -01/02, MW2- 36/04 and MW2- 03/06. Instruments at the three field sites will remain in place and active for the duration of the project, expected to last 2 years.

Installation Assessments: Goals and Methods

The purpose of assessing the installations was to collect and document information for the benefit of industry personnel and utilities tasked with implementing these instruments in the future.

The assessment look at the following: work methods and tools required for installation, ease of installation, start-up and operability requirements, time to install the instruments and follow-up maintenance.

The four installations are described separately in the sections below. They are organized in the order in which they were performed starting with the trial at EPRI Lenox followed by the NYPA sites, WP2-01/02, MW2 36/04 and MW2 03/06.

At each of the sites, photographs were taken to record and document the installations of EPRI sensors, ThermalRate systems, Sagometers and Weather Stations.

Installation at EPRI Lenox

The EPRI High Voltage Laboratory is located at 115 East New Lenox Road in Lenox MA. The figure below shows an aerial view of the site.

Figure 4-1 Aerial view of EPRI Lenox Site

The practice installation at EPRI's High-Voltage laboratory utilized an existing test line that included a wooden H-Frame structure similar to those on NYPA's system.

The objectives of the practice installation were to:

- provide the project team a chance to familiarize themselves with the instruments and systems and to sort out the best methods for assembling before the actual field installation.
- give the linemen a chance to practice installing some of the line sensors and other line hardware under de-energized conditions before having to do this on actual energized line. The Lenox install was done using live-line tools just as if the line were energized.
- identify an efficient sequence for mounting the instruments to the wooden transmission structures and practice with the pole banding material and mounting hardware.
- go through the actual wiring and connections of the instruments to the electronic junction boxes and allow time to troubleshoot any communication issues.

- make minor changes, review field installation logistics and document any lessons learned that could be used to improve the field installs

EPRI Sensor System

The EPRI sensor system included sensors that attach directly to the transmission line conductor, electronics that communicate with the sensors and solar panels to power the system.

An EPRI sensor is shown in the figure below. Before installing, the clamping jaw was preset for the conductor size. Presetting the jaw ensures a good tight fit to the conductor during installation. The clamping jaw is made of a composite material and is adjusted with two screws as seen in the figure below.

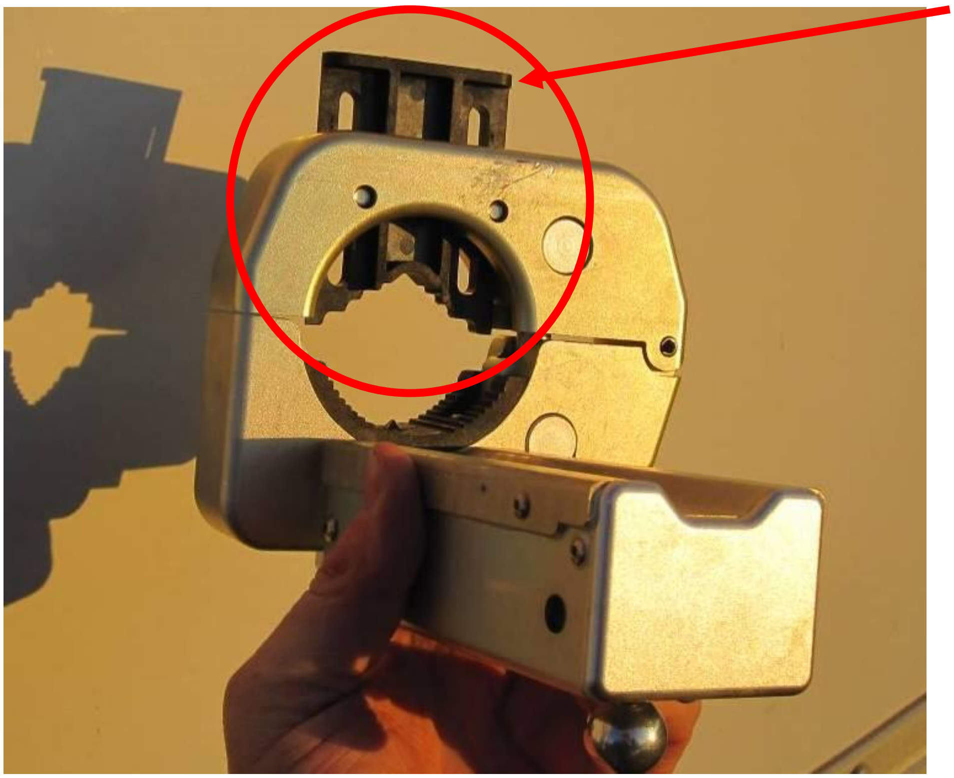


Figure 4-2 EPRI Sensor

Figure 4-3 The EPRI sensor is being installed on a test line at the Lenox lab

Figure 4-4 Bonding tip becomes stuck during the first install attempt.

The linemen had a chance to get familiar with the methods and tools required for attaching the EPRI sensor to the conductor. During the first attempt, the bonding leads became stuck under the clamping mechanism. With a little practice the lineman became comfortable with installing the sensors.

Figure 4-5 EPRI sensor attached to conductor

Figure 4-6 Electronics and solar panel for EPRI sensor

ThermalRate System

The ThermalRate sensor was attached to an aluminum arm mounted to one of the wooden H-Frame poles. The figure below shows the line crew pulling the communications wire through the sensor's mounting arm.

Figure 4-7 ThermalRate sensor being prepared for mounting

Figure 4-8 ThermalRate Sensor installed

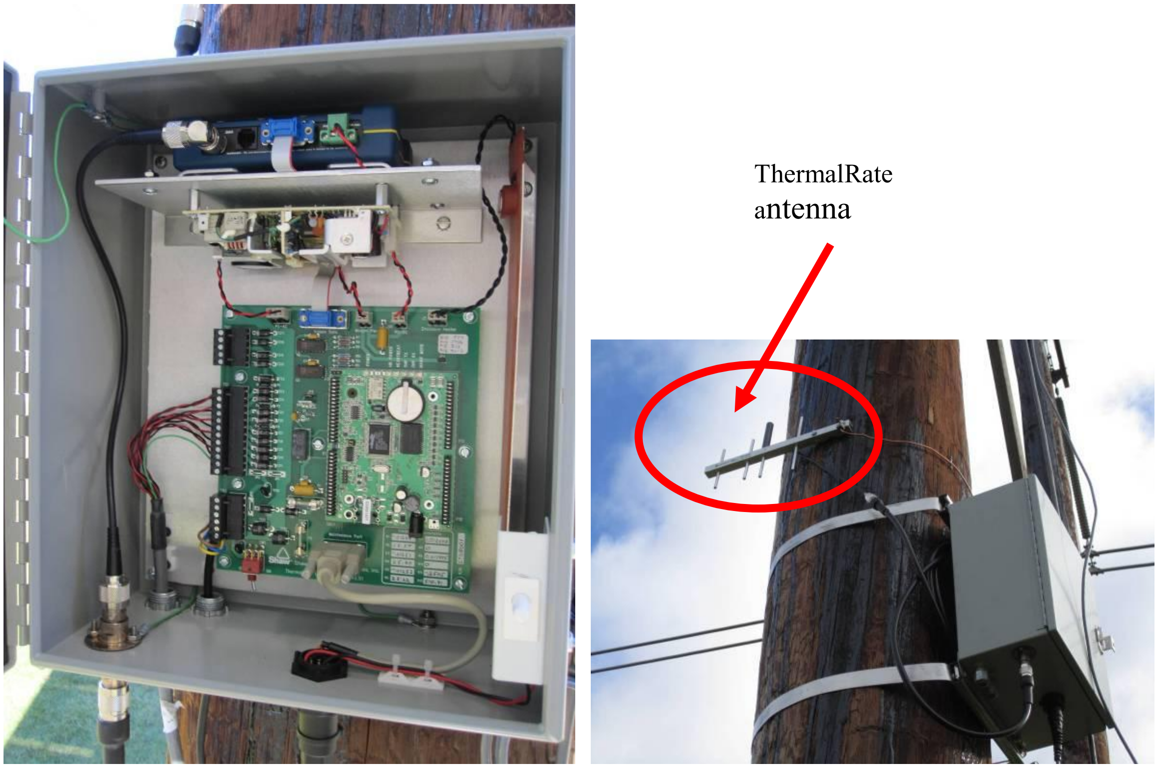


Figure 4-9 ThermalRate electronics box

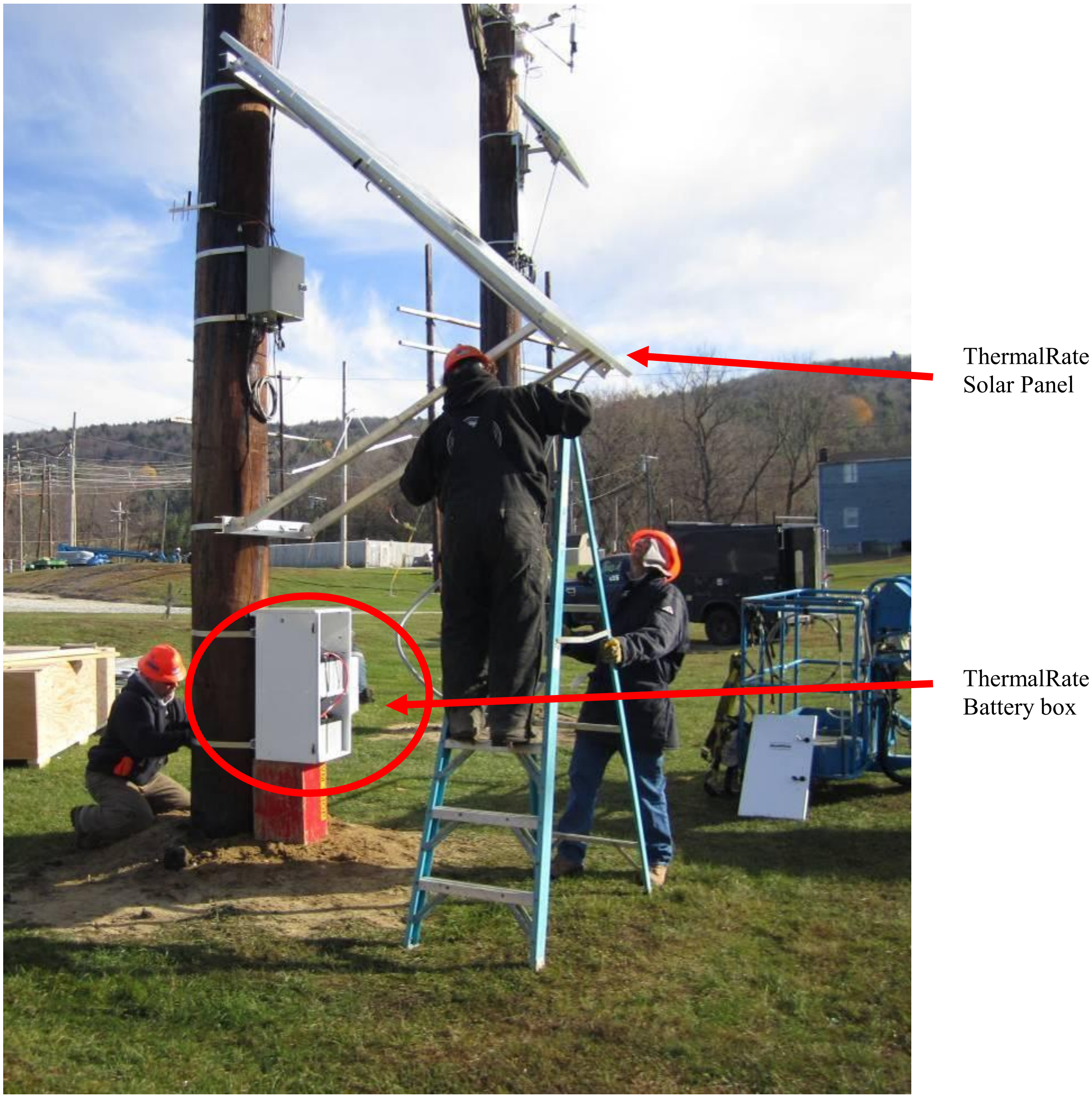


Figure 4-10 ThermalRate solar panel and battery box

Sagometer System

The Sagometer system was mounted to the other wooded pole adjacent to that of the Thermal Rate. The sagometer's camera, weather instruments, solar panel and electronics box are shown in the Figure below.

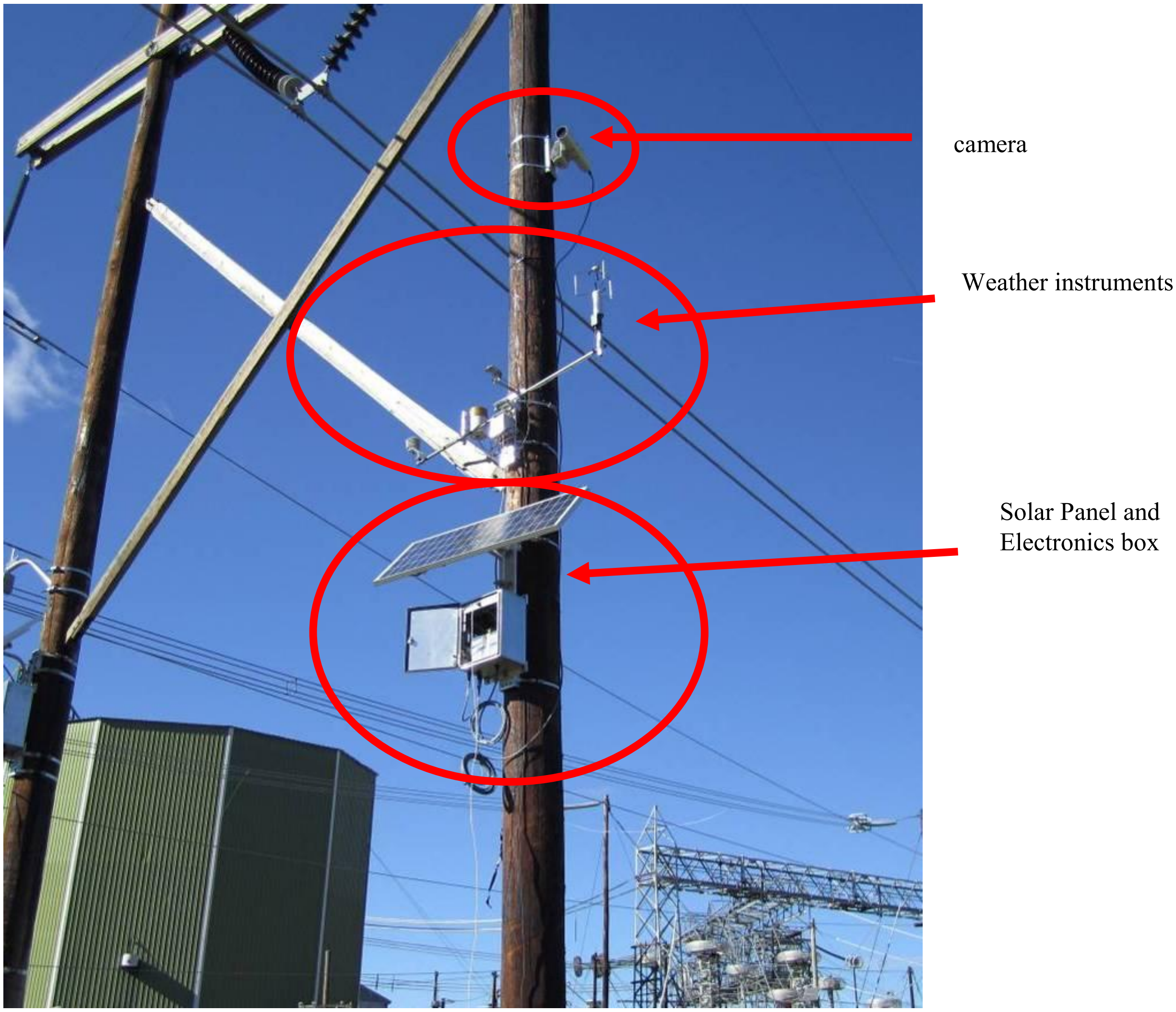


Figure 4-11 Sagometer System

The sagometer target is shown in the following figure. The target mounting clamp was made to accommodate a Drake 795 ACSR conductor and so did not fit correctly on the test line which was a larger diameter conductor. The target was mounted on a smaller section of conductor which was then secured to the test line.

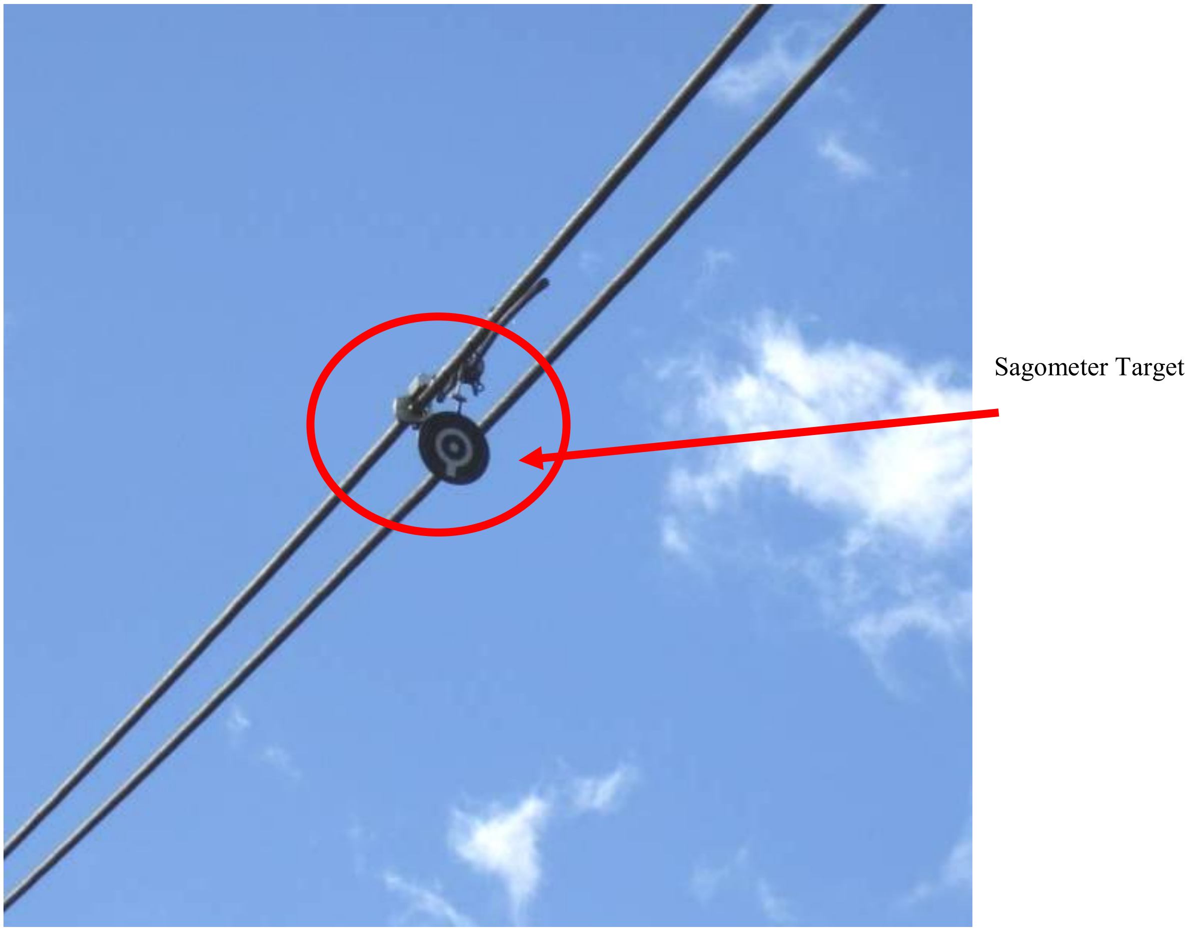


Figure 4-12 Sagometer Target

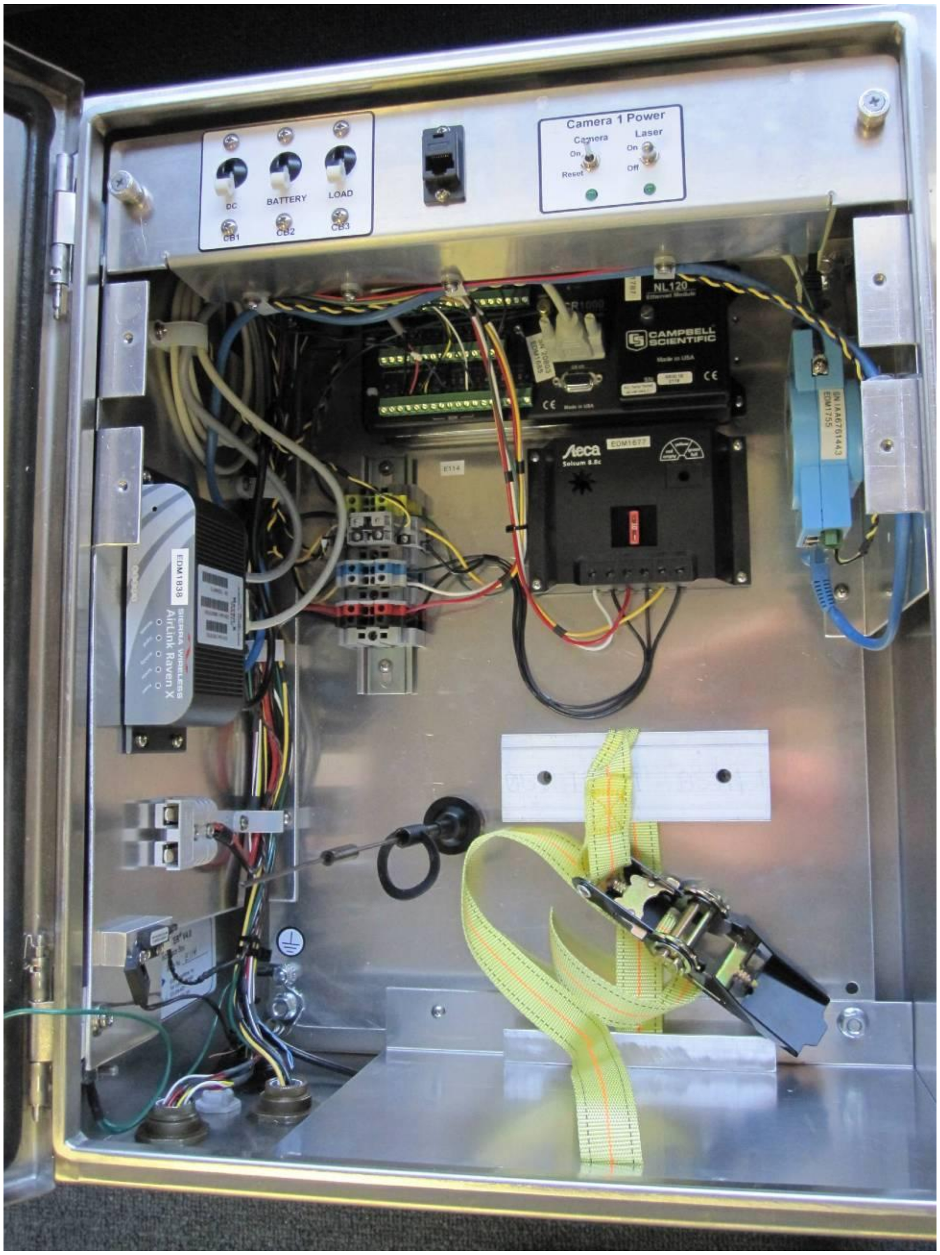


Figure 4-13 Sagometer Electronics box (battery removed)

Figure 4-14 Near completion of the practice installation at EPRI Lenox.

Summary of Lenox Installation

- The Lenox installation was performed over three days from November 1st thru 3rd 2011.

- This served as practice and was a beneficial learning experience for the project team. It provided an understanding of which instruments to install first, what order and what type of spacing worked best. For example, mounting the ThermalRate electronics box under its solar panel reduce the overall footprint for the instruments on the wood pole and at the same time shielded the electronics box from rain and sun light.

- The exact heights and spacing of all the instruments on the wood poles were somewhat open for adjustment at the start of the install. After completion, the relative positioning of the instruments were better identified and then noted for the field installs

- The line crew practiced installing the EPRI sensors on a de-energized test line. The line crew gained confidence with the methods and tools required for securing the sensors after trying a couple of times. One lesson learned was to be careful not to tighten the sensor clamp down onto the bonding leads, this happen during the first attempt to install a sensor, see Figure 4-4.

- The method for measuring and installing the pole bands that secured the instruments was practiced several times. This helped saved time during the field installs.

- After the systems were installed, time was spent working out communication issues between the data logger modems and server modems. Because the systems were relatively close to the receiver modems, they could be manually checked. This allowed the team to troubleshoot in an efficient manner.

- The large solar panel and batteries for the ThermalRate system were the heaviest components. The solar panel required some rigging to lift. A rigging method was worked out during the EPRI Lenox install for lifting and adjusting the solar panel which was used later at the actual field sites.

- The line crew was able to assess the types of tools were necessary for the installation. Having the right tools on hand saved time during the actual installations.

CCP-1 Training

The project team received training at NYPA's St. Lawrence facility in Massena, NY. NERC requirements were reviewed and CPP-1 (Clearance and Protection Procedure) Operations training was provided at the LEM Building. The Clearance and Protection Procedure establishes the administrative program and controls which provide a safe working environment for all personnel while working at NYPA's sites.

NYPA Installation Sites

The relative locations of the three NYPA field installation sites are shown in the line sketch below. The installation sites are marked with stars and the substations are shown as rectangles. Two of the sites are located on either end the MW2 line and the other site is located on WRY2 line.

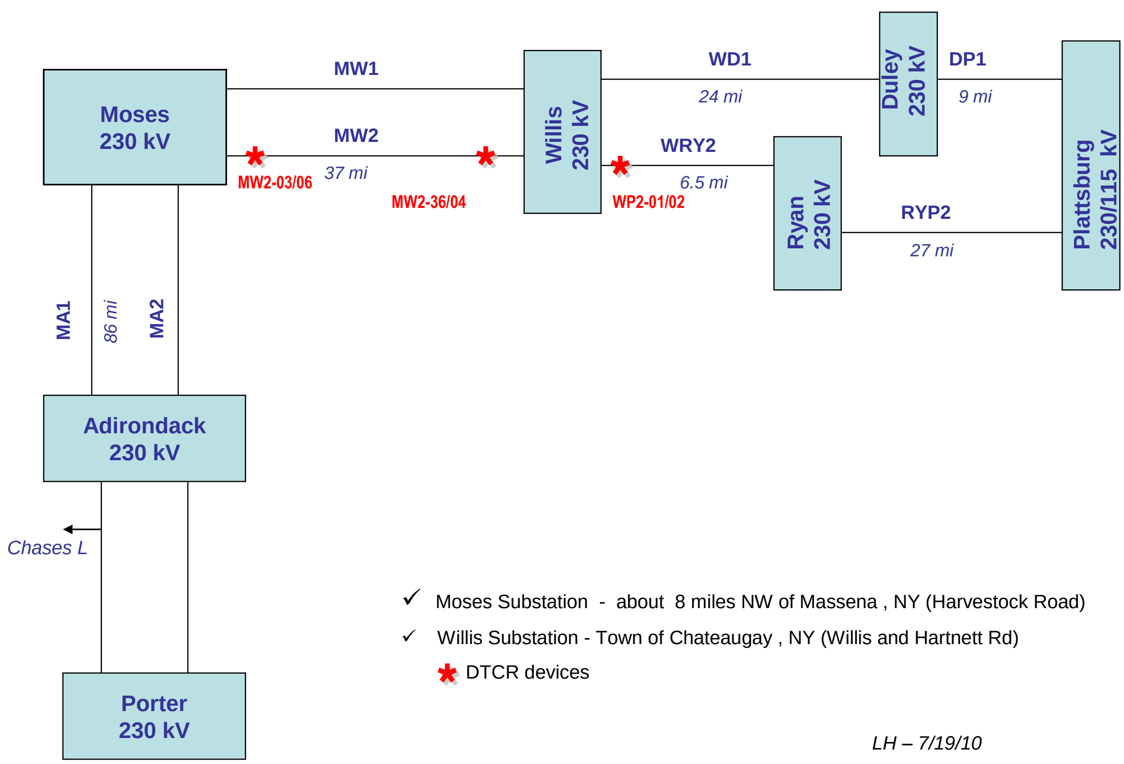


Figure 4-15 Sketch depicting the three field site locations

The latitude and longitude of the three field sites are listed in the table below.

Site Designations	Latitude	Longitude
WP2 – 01/02	44^{0} 58’ 14.8” N	74^{0} 46’ 54.6” W
MW2 – 36/04	44^{0} 53’ 17.1” N	74^{0} 8’ 55.7” W
MW2 – 03/06	44^{0} 53’ 24” N	74^{0} 6’ 51” W

Installation on the WP2-01/02 Structure

This site was located just across Co. Hwy. 33 from Willis Substation.

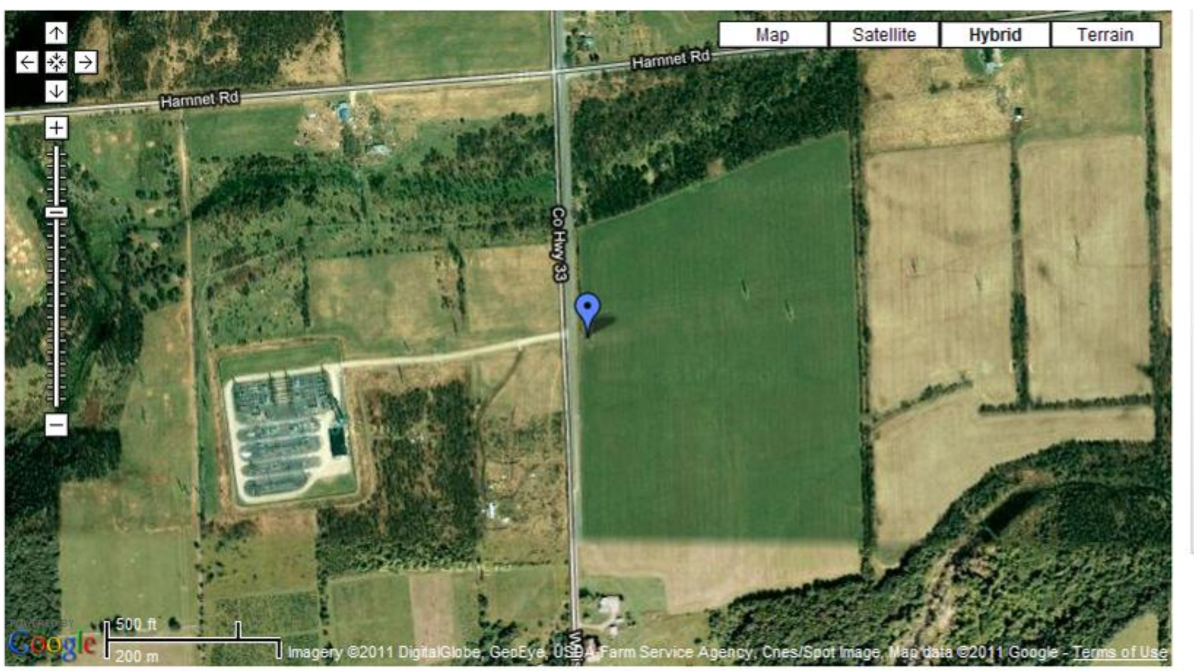


Figure 4-16 Aerial view of WP2-01/02.

This structure is at an elevation of approximately 1100 feet and this section of line is 81^0 clockwise from north, based on information extracted from the plan and profile drawings.

The conductor is 795 kcmil Drake ACSR. The wood structure at this site is classified as type "BB". The system voltage on this line is 230 kV.

As can be seen in the photo below, this section of line is mostly open level terrain with minimal sheltering from trees and other objects. Therefore, ruling span assumptions should be quite accurate. This site is in close proximity to a wind farm which suggests the line segment is located in a windy area.

Figure 4-17 Locations were marked under the line for the sagometer target and EPRI sensors

Figure 4-18 A tailgate meeting was held before work begins at WP2-01/02

EPRI Sensor

Figure 4-19 EPRI Sensor ready to install

Figure 4-20 Lineman tests hotstick prior to installing the EPRI sensors on the energized 230 kV line

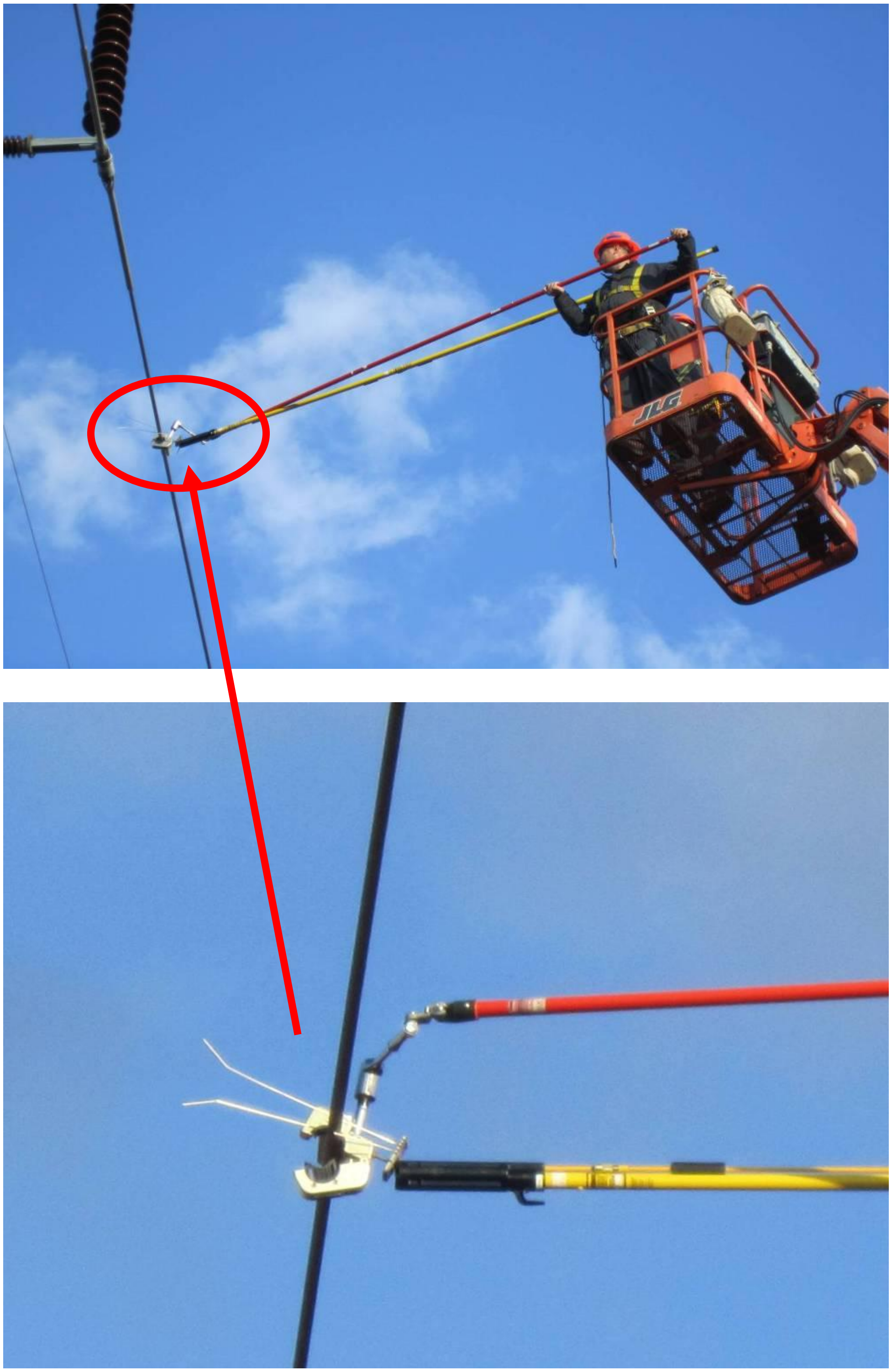


Figure 4-21 EPRI Sensor being installed

Figure 4-22 Remote ZAP unit used to check communications of the EPRI sensors in the field

Figure 4-23 EPRI sensor electronics box and solar panel installed

ThermalRate System

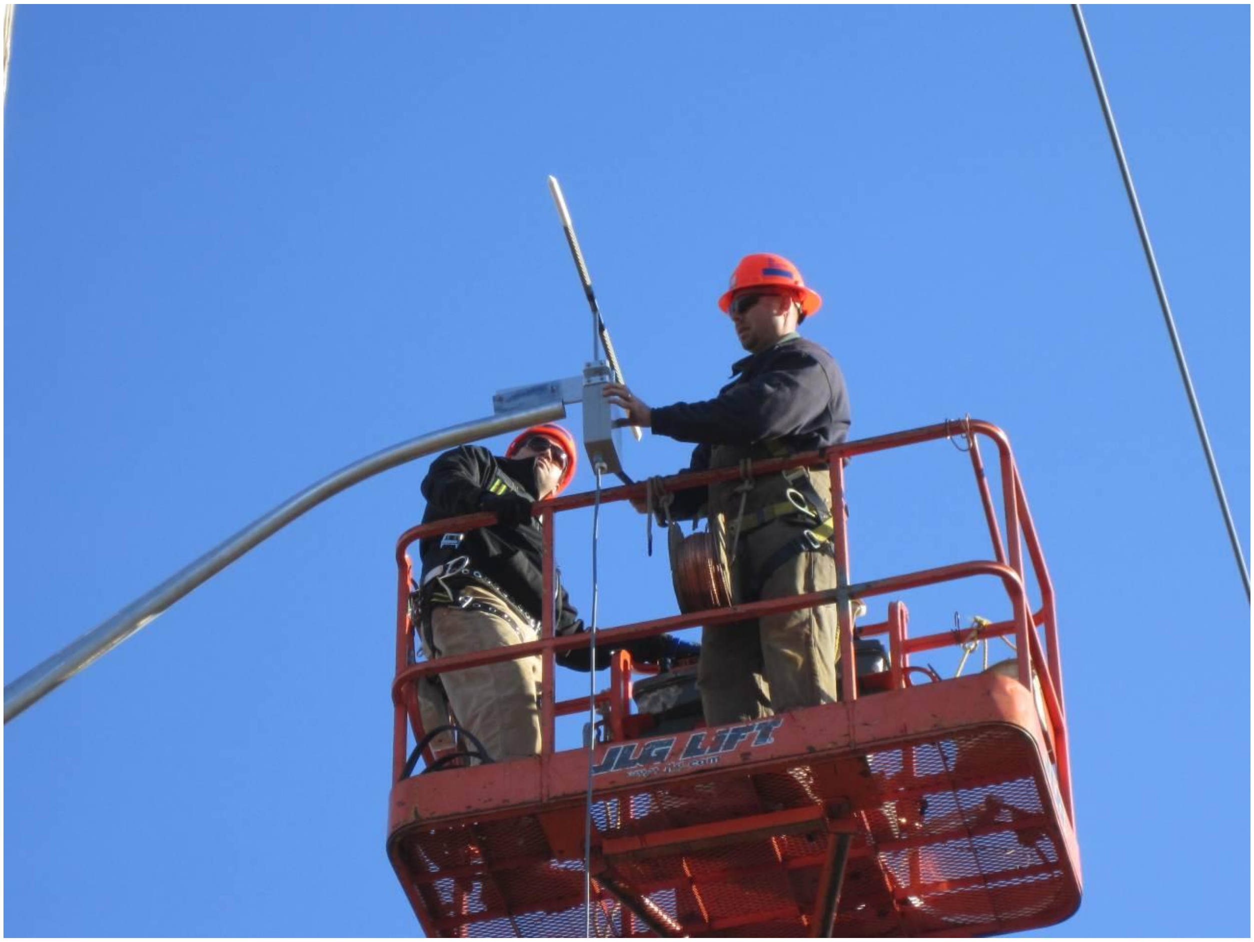


Figure 4-24 ThermalRate sensor being installed

Figure 4-25 Solar panel for the ThermalRate system being rigged for installation

Figure 4-26 ThermalRate Battery Box being wired

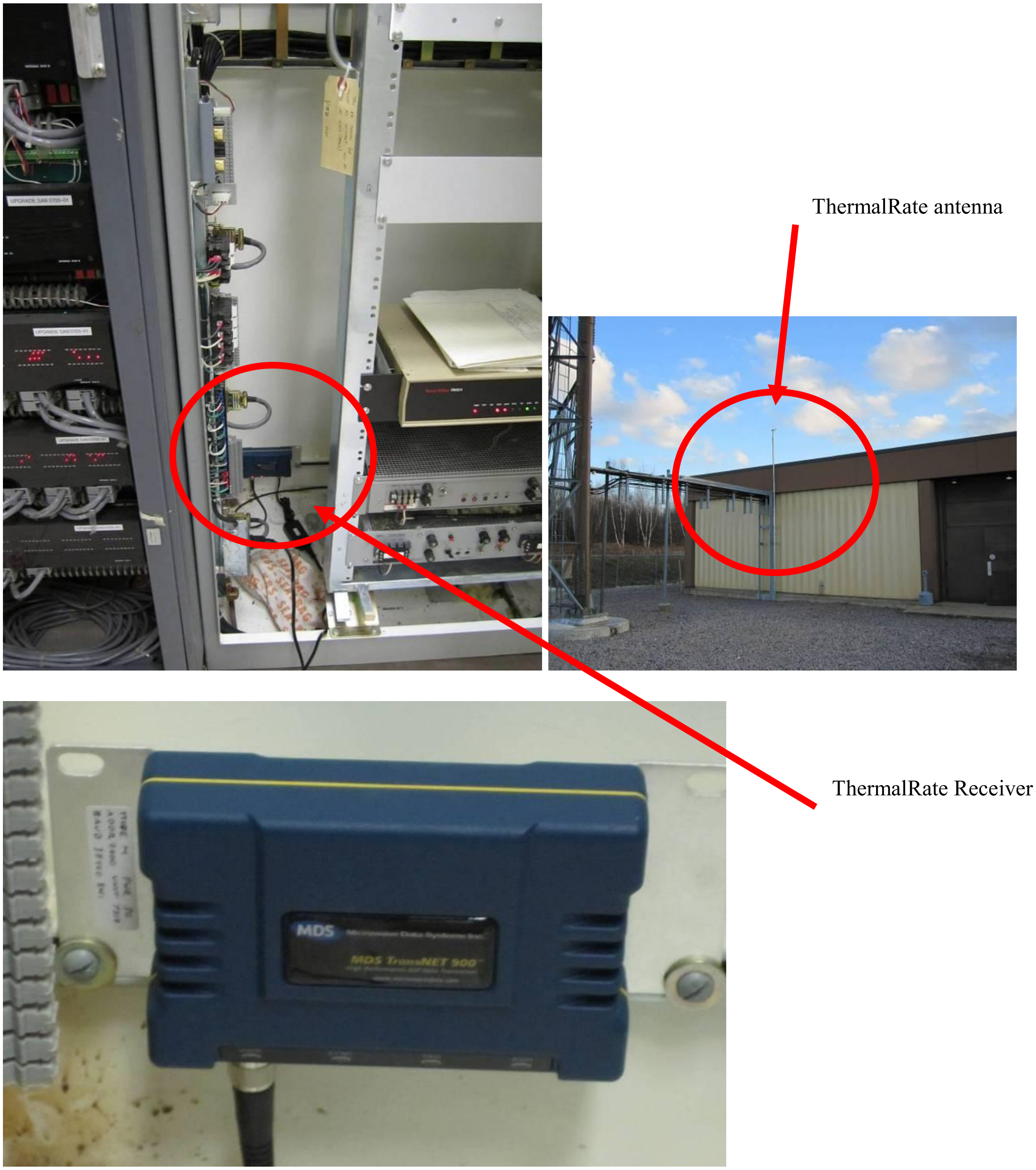


Figure 4-27 ThermalRate receiver installed at the Willis substation

Sagometer System

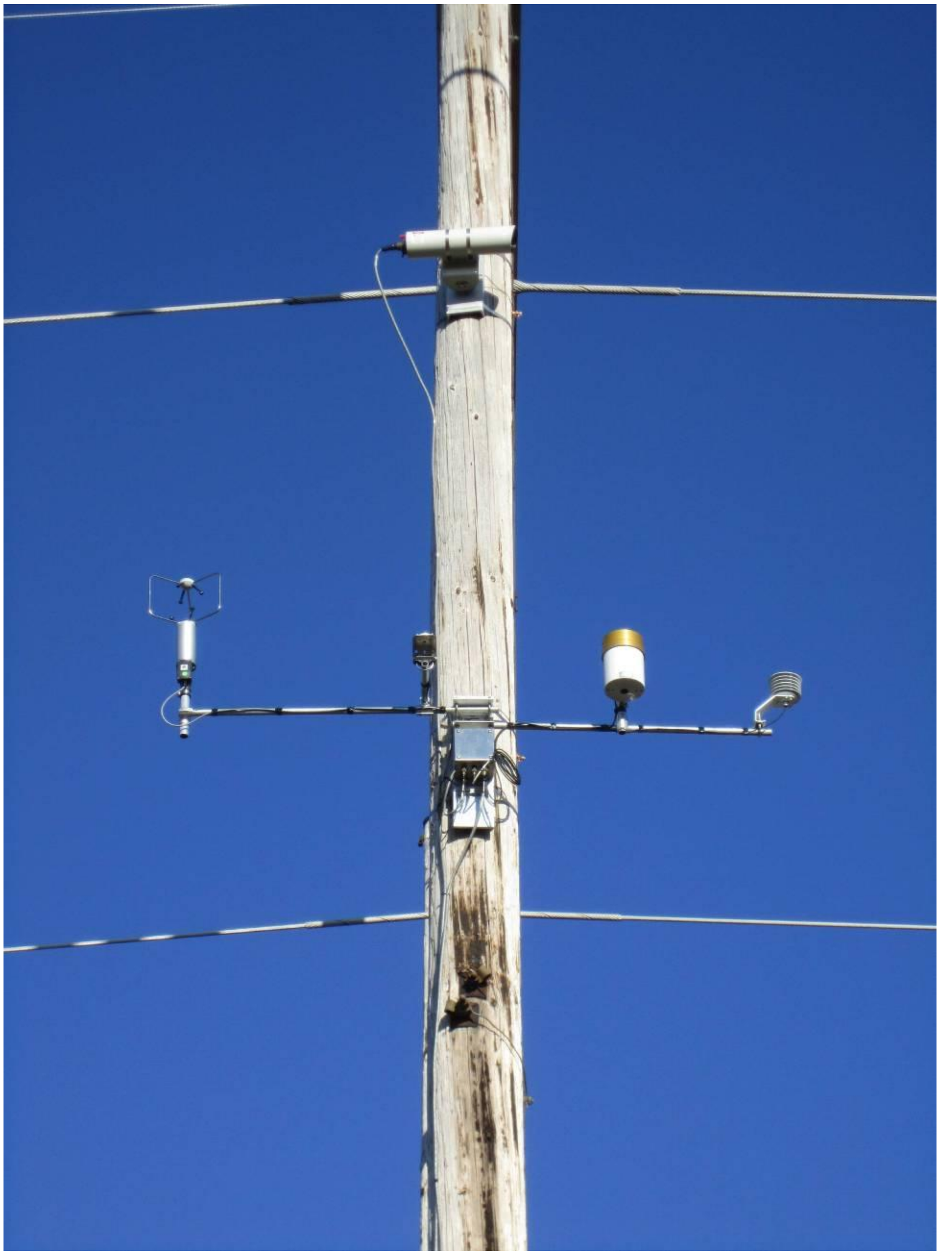


Figure 4-28 Sagometer camera and weather instruments

The conductor attachment point at structure WP2 01/02 is 51 feet above the ground. The conductor attachment point at structure WP2 01/03 is 52 feet above the ground. The height of the conductor at mid-span during the survey on 11/16/2010 was 34 feet. The height of the anemometer on structure WP2 01/02 is 35 feet.

Figure 4-29 Sagometer target being installed

Figure 4-30 Sagometer electronics box and solar panel being checked after installation

Figure 4-31 WP2-01/02 – "Site 1" completed - looking in an easterly direction

Figure 4-32 WP2-01/02 – "Site 1" completed - looking in an westerly direction

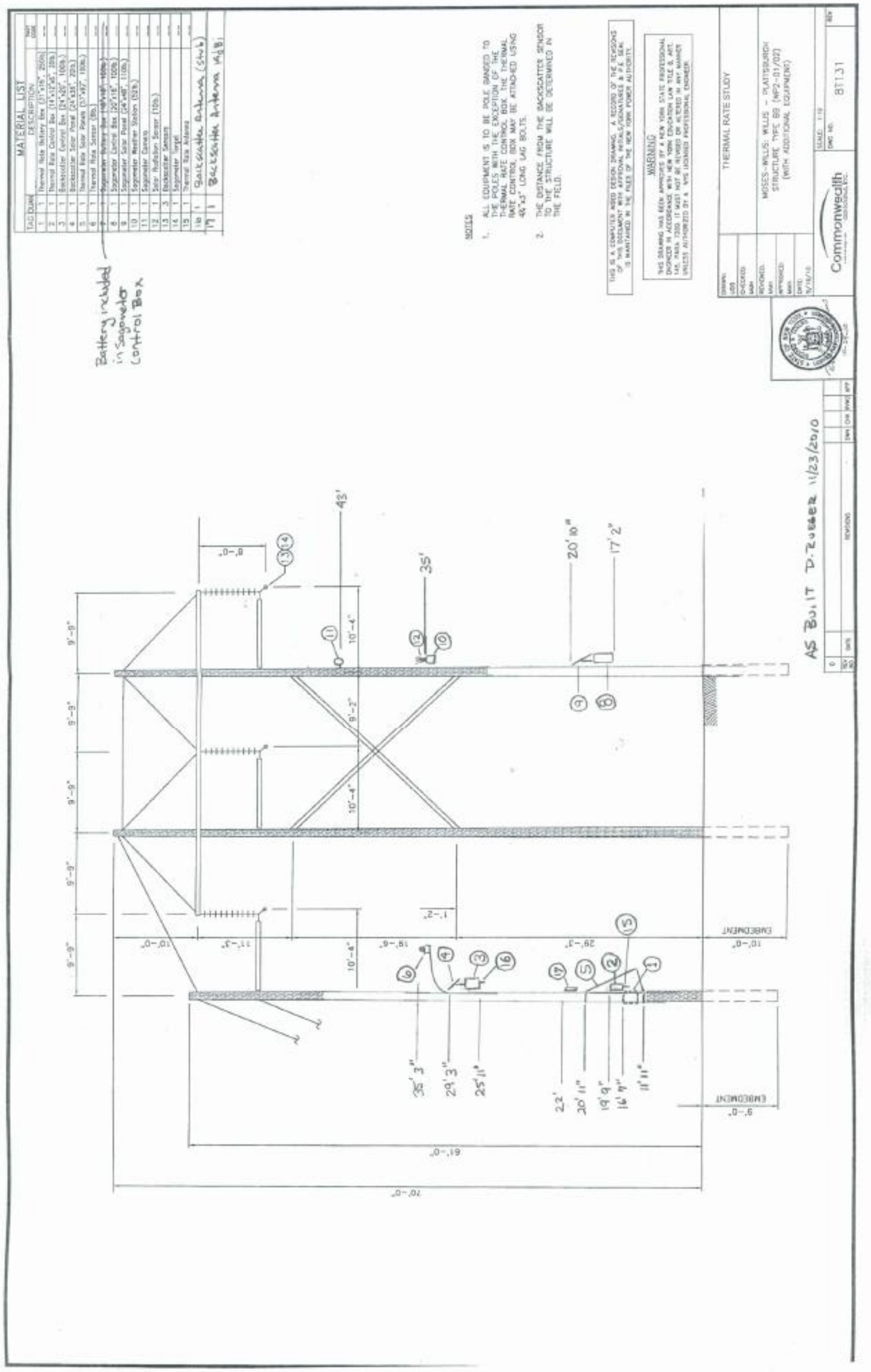


Figure 4-33 As built drawings were marked up after the installation was complete.

For the Survey Crew

Typical project sheet

Site Name WP2-01/02 **Form completed by** Dana Drake

Date 1/16/10	Wind speed *high* or *low*	Sky *clear* or *overcast*
Precipitation *dry* or *wet*	**Temperature**	Line name WP2-01/02

Survey Data

	Data Point	X	Conductor ~~height~~ Above sea level elevation	Ground elevation	Time of measurement
101	A	0	1151.20	1100.00	
103	1	49.82	1147.67	1100.02	11:17 a.m.
106	~~1~~ Target	147.05	1142.57	1101.80	11:19 "
107	2~~Target~~	~~150~~ 189.01	1141.16	1104.07	11:23 "
108	3	299.66	1139.62	1106.79	11:25 "
105	~~4~~ Mid Span	374.53	1140.41	1106.45	11:28 "
109	~~Mid Span~~ 4	459.93	1143.35	1106.97	12:08 P.M.
110	5	548.89	1147.75	1109.60	12:10 "
111	6	632.11	1153.86	1113.44	12:12 "
104	7	715.37	1161.69	1114.66	12:14 "
	~~8~~				
102	B	765.16	1167.17	1115.49	

Line direction in degrees from North N 81° E (*Magnetic* or *True*)
Two attachments and 5 other points along the line are required, additional is helpful
Assume an elevation of 100 at the base of pole A if true elevation is not known
Structure A Number 01/02
Structure B Number ____________

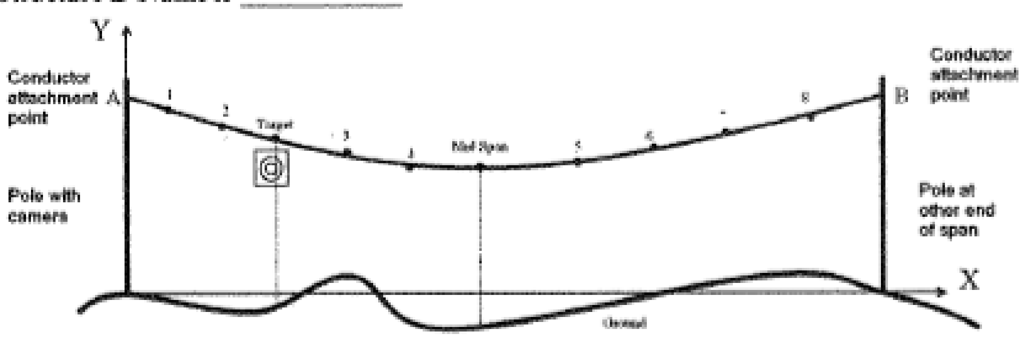


Figure 4-34 Survey Sheet for the span between WP2 01/02 and 01/03

Summary of Installation for WP2-01/02

- The installation at WP2-01/02 was performed from November 15th thru 16th 2011.

- The line crew noted that during installation of the EPRI sensors a wrench handle attached to the end of the hot stick fell off a few of times. The hotstick being used had a composite universal attachment end. When applying torque, this end can flex and loosen. It was noted by the line crew that a metal universal attachment ends work better in this type of application.

- A connector wire was broken off in the ThermalRate electronics box. The electronics box was taken down and swapped out with another one. The broken connector was repaired the next day. It may be beneficial to have an assortment of spare parts available for these types of situations.

- It took time on site to explain what was required for the survey of the first line. This was expected to some extent. However, it may work better to have a question and answer session prior to the first field install.

- There were a few initial communications issues between the Sagometer and remote server. These were mostly associated with modem settings. These issues were corrected on site.

- The ThermalRate system was not able to communicate with the RTU at Willis substation due to ongoing issues that could not be resolved during the field install. The main objective of this connection was to obtain the line current in real-time. It was noted that this would be completed at a later date

- The best method for installing the EPRI sensors and Sagometer target on the line was to start with the sensors farthest away and work back towards the structure.

- The solar panel support arms for the Thermal Rate system needed to be retightened. It was thought that the wind may loosen the lockdown screws.

Installation on the MW2-36/04 Structure

This site was located a few miles from the Willis Substation just off of Quarry Rd.

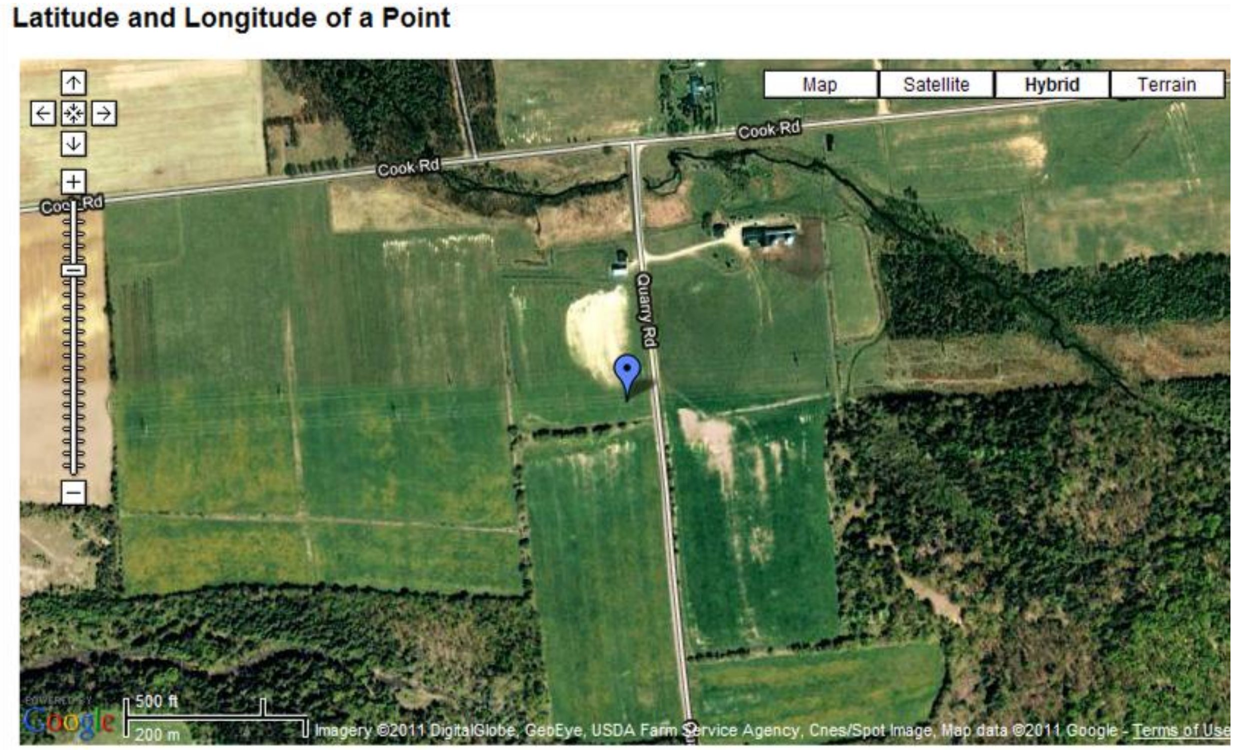


Figure 4-35 Aerial view of MW2-36/04, "Site 2"

This structure is at an elevation of approximately 1000 feet and this section of line is 86^0 clockwise from north, based on information extracted from the plan and profile drawings.

The conductor is 795 kcmil Drake ACSR. The wooden structure at this site is classified as type "AA".

As can be seen in the photo below, this section of line is mostly open level terrain with minimal sheltering from trees and other objects. Therefore, ruling span assumptions should be quite accurate. This site is also in close proximity to a wind farm which suggests the line segment is located in a windy area.

Figure 4-36 Locations were marked under the line for the Sagometer target and EPRI sensors

Figure 4-37 The field project team gathers before work begins at MW2-36/04

EPRI Sensor

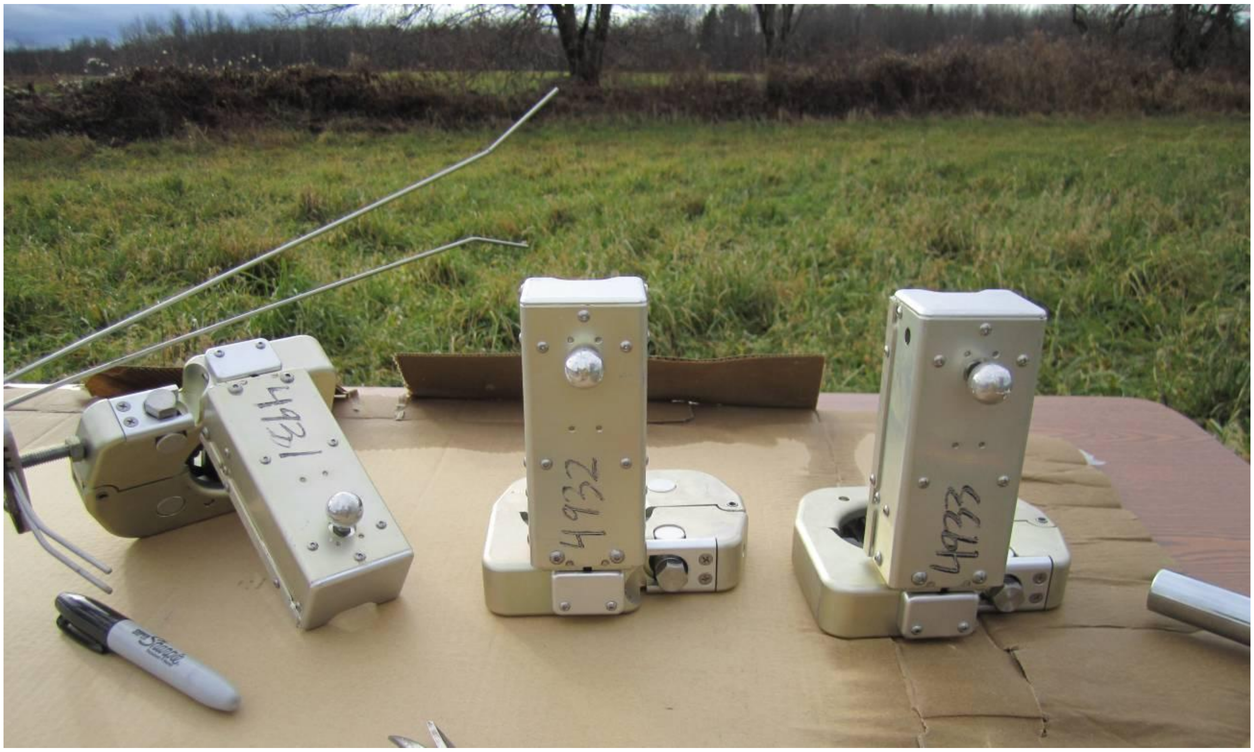


Figure 4-38 EPRI sensors ready to install

Figure 4-39 Lineman tests hotstick prior to installing the EPRI sensors on the energized 230 kV line

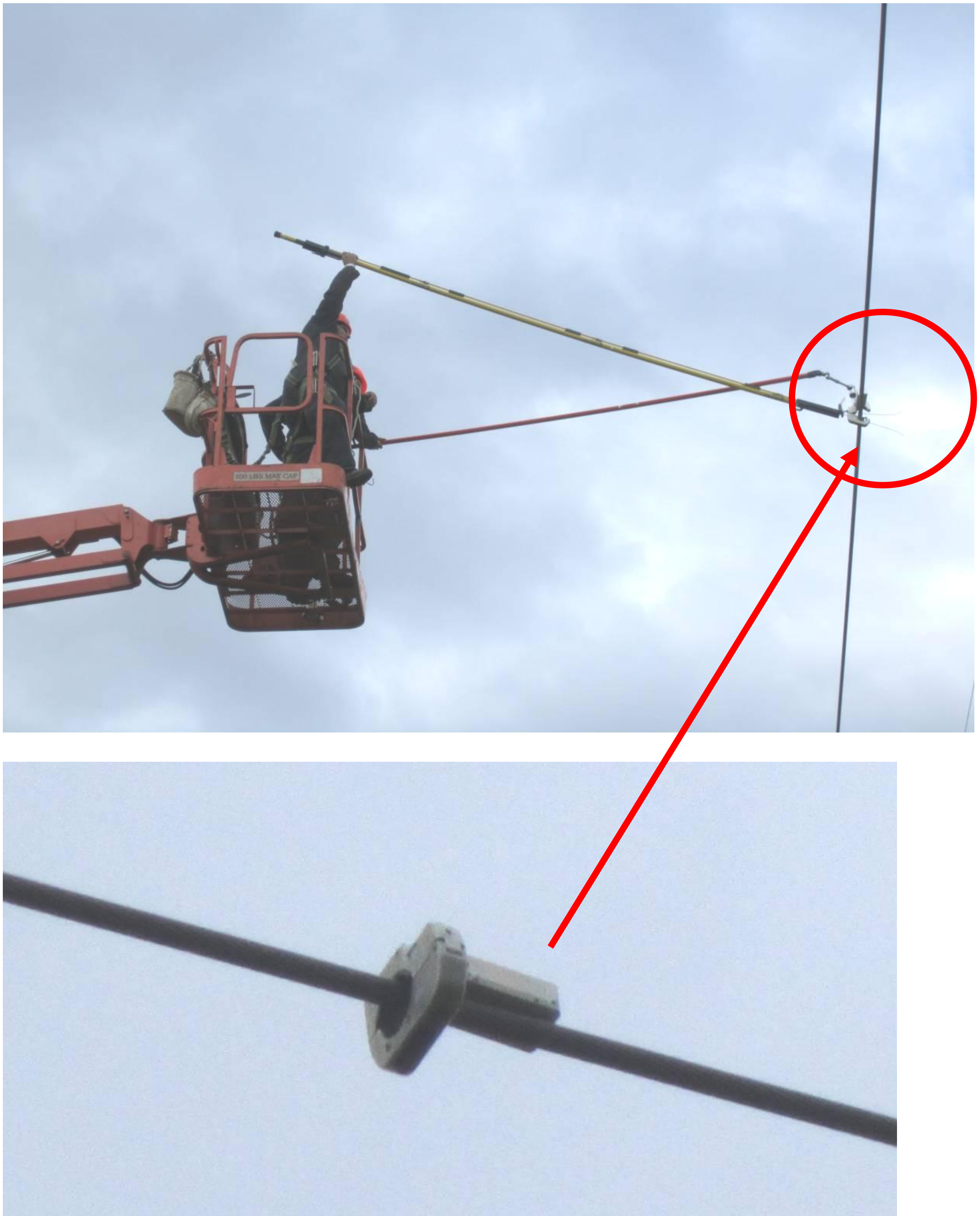


Figure 4-40 EPRI sensor being installed

Figure 4-41 EPRI sensor electronics box and solar panel installed

ThermalRate System

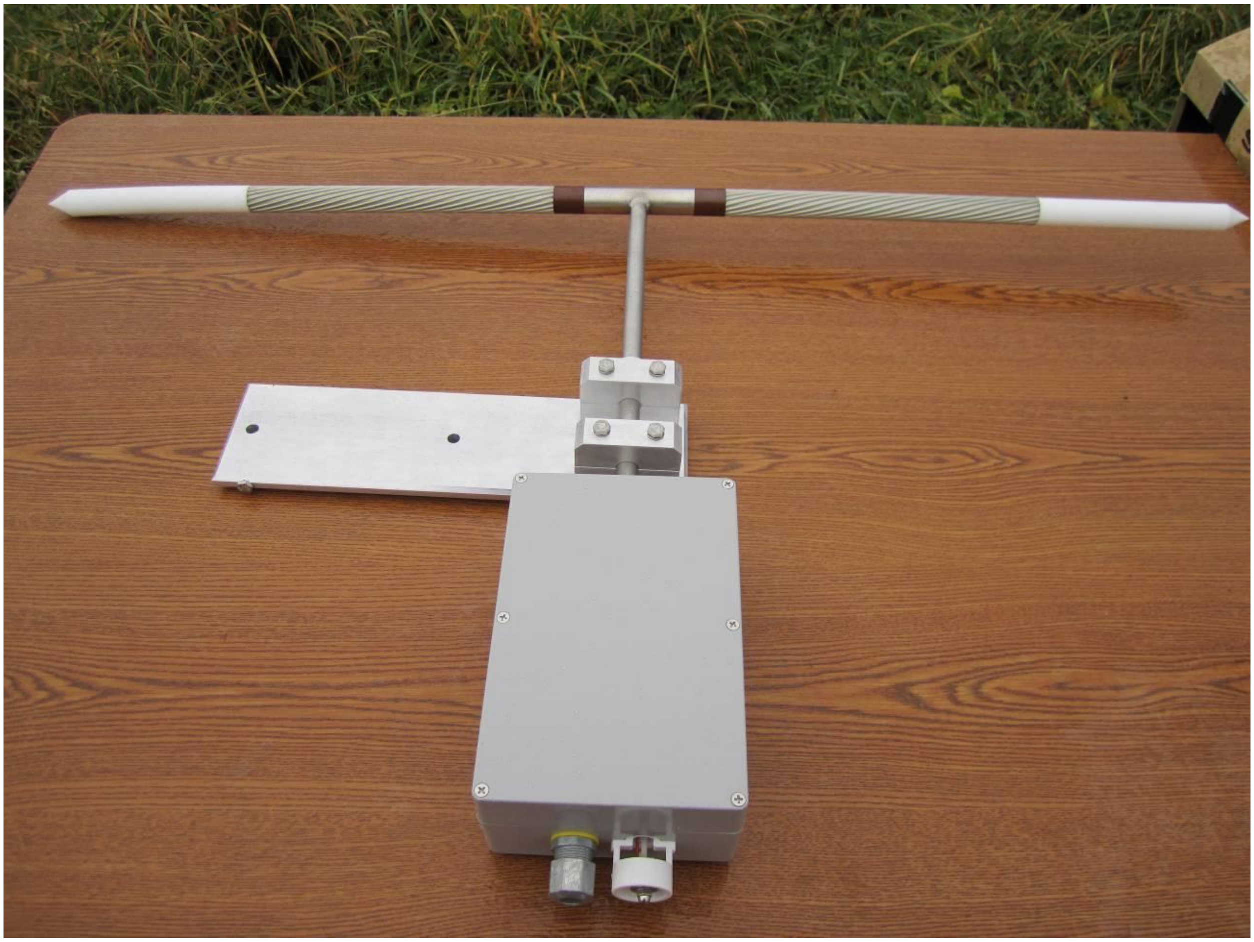


Figure 4-42 ThermalRate sensor being readied for installation

Figure 4-43 Installing ThermalRate sensor

Figure 4-44 ThermalRate system solar panel and electrical box being installed

Figure 4-45 ThermalRate battery box

Sagometer System

Figure 4-46 Installing the Sagometer camera

Figure 4-47 Installing the Sagometer target

Figure 4-48 Sagometer weather instruments installed

The conductor attachment point at structure 36/04 is 57 feet above the ground. The conductor attachment point at structure 36/05 is 42 feet above the ground. The height of the conductor at mid-span during the survey on 11/17/2010 was 33 feet. The height of the anemometer on structure 36/04 is 38 feet.

Figure 4-49 Sagometer electronics box and solar panel installed

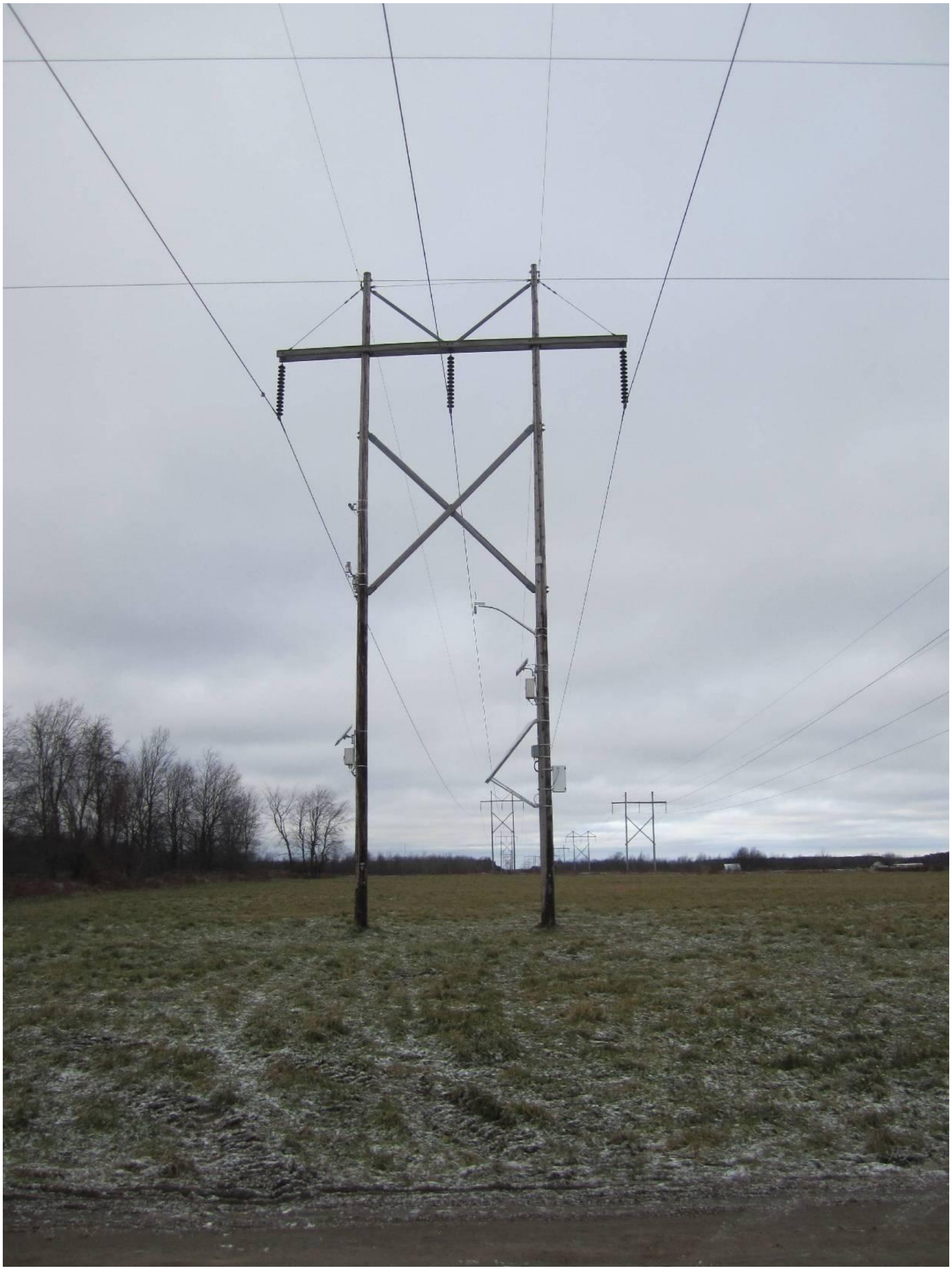


Figure 4-50 Install completed at MW2 - 36/04 – looking in a westerly direction towards Moses Substation

Figure 4-51 Install completed at MW2 - 36/04 - looking back towards Willis Substation in an easterly direction

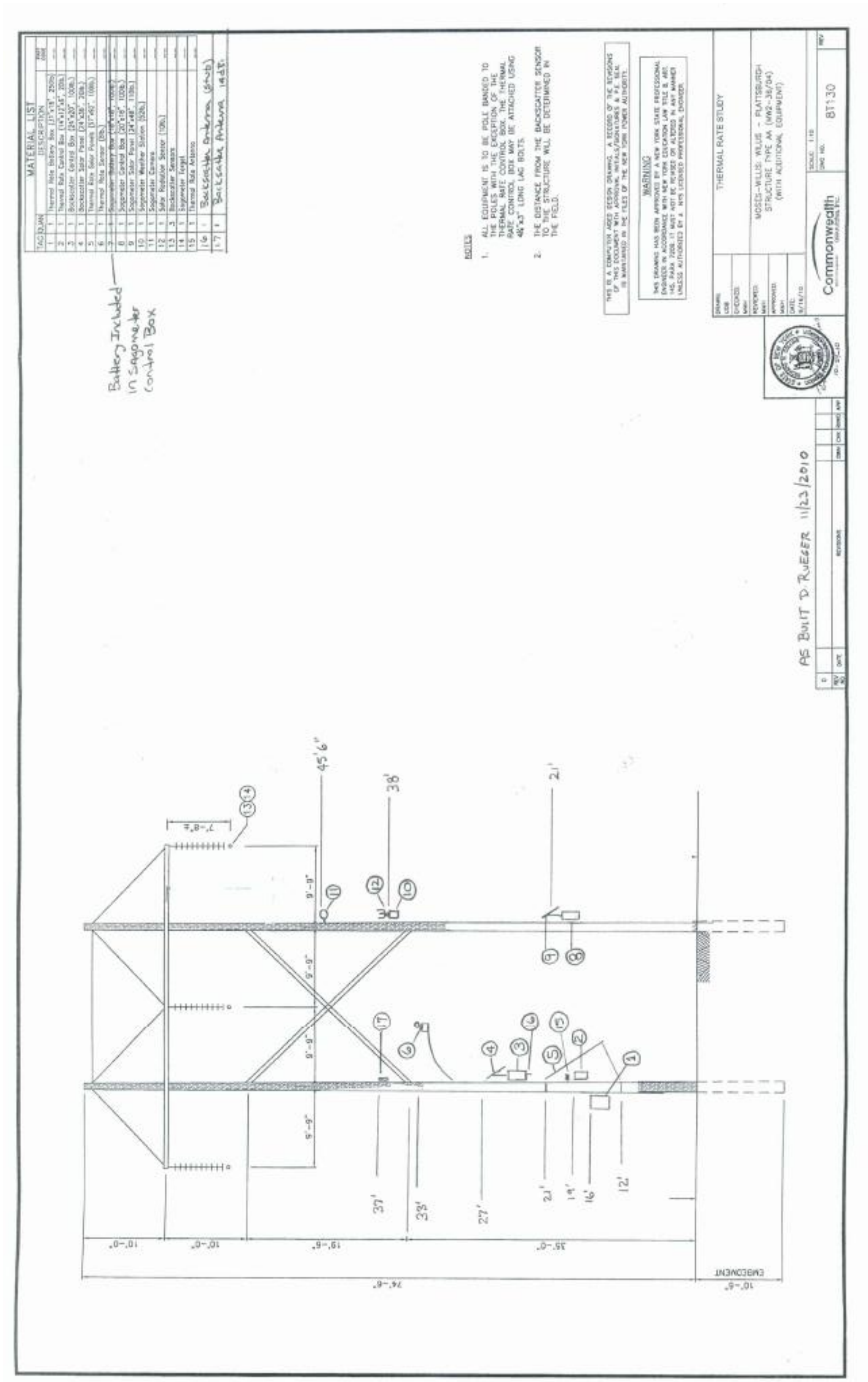


Figure 4-52 As built drawings were marked up after the installation was complete.

For the Survey Crew
Typical project sheet

Site Name Quarry Rd. **Form completed by** Dana Drake

Date Nov. 17, 2010	Wind speed *high* or *low*	Sky *clear* or *overcast*
Precipitation *dry* or *wet*	**Temperature** 50°	Line name MW2 36/04

Survey Data

	Data Point	X	Conductor height	Ground elevation	Time of measurement
201	A	0	1057.03	1000.00	9:05 am
203	1	50.00	1052.28	1000.65	10:14
206	2	128.62	1046.19	1001.87	10:16
213	Target	~~150~~/48.56	1044.55	1001.95	11:12
207	3	206.74	1041.41	1002.00	10:18
208	4	285.86	1038.03	1002.08	10:20
ensor 205	Mid Span	~~443.12~~ 363.42	1035.89	1002.64	10:45
209	5	443.12	1035.50	1003.05	10:50
210	6	521.74	1036.36	1002.50	10:53
211	7	600.36	1038.73	1002.14	10:55
204	8	679.00	1042.56	1002.64	10:57
202	B	729.00	1045.78	1003.61	9:15
212	Sensor	181.54	1042.65	1001.94	

Line direction in degrees from North N 86° E (*Magnetic* or *True*)
Two attachments and 5 other points along the line are required, additional is helpful
Assume an elevation of 100 at the base of pole A if true elevation is not known
Structure A Number MW2 36/04
Structure B Number MW2 36/05

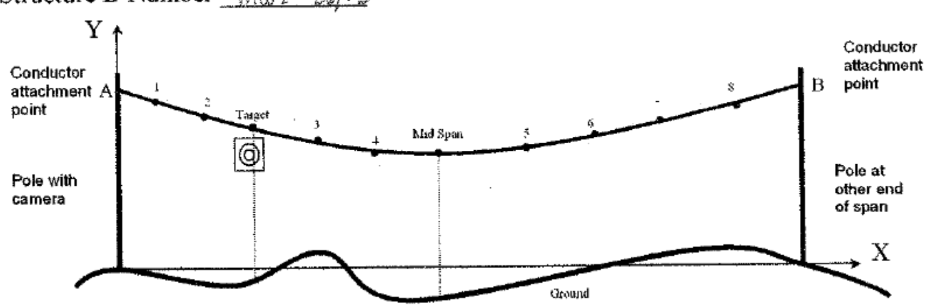


Figure 4-53 Survey sheet for the span between MW2-36/04 and 36/05

Summary of Installation for MW2 – 36/04

- The installation at MW2 – 36/04 was completed on November 17^{th} 2011.
- Heavy rain in the morning caused a shutdown of work for about 45 minutes.
- EPRI sensors were installed relatively quickly at this site. The line crew was more familiar with the installation method and it only took a few minutes at each conductor location to install the sensor. Three sensors were mounted approximately 5’, 182.5’ and 365’ out from structure 36/04.
- The electronic boxes and other instruments were installed relatively quickly at this site as well.
- The Sagometer target was moving around somewhat due to windy conditions during the calibration process. Excessive movement of the target can affect calibration and one should be aware of this effect.
- The communications check with all three systems went smooth. No major issues were noted.
- The site installation was completed in just one day.

Installation on the MW2-03/06 Structure

This site was located near Moses Substation just off of Haverstock Rd.

Figure 4-54 Aerial view of MW2 - 03/06

This structure is at an elevation of approximately 200 feet and this section of line is 121^0 clockwise from north, based on information extracted from the plan and profile drawings.

The conductor is 795 kcmil Drake ACSR. The wooden structure at this site is classified as type "AA".

As can be seen in the photos below, this section of line is mostly open level terrain with minimal sheltering from trees and other objects. Therefore, ruling span assumptions should be quite accurate.

Figure 4-55 Tailgate meeting at the start of MW2 03/06 site

Figure 4-56 Looking back at structure MW2 - 03/06 towards Moses substation before installation begins

Figure 4-57 Locations were marked under the line for the sagometer target and EPRI sensors

Figure 4-58 Lineman tests hotstick prior to installing the EPRI sensors on the energized 230 kV line

EPRI Sensor

Figure 4-59 EPRI Sensors being installed

Figure 4-60 EPRI Sensor electronics box and solar panel

ThermalRate System

Figure 4-61 ThermalRate sensor and arm installed

Figure 4-62 Linemen install ThermalRate electronics box

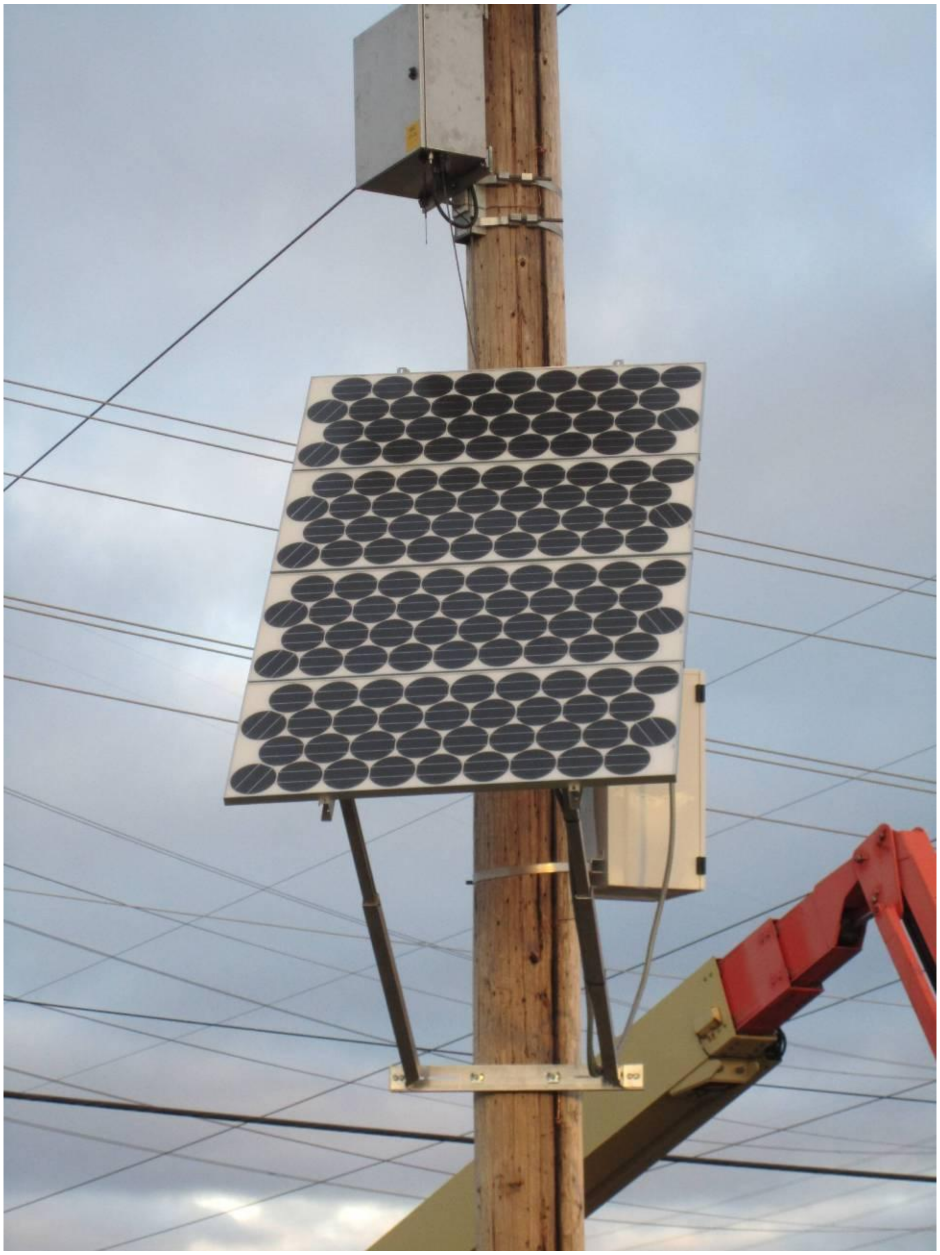


Figure 4-63 ThermalRate solar panel installed

Sagometer System

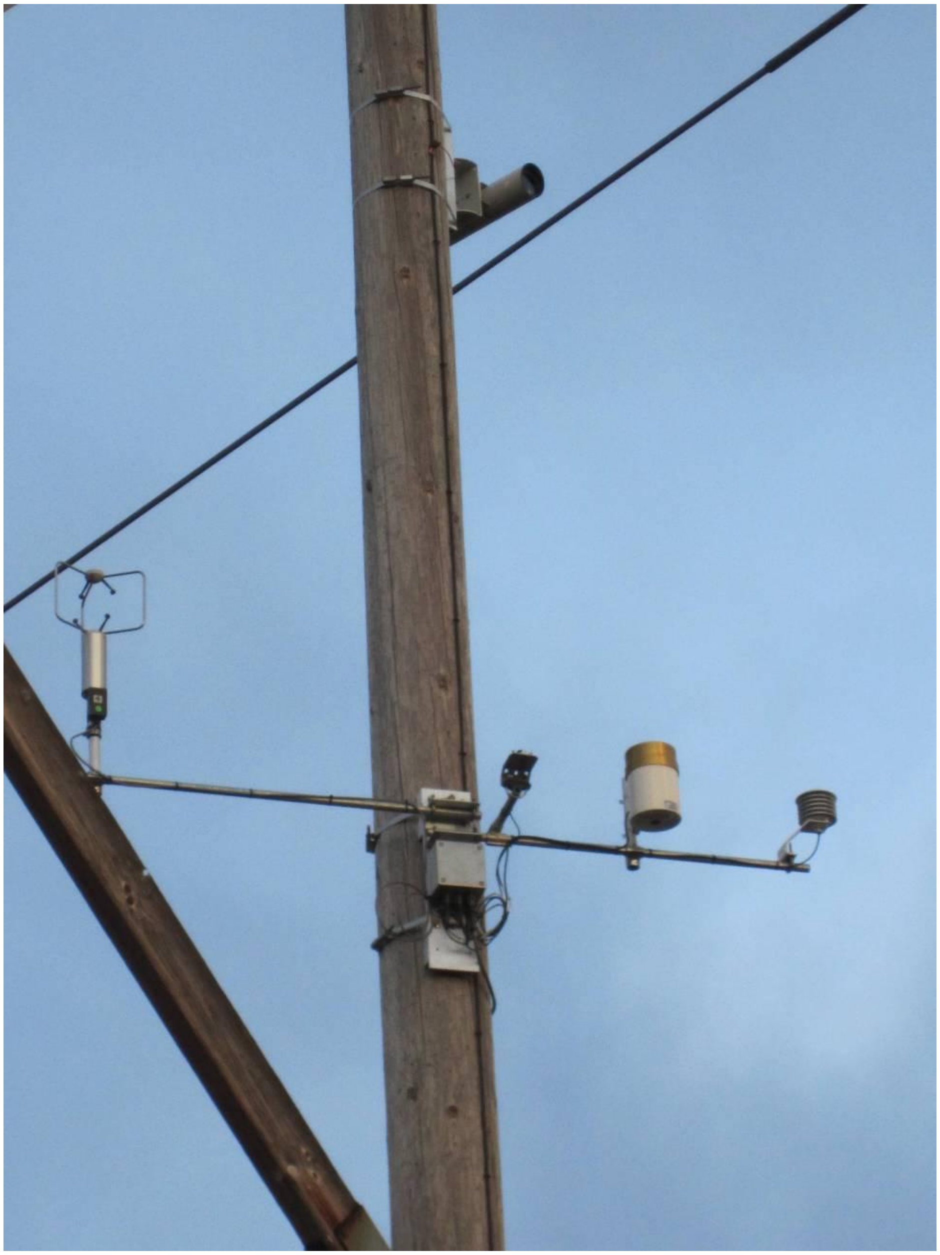


Figure 4-64 Sagometer camera and weather instruments installed

The conductor attachment point at structure MW2 - 03/06 is 52 feet above the ground.
The conductor attachment point at structure MW2 - 03/07 is 48 feet above the ground.
The height of the conductor at mid-span during the survey on 11/18/2010 was 36 feet.
The height of the anemometer on structure MW2 - 03/06 is 36 feet.

Figure 4-65 Sagometer target installed

Figure 4-66 Sagometer solar panel and electronics box

Figure 4-67 Sagometer camera, weather sensors, solar panel and electronics box

Figure 4-68 MW2 03/06 site completed looking back in the direction of Willis Substation

Figure 4-69 MW2 03/06 Completed looking towards Moses Substation

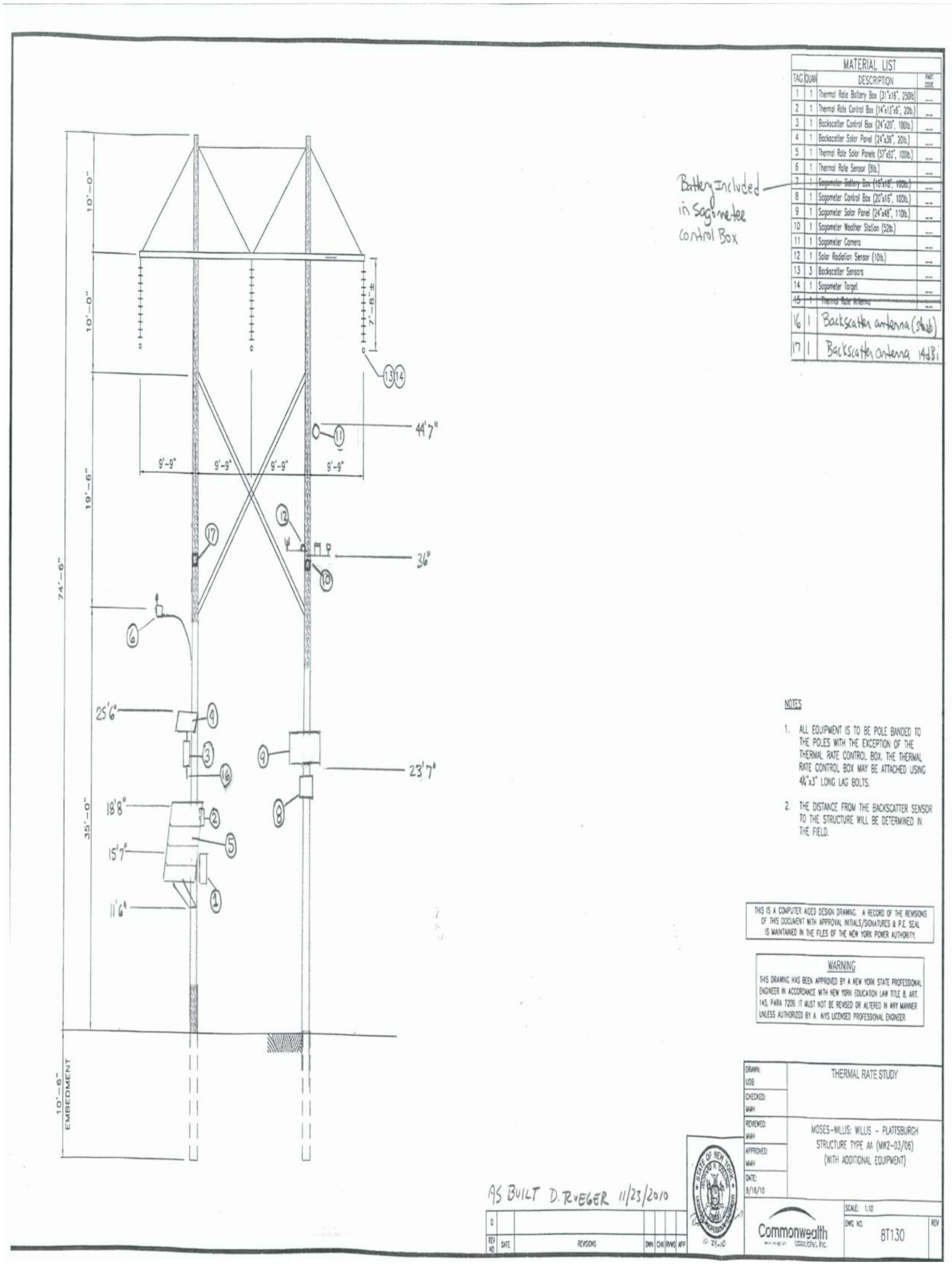


Figure 4-70 As built drawing for site MW2 - 03/06

For the Survey Crew

Typical project sheet

Site Name Haverstock Rd **Form completed by** Dana Drake

Date 11 18 10	Wind speed *high* or *low*	Sky *clear* or *overcast*
Precipitation *dry* or *wet*	**Temperature** 40°	Line name MW2 - 03/06

Survey Data

	Data Point	X	Conductor height	Ground elevation	Time of measurement
301	A	0	252.09	200.00	10:05 am
303	1	50.00	248.41	200.50	11:03 am
306	2	122.58	244.01	200.80	11:05
313	Target	~~150~~ 147.07	242.44	200.98	11:12
307	3	195.15	240.80	201.33	11:07
308	4	267.72	238.78	201.89	11:08
Sensor 305	Mid Span	338.09	238.06	201.72	10:45
309	5	412.87	238.26	201.69	10:47
310	6	485.44	239.70	201.74	10:49
311	7	558.01	242.29	201.40	10:52
304	8	630.61	246.00	200.96	10:54
302	B	680.61	249.24	200.92	10:25
312	Sensor	168.42	241.80	201.18	11:10

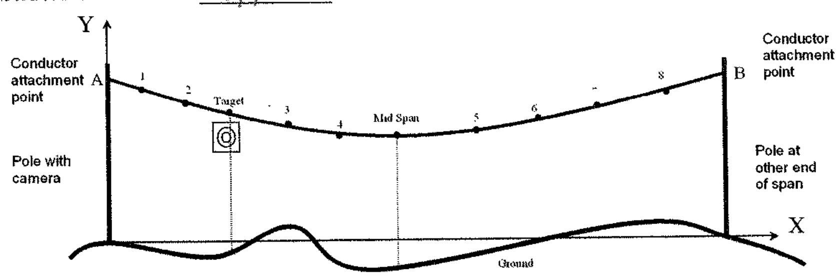
Line direction in degrees from North S 59° E (AZ: 121°) (*Magnetic* or *True*)

Two attachments and 5 other points along the line are required, additional is helpful

Assume an elevation of 100 at the base of pole A if true elevation is not known

Structure A Number 3/6

Structure B Number 3/7



Target elevation for say camera calib. "Conductor height" Time 3:06pm

35.79
207.09
242.88

Figure 4-71 Survey sheet for the span between MW2 03/06 and 03/07

Summary of Installation for MW2 – 03/06

- The installation at MW2 – 03/06 was completed on November 18th 2011.

- This was the fourth installation of the project. The team had worked out an efficient method for installing the instruments. Below is a chronological order of the install at this site:

    - 8:15 am - team arrived
    - 8:30 am – unloaded truck and instruments prepared
    - 9:15 am – lifts and line crew arrive
    - 10:00 am - hot sticks checked and tested
    - 10:15 am - first EPRI sensor installed
    - 11:00 am – other two EPRI sensors and target installed
    - 12:15 – 1:15 pm – lunch
    - 1:15 – 3:15 pm – video sagometer and control box installed on north pole; EPRI sensor control box and Thermal Rate sensor and control box installed on south pole.
    - 3:25 pm Thermal Rate solar panel and battery box installed

- There was a software communication issue between the Sagometer camera and data logger during setup and calibration. A software switch enabled to shut power off to the camera during normal field operation was set “on”. This condition made the camera appear to be down. The problem was corrected by bypassing the camera “off” setting while adjustments were being made during calibration and then reset to power “off” at a specific interval later.

- The line crew dropped the tool socket once while installing the first EPRI sensor.

- The installation of this site was completed in one day.

5

INSTRUMENTATION PERFORMANCE AND MAINTENANCE ISSUES

This section provides a chronological listing of performance observations and maintenance issues associated with each of the systems and their instrumentation. The time period covered runs from November 19th 2010 to August 16th 2011. Summary and conclusions are provided at the end of this section.

Video Sagometer

3/24/11 - It was observed in the Sagometer data records, columns for GC, GC corrected for target swing, GC corrected for tilt, it seems like there should be GC corrected for swing AND tilt. EPRI first used the GC corrected for tilt, but found that there is unrealistic GC variation (3-4 ft at midspan throughout a day). The GC alone looked more believable. EDM was to investigate.

3/27/11- Power was cycled on the Sagometer control boxes at NYPA field sites MW2 03/06 and MW2 36/04 to restore communications. EDM confirmed that it could now communicate with the Video Sagometer cameras at these two sites.

4/4/11 - Communications with Sagometer failed WP2 01/02.

5/6/11 – It was noted that the Sagometer Solar Panel circuit breaker may have been inadvertently left off or some activity may have indirectly caused the tripping of this breaker. Solar Panel breaker was turned ON. Solar panel voltage and current tested ok. The charger/regulator resumed normal functions and began battery charging. Although the battery would eventually return to full charge, it was replaced with a fresh battery to expedite the troubleshooting process.

The newest operating system was loaded into the data logger. Program files and settings were reloaded into the data logger. Camera and weather sensor data was verified.

6/21/11 - It was noted at sites WP2-01/02 and MW2-03/06 that they appear to have a downed Sagometer cameras. EDM stated that the issue appears to be with the data logger's ability to handle the ethernet connection to the camera.

6/30/11 – EDM makes three changes to the Sagometer data logger on the PPP/Ethernet options at the WP2 01/02 site. This issue is still being investigated.

8/15/11 and 8/16/11 - EDM visited the three NYPA/DOE Sagometers and installed the following enhancements:

System Power Reset – power to the full system can be reset by setting a variable via a remote Loggernet connection. A full system reset should restore a camera-data logger communications failure.

Modem Power Control – Modem power was rerouted such that data logger programs and operating systems can be uploaded remotely without the risk of loosing cellular communications.

Operating System – The most recent operating system was uploaded to the data logger, resulting in better ethernet communications.

Data logger Program – a more efficient data logger program was installed in all three systems.

Data logger-Camera Ethernet - (WP2 only) the camera and data logger programs were modified to increase the reliability of receiving uncorrupted data strings at the data logger. This upgrade is significant for two camera systems, marginally so for single camera systems.

The camera-data logger communication failures for WP2 and MW2-03/06 were restored by resetting (turning off then back on) system power.

The average time at each site was 1 1/2 hours.

EPRI Sensors

12/21/10 - Dan Lawry brought wireless equipment (provided by EPRI) to verify communication to the EPRI sensor 4936 at MW2 03/06 and the sensor 4932 at MW2 36/04. Communication had been lost to these two sensors. These are the middle sensors at each location, so the indication is that the Sensors are bad, rather than the antenna or coax on the pole side. The wireless equipment was not able to contact the bad sensors (even locating the wireless equipment underneath the sensors), so the sensors themselves must be the problem. They will be scheduled to be replaced at a future date.

3/27/11 to 3/28/11 - Dave Rueger brought new EPRI replacement sensors to NYPA field sites, MW2 03/06 and MW2 36/04. On Monday March 28th, NYPA line crew replaced the six sensors at these two sites under de-energized conditions. In addition, a new sensor communication module was installed at the MW2 03/06 site. The following is a list of sensor serial numbers versus location at these two sites:

MW2 03/06

s/n 4960 – 5 feet out from the structure

s/n 4962 – 170 feet out from the structure

s/n 4969 – 340 feet out from the structure

MW2 36/04

s/n 4971 – 5 feet out from the structure

s/n 4983 – 182.5 feet out from the structure

s/n 4984 – 365 feet out from the stucture

5/6/11 - replaced communication module for EPRI sensors at WP2 01/02. A communication issue between EPRI sensors and data logger still existed after the replacement. It may be the data logger itself since the new communication module was providing an audible tone indicating it was talking to each sensor. This issue was being reviewed remotely.

8/16/11 – replaced EPRI sensor communication module at MW2 36/04 with updated module. Note existing module was functioning ok, this was just and upgrade.

The communication module at WP2 01/02 was replaced. This corrected the issue and data could now be received from EPRI sensor 4943 and 4942. The third sensor 4944 was not working. All three sensors are scheduled to be updated at the next line clearance opportunity. Three EPRI sensors were left secured to the top of the electronics box. They will be installed at the following locations on the next trip:

s/n 6811 – 5 feet out from the structure

s/n 6813 – 190 feet out from the structure

s/n 6818 – 380 feet out from the structure

ThermalRate

RTU ISSUE

NYPA has a GE D20 RTU at Willis sub that will be sending line currents by DNP3 every 20 seconds to both the ThermalRate systems at WP2 01/02 and MW2 36/4.

In the RTU, there are already points containing the MW2 line current and WP2 line current. Each point is from 0 to 32767 counts (which correspond to 0 to 1200 A for the WM2 line and 0 to 3276.7 amps for the WP2 line.) NYPA created another point (a pseudo point, which does measure anything but contains the result of a calculation) which took the MW2 raw value and divided it by 27 to get the value in amps. This approach only allowed division by an integer, so 32767/27=1213 amps, which has a 13 A error. For the WP2 line, a point was created which takes the raw counts and divides by 10. 32767/10=3276, which is close to 3276.7.

An initial assumption is that the WP2 line has a CT with a limit of 3276.7 and the MW2 line has a CT with a 1200 amp limit. This was to be confirmed with NYPA. The 1200 A CT will probably have to be replaced to make use of the dynamic ratings.

NYPA will change the RTU configuration so that the line current is given to the TRMs every 20 seconds. The RTU will update the TRM's analog output point. He will stagger the communication to the TRMs so that he can use the same RTU dB9 port and alternate the DNP address.

NYPA made these changes to the RTU configuration and tested them on a test RTU. NYPA will download the configuration to Willis at a later date.

Thermal Rate

12/21/10 - Dan Lawry drove to the field site WP2 01/02 to replace the ThermalRate Sensor. It took about an hour to replace, and this was done from the JLG lift by the linemen. It was suspected that high electric field at the ThermalRate sensor location had damaged a thermocouple transducer. The replacement sensor has ground connections to the conductor replicas to fix this issue. Since the ThermalRate sensor does not need to be located close to the conductors, this was the first time an installation had been done in so high an electric field. Short term electric field testing was previously performed, but this failure took days to happen. The other two sites could also develop this problem, but Thermalrate is taking the approach to not change anything unless there is an actual problem.

During this same day, 3/8" nuts on the arms of the ThermalRate solar panels were replaced with both locknuts (the kind with nylon inserts) and lock washers. These had been loosening with the motion due to wind.

At the MW2 03/06 location, Dan also fixed a wiring problem preventing the EPRI sensor box from reading the ThermalRate data. During the initial installation in November, a misunderstanding resulted in thinking the interconnect wiring was working when it actually was not. This took about an hour.

03/24/11 - EPRI noted that WS equivalent perpendicular is capped at 30 ft/sec. Dan Lawry stated that this is done on purpose because it could give ratings that are too high for the operator to trust, and the system starts losing accuracy because the hot rod's temp is not higher than the cold rod by enough.

6/31/11 – Dan Lawry noted that NYPA was polling data and supplying line current every 2 seconds from ThermalRate, which is too fast. This may be bogging down the ThermalRate processor, and that could be why you're seeing line amps updates sporadically. Dan requested NYPA to slow the polls to every 30 seconds. This issue is associated with MW 36/04 and WP2 01/02 sites.

7/12/11 – NYPA noted that the person who will make this change will back in 2 weeks.

8/16/11 – The top bolts were tightened on the ThermalRate solar panel.

8/17/11 – A suggestion proposed to that it may be better to give up on the idea of getting the current via the NYPA RTU, and use the current measured from the EPRI sensors for our calculations. The RTU connection seems to be disrupting the ThemalRate operation, and we're not getting the data anyway. This will be reviewed.

Summary and Conclusions

Table 5-1 summarizes the performance and maintenance issues at the three field sites since installation.

Table 5-1 Instrumentation Performance and Maintenance Issues Summary

Date	Site(s)	System	Component	Description of Issue	Resolution of Issue
12/21/10	MW2 03/06 and MW2 36/04	EPRI sensor	sensor	lost communication with 2 sensors	sensors to be replaced
12/21/10	WP2 01/02	Thermal Rate	Thermal Rate sensor	high E-Field at the Sensor location had damaged a thermocouple transducer	the replacement sensor has ground connections to the conductor replicas to fix this issue
12/21/10	WP2 01/02	Thermal Rate	Thermal Rate solar panel	Nuts loosen up panel bracket	replaced with both locknuts (the kind with nylon inserts) and lockwashers. These had been loosening with the motion due to wind
12/21/10	MW2 03/06	Thermal Rate	electrical box wiring	fixed a wiring problem preventing the EPRI sensor box from reading the ThermalRate data	during the initial installation in November, a misunderstanding resulted in thinking the interconnect wiring was working when it actually was not

3/24/11	All	sagometer	sensor	tilt sensor anomaly	this issue to be investigated.
3/24/11	All	Thermal Rate	Data logger/ software	EPRI noted that WS eq perp is capped at 30 ft/sec.	this is done on purpose because it could give ratings that are too high for the operator to trust, and the system starts losing accuracy because the hot rod's temp is not higher than the cold rod by enough
3/27/11	MW2 03/06 and 36/04	sagometer	data logger / software	lost communications with video sagometer cameras	recycle power manually
3/2711	MW2 03/06 and MW2 36/04	EPRI sensor	sensor	Trip to replace sensors	Replace 6 sensors with updated versions. In addition, an updated sensor communication module was installed at the MW2 03/06 site.
4/4/11 to 5/6/11	WP 01/02	sagometer	Solar panel circuit breaker	lost communications to sagometer	breaker found off on solar panel . Reset beaker and install new battery (breaker may have been inadvertently left off on last visit or tripped)

5/6/11	WP 01/02	sagometer	data logger / software	updated software	the newest operating system was loaded into the data logger
5/6/11	WP 01/02	EPRI sensor	Communication module	sensor communication module issue	A communication issue between EPRI sensors and data logger still existed. The matter was to be investigated further remotely
6/21/11	WP2-01/02 and MW2-03/06	sagometer	data logger software	downed Sagometer cameras.	EDM noted that the issue appears to be with the data logger's ability to handle the ethernet connection to the camera. This issue to be investigated.
6/30/11	WP2-01/02 and MW2-03/06	sagometer	Data logger/ software	downed Sagometer cameras	EDM made three changes to the Sagometer data logger on the PPP/Ethernet options at the WP2 01/02 site. Issue to be investigated.
6/31/11	MW 36/04 and WP2 01/02	Thermal Rate	Data logger/ software	Pike noted that NYPA was polling data and supplying line current every 2 seconds from ThermalRate, which is too fast.	Pike requested NYPA to slow the polls to a 30 second

8/15/11 and 8/16/11	WP2-01/02 and MW2-03/06	sagometer	Data logger / software	downed sagometer cameras	System Power Reset, Modem Power Control, Operating System, Data logger Program, Data logger-Camera Ethernet and The camera-data logger communication failures for WP2 and MW2-03/06 were restored by resetting (turning off then back on) system power. All three sites working
8/16/11	WP2-01/02 and MW2-36/04	EPRI Sensor	Communication module	Updated communication module at MW2 36/04. Communication module at WP2 01/02 not working	Installed updated communication modules at MW2 36/04 and at WP2 01/02. Both sites working
8/16/11	WP2-01/02	Thermal Rate	Thermal Rate solar panel	top nuts loosen up panel bracket	tighten nuts on top of bracket

6
SUMMARY OF DATA AND ANALYSES

Discussion about errors that enter the data

There is a host of ways errors can enter the field data. Each sensor has strengths and weaknesses. The challenge is choose and setup the sensors in such a way that the strengths are maximized and the weaknesses are minimized. However, even if this is done it is still important to be able to detect and isolate problematic data. Monitoring system battery voltage, communication signal strength, correlation coefficients and other such parameters can shed light on the systems health. It is important to work with the venders of these systems to understand what parameters to monitor and what to look for in each of those items. In some cases decisions about the data integrity must be made based on these system health parameters.

Real Time versus Post Processing

Sometimes it can be difficult to tabulate system health parameters. System performance can be looked at in a number of ways. When post processing data, data is collected downloaded and then used for calculation. As long as the data is recorded by the data logger and does not get overwritten before it is downloaded, everything is good. However, this is not the case with real time data processing. With real time data processing timing is everything. The latest data must be available and a solid communication link must be established when the data is needed. If this communications link should fail then the data is going to be late. If the data does not arrive at the data logger in time, then the data that is retrieved will be stagnant. The software that retrieves the data will make several attempts to reconnect if the communication connection should fail. If after several attempt the software fails to connect, it waits until the next retrieval cycle. Once the software connects it will download the data including that data that it was unable to collect in the previous attempts. As it turns out it is difficult to get meaningful data from the software that somehow would tabularize this sort of information.

Missing data

Missing data happens when the data coming from a field sensor never gets to the data logger or if the server was not able to download the data from the loggers before the data was overwritten by new data. Sensors occasionally fail for any number of reasons. Sometimes the problem is a result of broken communications between the sensor and the logger. Communications between the sensor and the logger can be wireless or wires. Communications failures between the sensor and the logger can be a result of protocol conflicts, physical damage, wireless transmitter issues, antenna issues, or any number of other possibilities.

Out of range data

Incoming data is checked for accuracy. In almost all cases the data has an expected range. For example one would expect the air temperature to be between -50C and 50C. If the data comes in outside that range one can expect that there may be some sort of problem. Additional like data from nearby sensors has a tremendous advantage; the data can be compared and sometimes substituted.

Data quality indicators

Some of the sensors have data integrity indicators. An example of this would be the line clearance measurements. This is a case where the camera uses image recognition to identify the target hanging from the transmission line. The camera has an image stored in memory and it compares the image in memory with the current image. By counting the number of pixels that compare favorable with the stored image a percentage of recognized pixels can be computed. Consequently it is possible that the camera could report a target that is in range but the data quality indicator could suggest that its confidence in that recognition is poor.

Bad data

In some cases the data logger recognizes that bad data is coming in or that there is some sort of problem. In these cases the logger may report a number like 999. Data that is out of range or that has poor quality indicators could also fall under the heading of bad data. The 999 indicator is somewhat dependant on how the data logger has been programmed. It could also suggest that there was missing data. It is important to work with the venders to determine the error codes reported by the data loggers. In some cases it can be difficult to determine if the data is bad. An example of this is data that is in rage but that is stagnant. In these cases it may be best to just use the human eye and look at the time series plots and look for groups of data that sits at on level for a long period of time.

The sagometer weather stations working well

In general, the weather stations seem to perform well. In the case of these lines were there is so little current flowing in relation to the size of the conductor, the weather station is the best choice for providing consistent ratings. The weather station has the advantage of not requiring current on the line to provide rating information. The weather station also is simple and makes use of sensors with a tractable calibration. It also has the advantage of providing information that can be checked against nearby weather stations.

Sagometer camera performance is less than ideal

The sagometer camera technology is having some growing pains. There have been a few issues with battery / solar panel sizing and internal sensor communications. The other issue is that the line is so lightly loaded that the conductor for the most part is sitting at ambient temperature.

Without having sufficient current in the line to heat it up well over ambient temperature, ratings based on this device are impossible. This would be true of a tension based system as well.

EPRI sensor performance OK

The EPRI sensors are doing OK given that they are in a pre-commercial development stage. There have been some issues with internal communications between the logger and the sensors and some deficiencies were discovered in the potting compound. With that said, they have been the only source of line current data for almost 1 year now. These sensors also provide a sanity check for computed conductor temperature. The down side to rating with these sensors is that, like the Sagometer, they require more current on the line before they can be use for rating calculations. One thing that has helped the performance of this system is that there are multiple sensors, if one fails there are two others that can fill in the gaps.

ThermalRate difficult to determine performance until NYPA makes changes

It has been difficult to accurately determine the performance of the ThermalRate system because the load data coming from the EMS system has resulted in disturbing the performance of the ThermalRate device. EPRI and Shaw Energy have been working with NYPA in an attempt to slow down the data rate going to the ThermalRate device. Indications are that once NYPA makes this change the ThermalRate device will provide timely data. Right now only one ThermalRate device is working properly, this device is the one that is not connected to the NYPA system.

Ratings

A number of ratings are available. Because so many sensors have been applied to this line several rating models can be developed. Each model will have its strengths are weakness depending on the physics involved.

Weather Model

The weather model uses 5 sensors. See list below.

- Wind speed
- Wind direction
- Air temperature
- Solar radiation
- Current

These sensors are used along with a number of specifics about the line to calculate both short-term and long-term ratings. One could argue that current is not needed, however, the short-term ratings 4 hrs, 15 min ratings would not be possible without the current. The weather model has the advantage that it is independent of the line other than the current. It is simple to setup and easy to trace the origins of the calibration. It is also relatively easy to check that the numbers produced by the sensors are approximately correct. This can be done by going on the web and looking at local weather conditions. Another advantage to the weather station is that if it is working it will always be able to provide a rating. The disadvantage of the weather station is it only measures the data at one point in space. Placement of the weather station in important. A weather station in an area sheltered from the wind will provide more conservative ratings.

ThermalRate Model

ThermalRate is basically a weather station. When this device is used for ratings with DTCR the ThermalRate system provides DTCR with an equivalent perpendicular wind speed. All other weather inputs are taken from the Sagometer weather station.

Airport Model

The airport model is completely independent from field sensors other than line current. EPRI is experimenting with airport based weather model. The thought is if a sensor or weather station system should fail – could the airport data be used. It is likely that the model will need to be made more conservative as airports are often some distance from the line and tend to be much less sheltered. This information also acts as a sanity check for the Sagometer weather station.

Sagometer Model

For this model to be valid, significant current must be flowing in the line, such that the line must be physically warm. In this case 350 amps was selected as the cutoff. Anything below this current level and the Sagometer model can not be used.

EPRI Sensor model

This model suffers from the same constraints as the Sagometer model. Over 350 amps must be flowing in the line before any useful ratings can be calculated.

Model matrix

The matrix below shows the 3 circuit names in green, each circuit has five models associated with it. The items in blue do not require high current for the model to be valid. The items in red require sufficient current such that the conductor temperature is high enough that it can be used as a hot wire anemometer.

Table 6-1 Model matrix

Site	Model	Model	Model	Model	Model
WP2 01-02	Weather Sagometer Sensors	Weather ThermalRate Sensors	Sag based Sagometer Camera	Sag based EPRI Sensor Conductor Temp.	Weather Airport Sensors
MW2 36-04	Weather Sagometer Sensors	Weather ThermalRate Sensors	Sag based Sagometer Camera	Sag based EPRI Sensor Conductor Temp.	Weather Airport Sensors
MW2 03-06	Weather Sagometer Sensors	Weather ThermalRate Sensors	Sag based Sagometer Camera	Sag based EPRI Sensor Conductor Temp.	Weather Airport Sensors

The plot shown below in Figure 6-1 is raw data from the Sagometer weather station at site MW2 36/04. The plot shows ambient air temperature, solar radiation and precipitation as measured during the month of June, 2011.

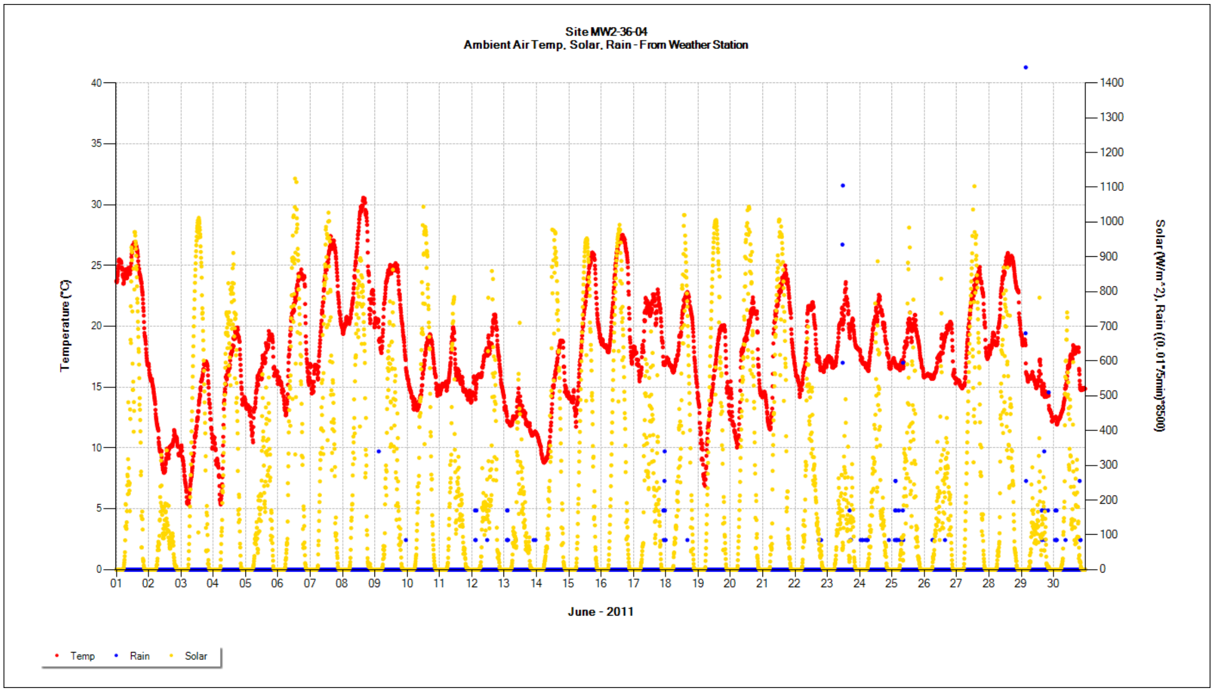


Figure 6-1 Air temperature, Solar, Rain

The plot shown below in Figure 6-2 is raw data from the Sagometer weather station at site MW2 36/04. The plot shows cumulative distribution for ambient air temperature as calculated for the month of June, 2011.

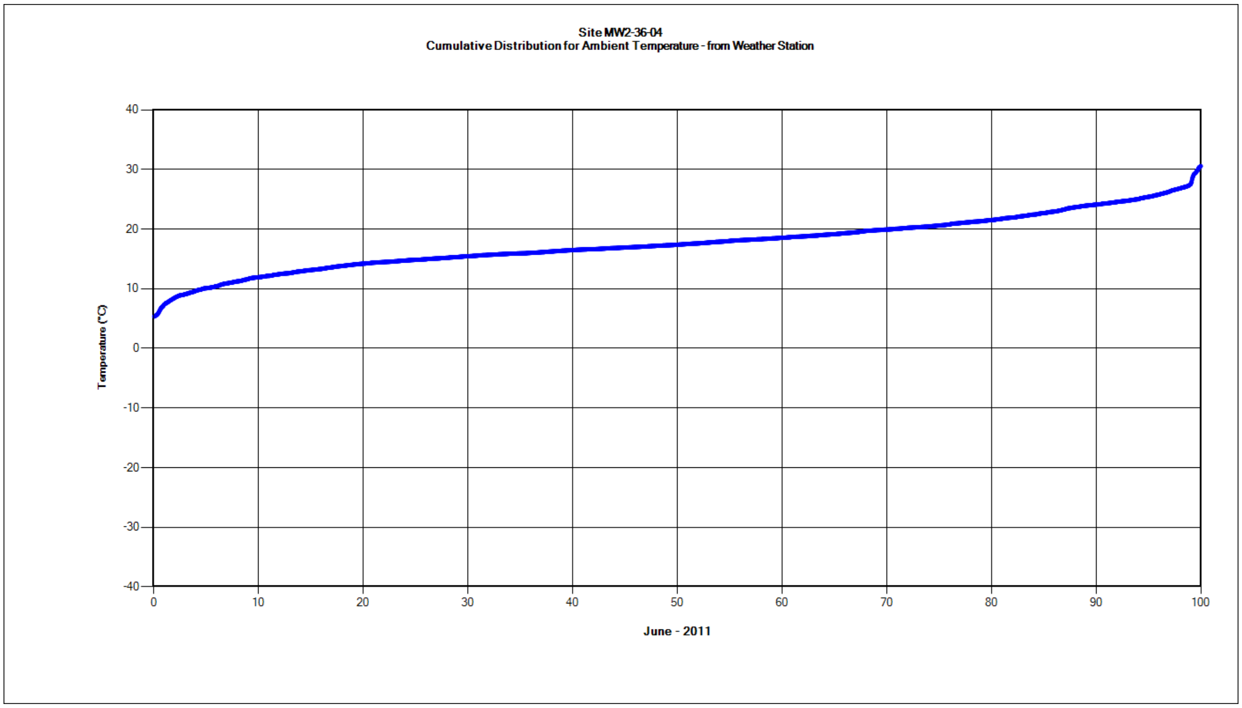


Figure 6-2 Cumulative Distribution Air temperature

The plot shown below in Figure 6-3 is raw data from the Sagometer weather station at site WP2 01/02. The plot shows a time series of wind speed and wind direction for the month of June, 2011.

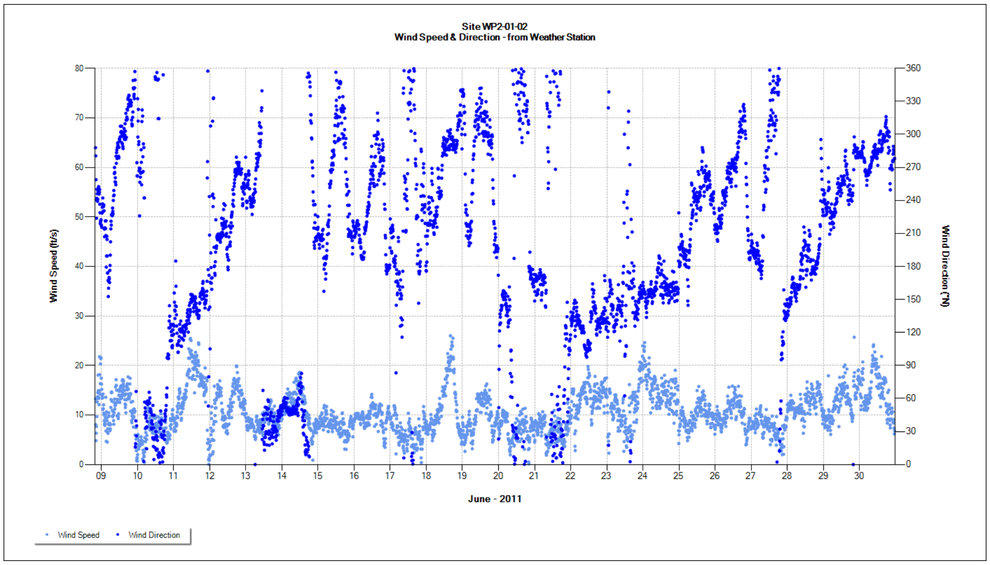


Figure 6-3 Wind Speed and Direction weather station

The plot shown below in Figure 6-4 is raw data from the Sagometer weather station at site WP2 01/02. The rose plot shows wind speed and wind direction for the month of June, 2011.

A wind rose is a graphic tool used by meteorologists to give a succinct view of how wind speed and direction are typically distributed at a particular location. Using a polar coordinate system of gridding, the frequency of winds over a long time period are plotted by wind direction, with color bands showing wind ranges. The directions of the rose with the longest spoke show the wind direction with the greatest frequency. Presented in a circular format, the wind rose shows the frequency of winds blowing from particular directions over a 1 month period. The length of each "spoke" around the circle is related to the frequency that the wind blows from a particular direction per unit time. Each concentric circle represents a different frequency, emanating from zero at the center to increasing frequencies at the outer circles. A wind rose plot may contain additional information, in that each spoke is broken down into color-coded bands that show wind speed ranges.

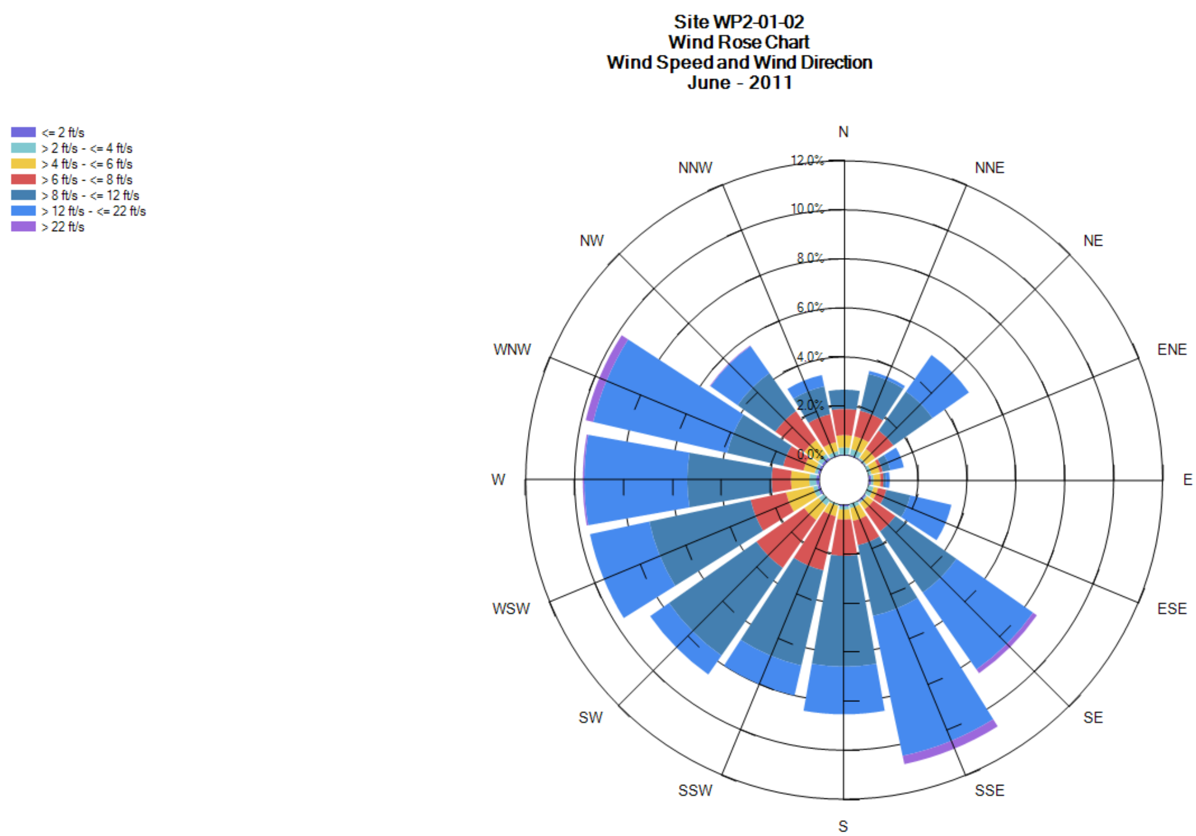


Figure 6-4 Wind Rose Plot

The plot shown below in Figure 6-5 is raw data from the Sagometer weather station at site WP2 01/02. The plot shows cumulative distribution for ambient air temperature as calculated for the month of June, 2011.

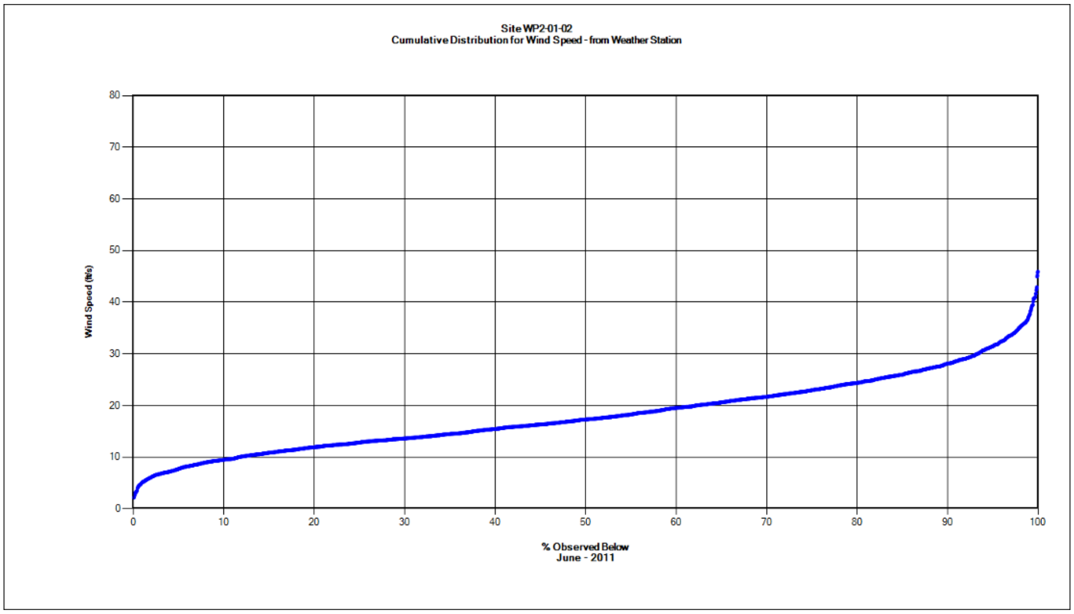


Figure 6-5 Cumulative Distribution wind speed

The plot shown below in Figure 6-6 is raw data from the ThermalRate system at site WP2 01/02. The plot shows effective perpendicular wind speed for the month of February, 2011.

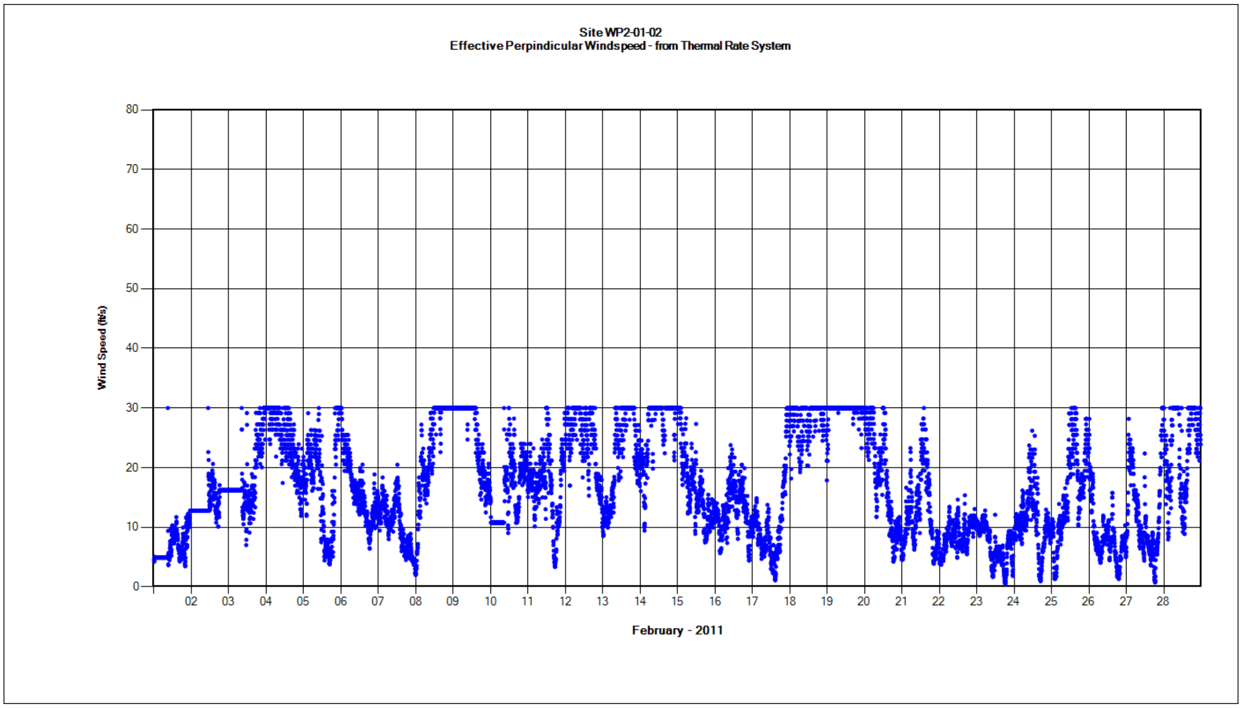


Figure 6-6 Effective perpendicular wind speed

The plot shown below in Figure 6-7 is raw data from the ThermalRate system at site WP2 01/02. The plot shows cumulative effective perpendicular wind speed for the month of February, 2011.

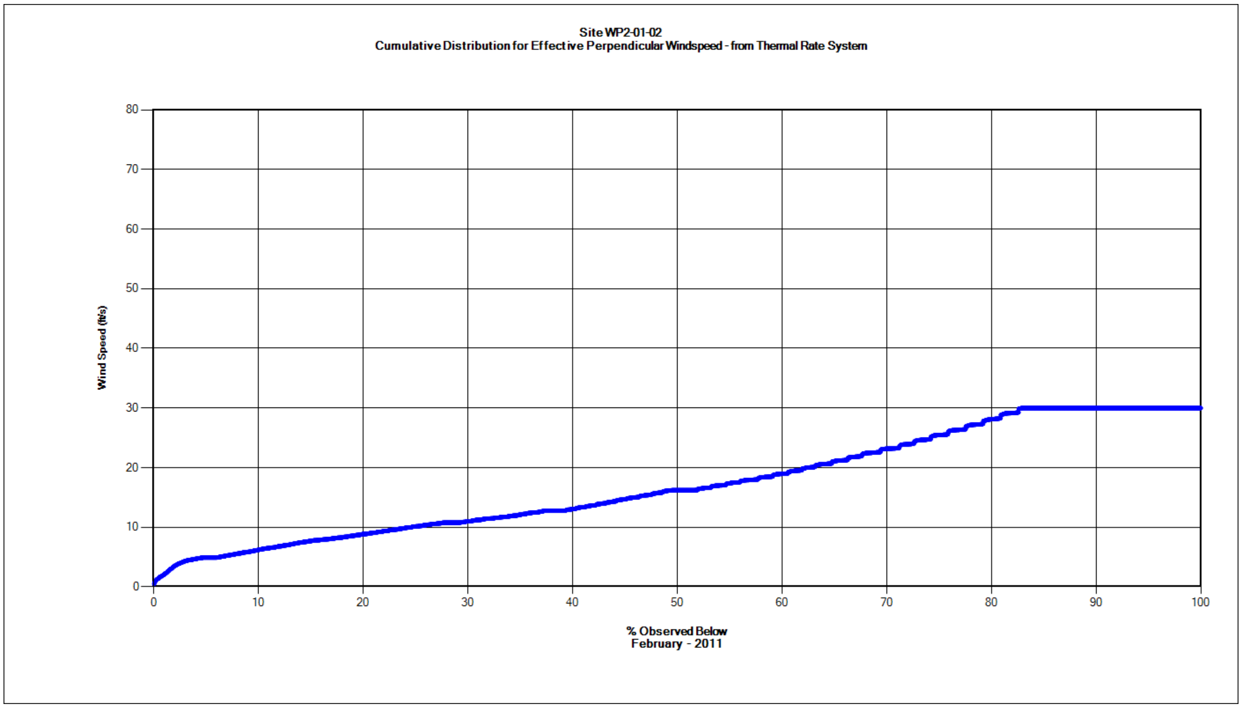


Figure 6-7 Cumulative effective perpendicular wind speed

The plot shown below in Figure 6-8 is raw data from the Sagometer weather station at site WP2 01/02. The plot shows clearance at the target and percent correlation as calculated for the month of February, 2011.

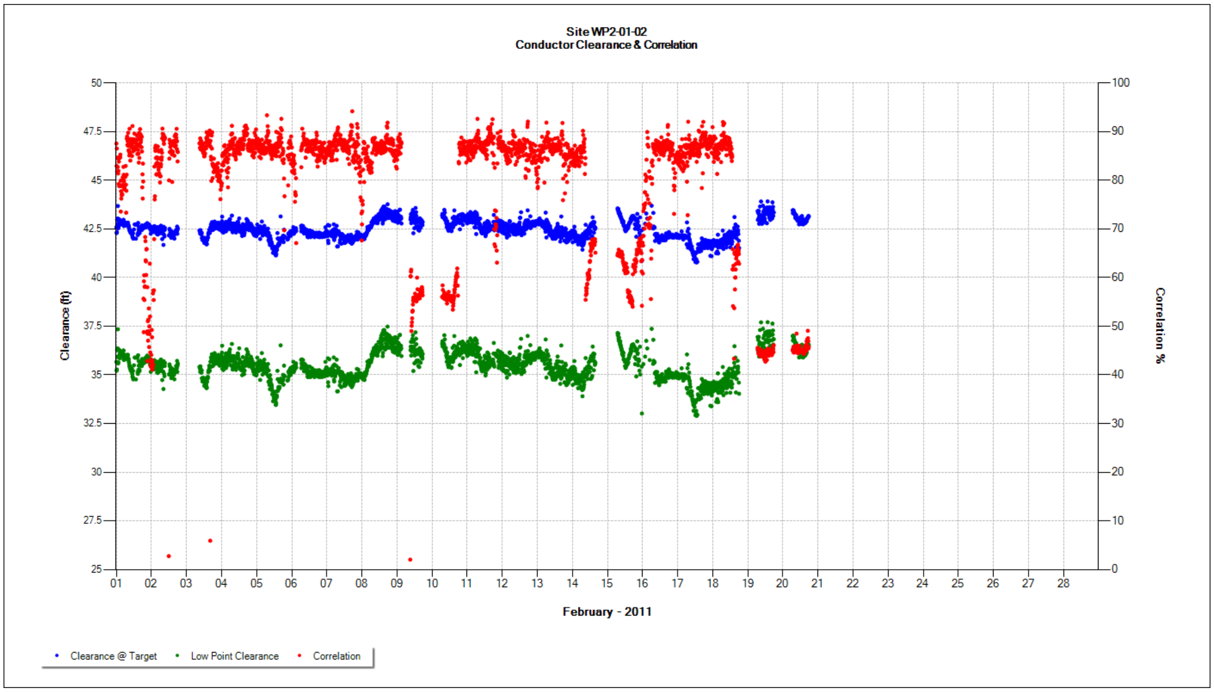


Figure 6-8 Conductor clearance and correlation

The plot shown below in Figure 6-9 is raw data from the Sagometer weather station at site WP2 01/02. The plot shows conductor clearance and calculated tension as calculated for the month of February, 2011.

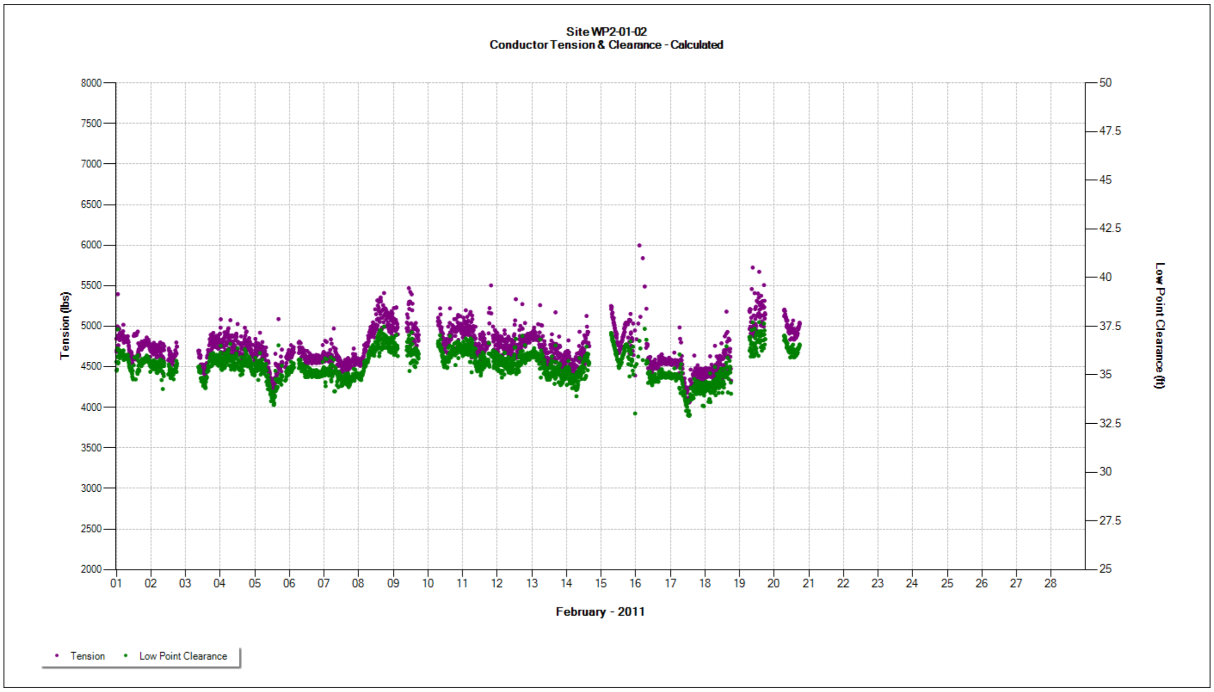


Figure 6-9 Conductor clearance and calculated tension

The plot shown below in Figure 6-10 is raw data from the EPRI sensors at site MW2 36/04. The plot shows conductor temperature as measured for the month of June, 2011. Two of three sensors were non-functional during this period.

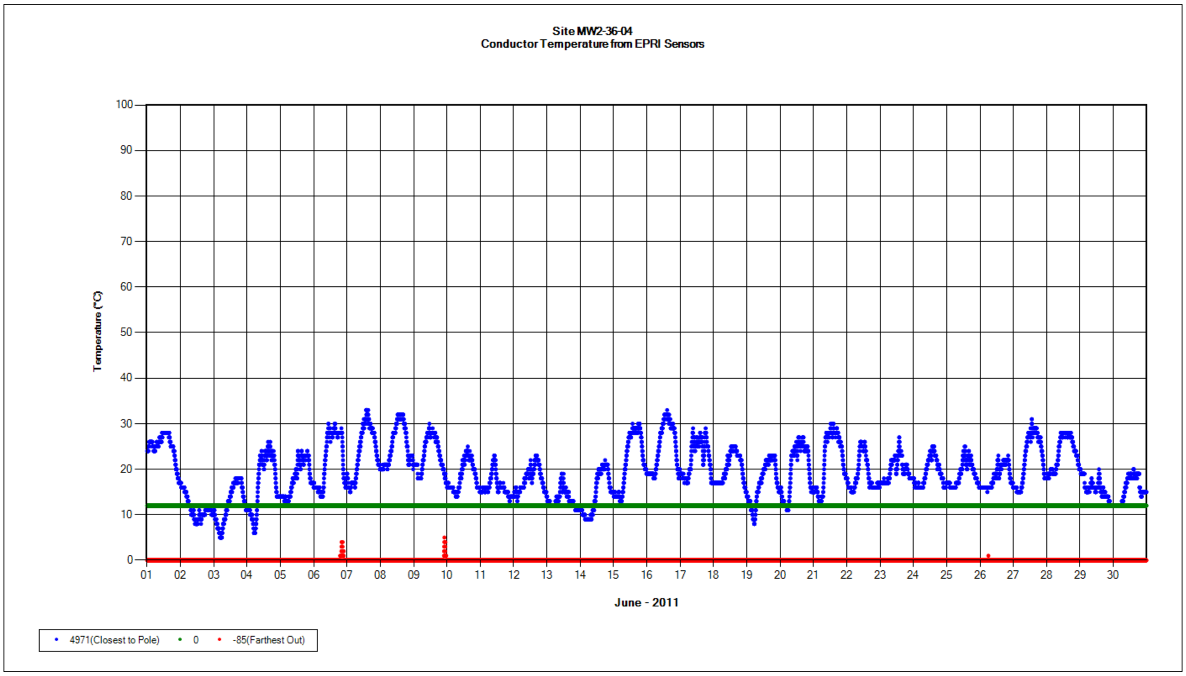


Figure 6-10 Conductor temperature

The plot shown below in Figure 6-11 is a collection of data from all available sensors at site MW2 36/04. The plot shows conductor temperature as calculated for the month of June, 2011. It can be observed from this plot that all data is tracking well.

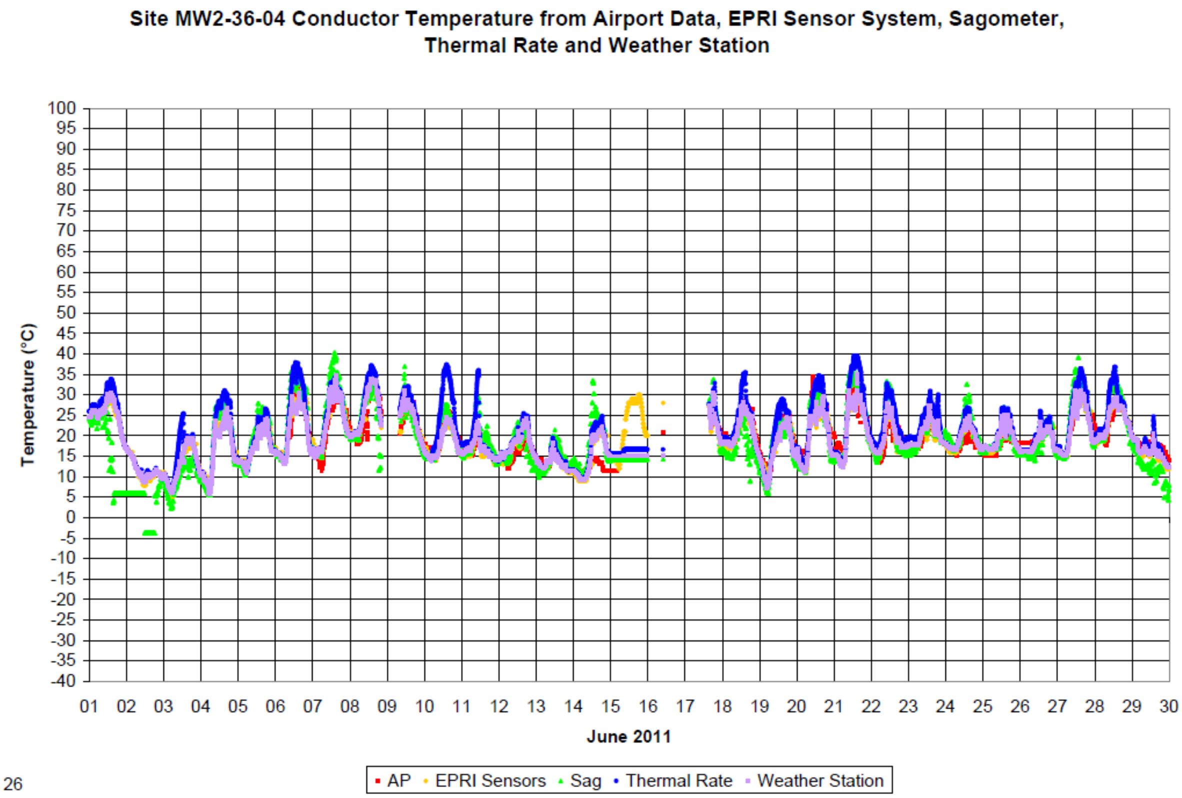


Figure 6-11 Conductor temperature for all sensors

The plot shown below in Figure 6-12 is raw data from the EPRI sensors at site MW2 36/04. The plot shows conductor current as measured for the month of June, 2011. Two of three sensors were non-functional during this period.

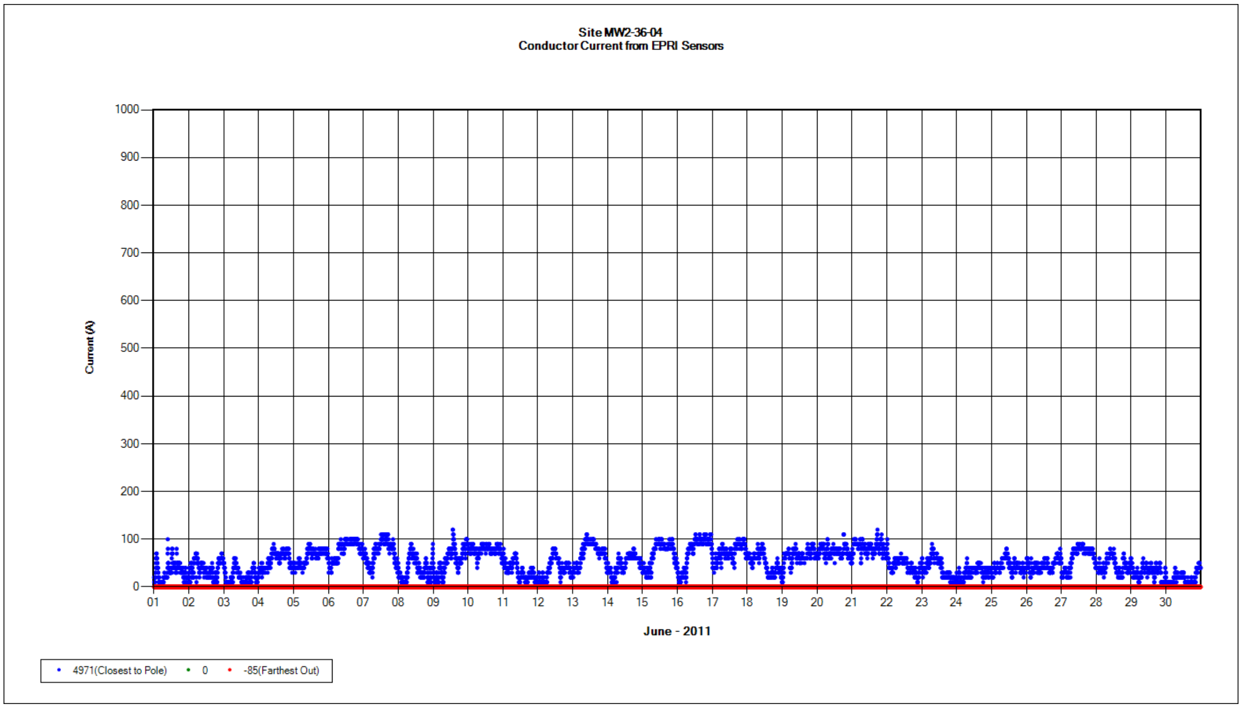


Figure 6-12 Conductor current

The plot shown below in Figure 6-13 is raw data from the EPRI sensors at site MW2 36/04. The plot shows conductor inclination as measured for the month of June, 2011. Two of three sensors were non-functional during this period.

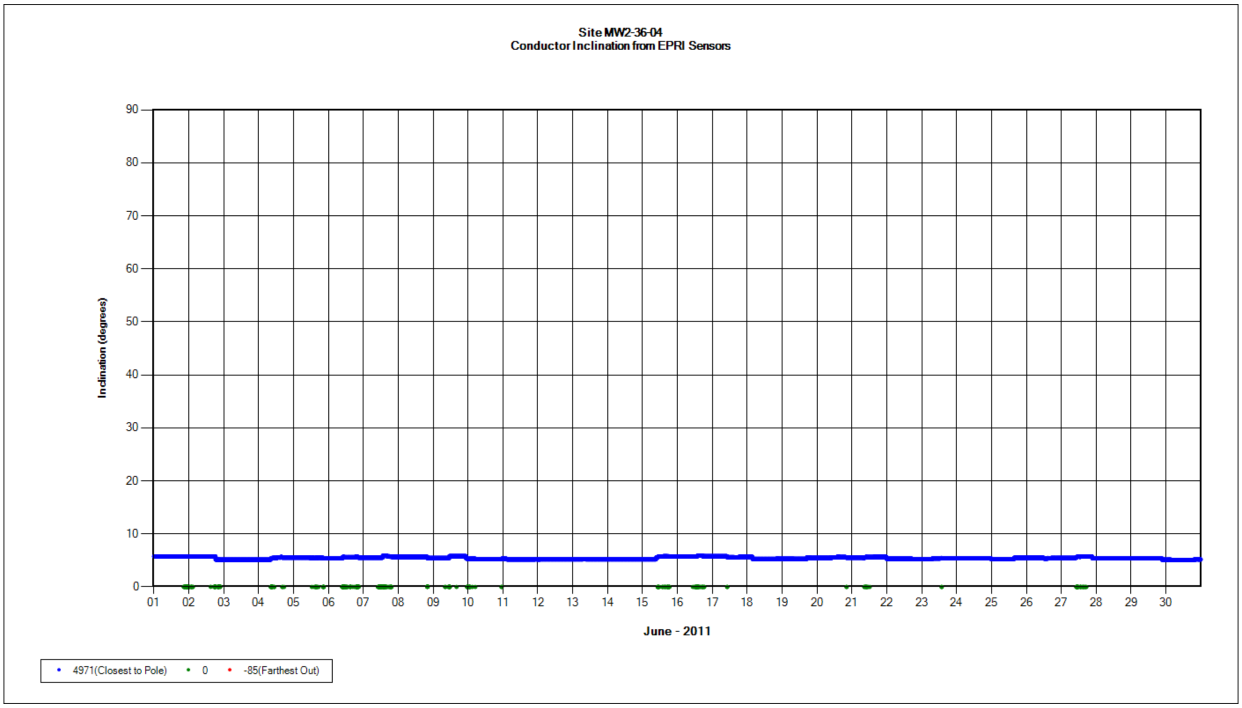


Figure 6-13 Conductor inclination

The plot shown below in Figure 6-14 is raw data from the Sagometer and EPRI sensors at site WP2 01/02. The plot shows battery voltage as measured for the month of February, 2011. On February 9th a change was made to the Sagometer software that resulted in a reduction in power consumption.

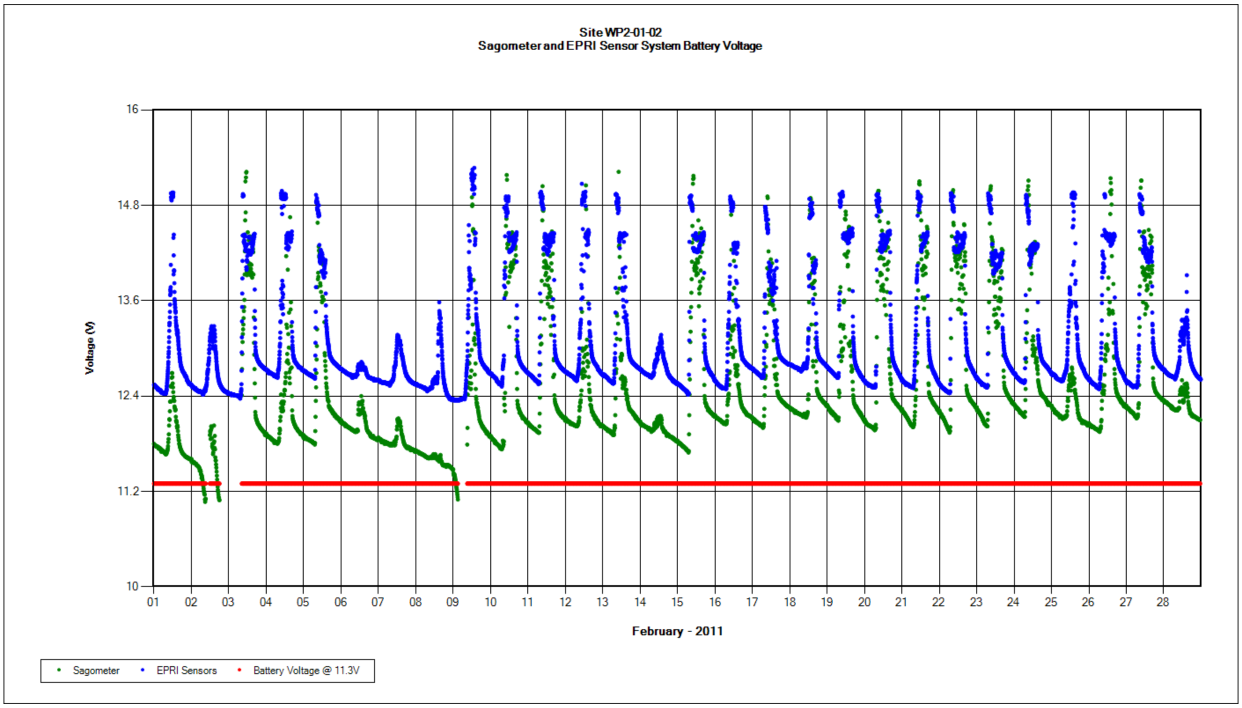


Figure 6-14 Battery voltage

The plot shown below in Figure 6-15 is pie chart that indicates the quality of the raw data coming from the Sagometer weather station at site MW2-36/04. The plot covers the month of June 2011. It can be seen that the weather station had only 39 out of 4280 points missing.

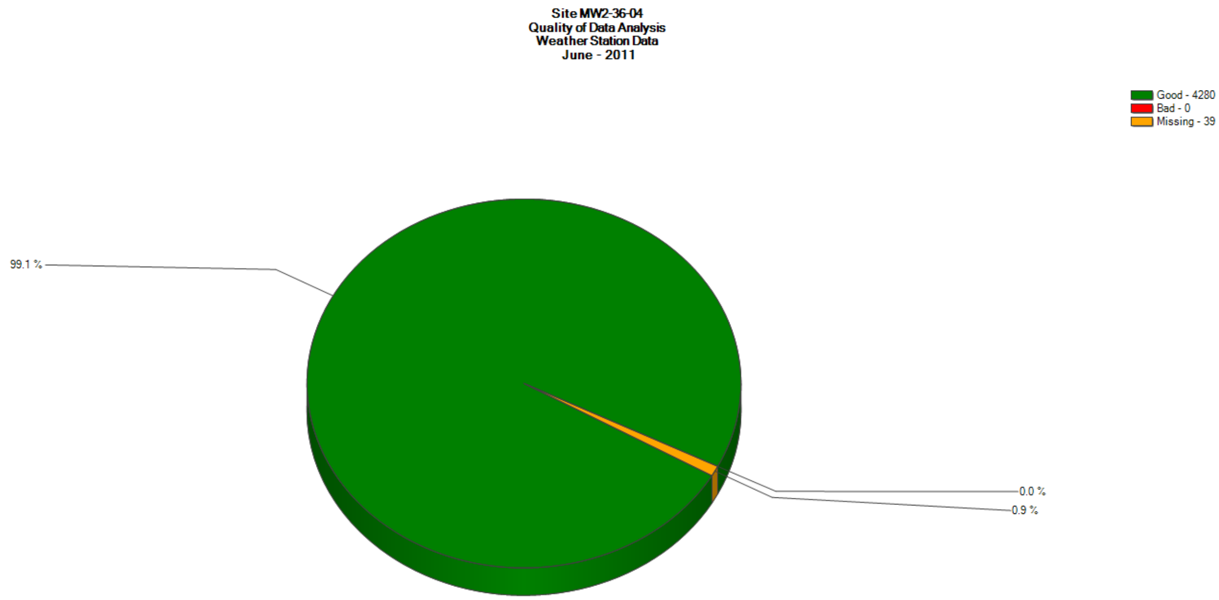


Figure 6-15 Data quality weather station

The plot shown below in Figure 6-16 is pie chart that indicates the quality of the raw data coming from the Sagometer camera unit at site WP2-01/02. The plot covers the month of February 2011.

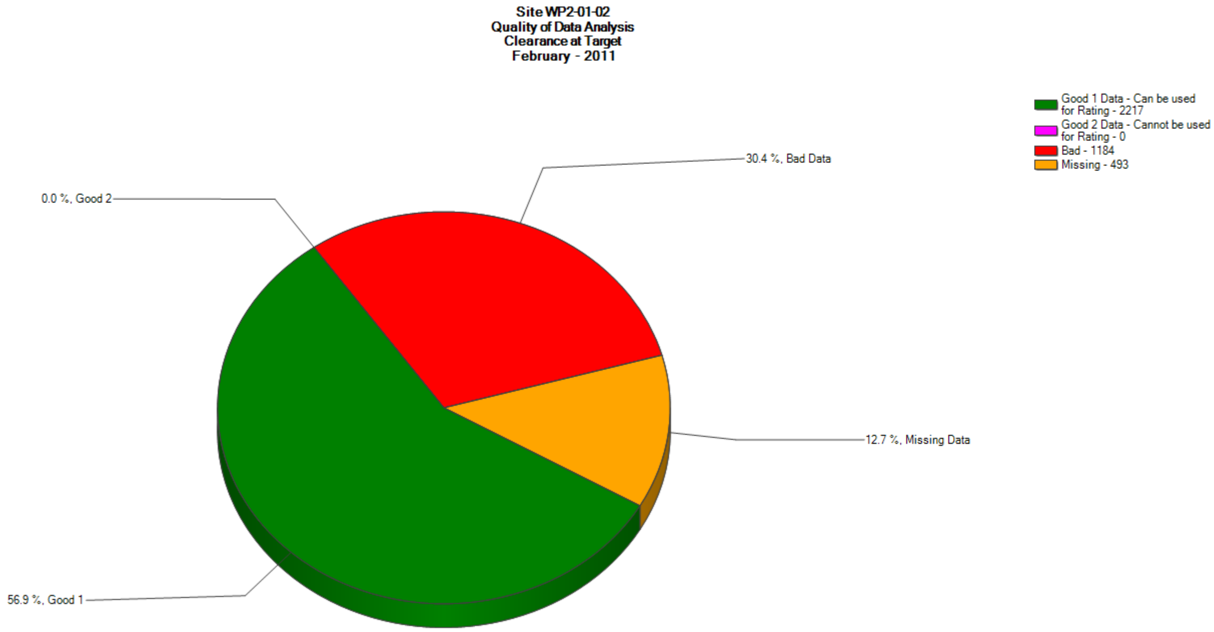


Figure 6-16 Data quality clearance at target

The pie charts shown below in Figure 6-17 are based off of the Sagometer weather station rating calculations at site MW2-03/06. The rating calculations are based on numerous data inputs, if anyone of the inputs are not available the rating calculation becomes invalid as represented in the pie charts. The plot covers the months from February to June 2011.

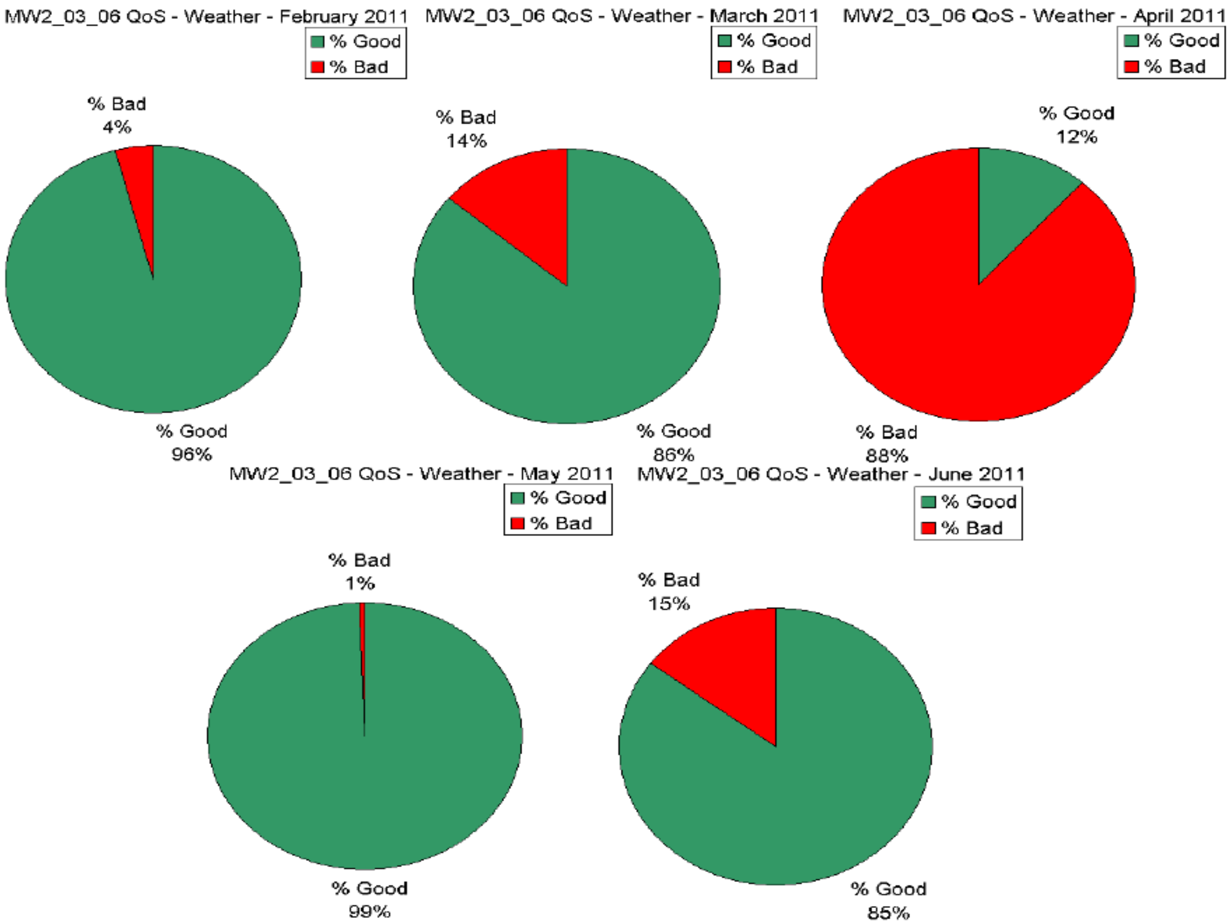


Figure 6-17 Equipment usability weather station

The pie charts shown below in Figure 6-18 are based off of the airport weather station rating calculations at site MW2-03/06. The rating calculations are based on numerous data inputs, if anyone of the inputs are not available the rating calculation becomes invalid as represented in the pie charts. The plot covers the months from February to June 2011.

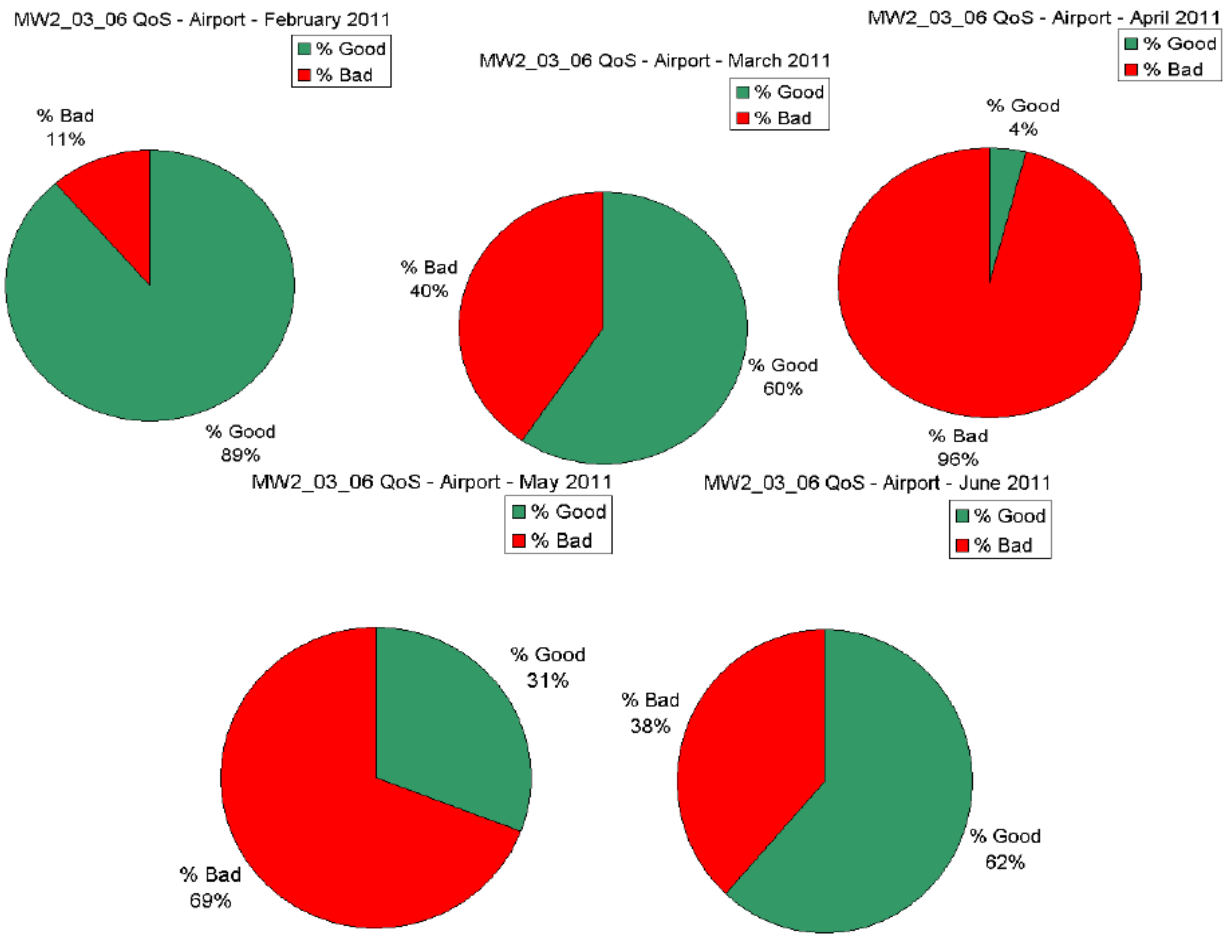


Figure 6-18 Equipment usability airport weather station

The pie charts shown below in Figure 6-19 are based on the ThermalRate system rating calculations at site MW2-03/06. The rating calculations are based on numerous data inputs, if anyone of the inputs are not available the rating calculation becomes invalid as represented in the pie charts. The plot covers the months from February to June 2011.

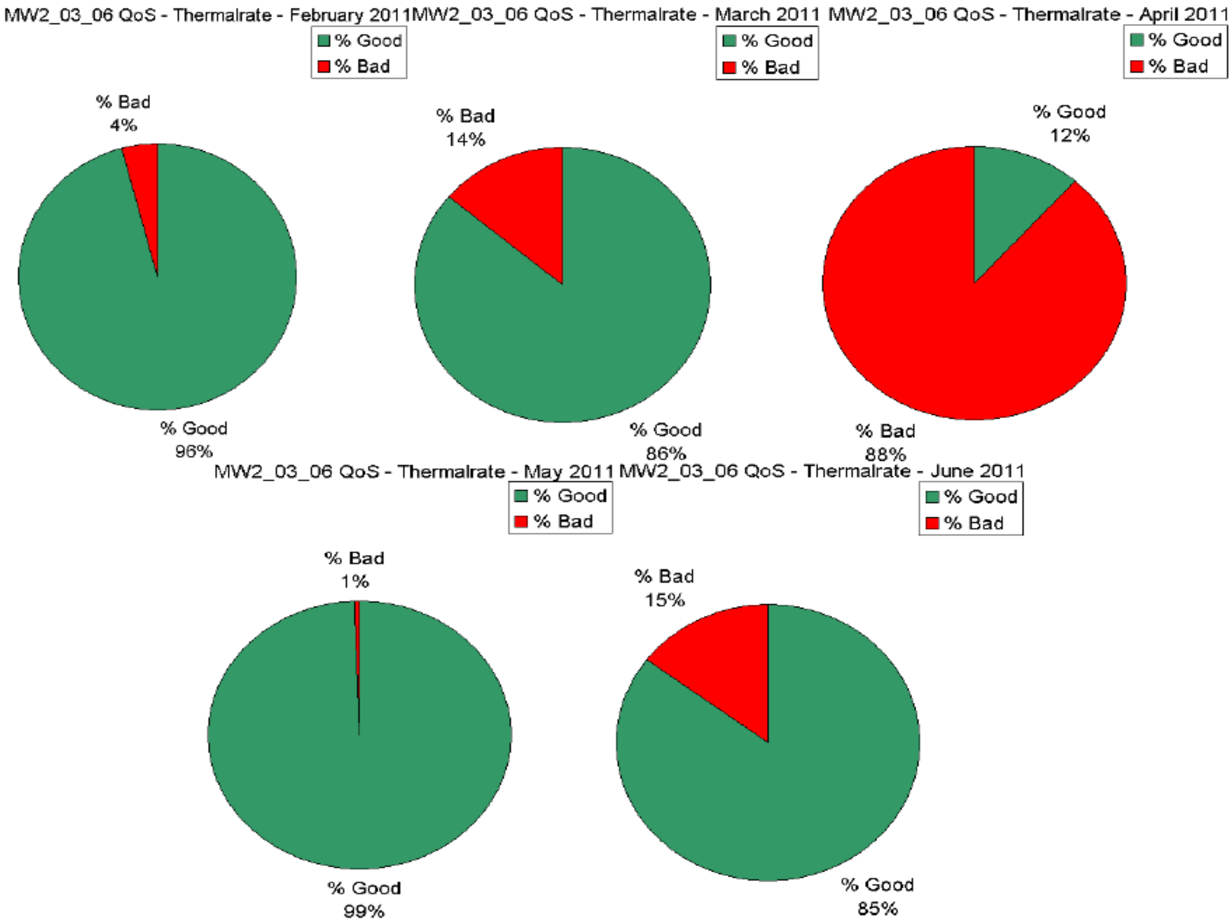


Figure 6-19 Equipment usability ThermalRate

The pie charts shown below in Figure 6-20 are based off of the Sagometer camera rating calculations at site MW2-03/06. The rating calculations are based on numerous data inputs, if anyone of the inputs are not available the rating calculation becomes invalid as represented in the pie charts. The plot covers the months from February to June 2011.

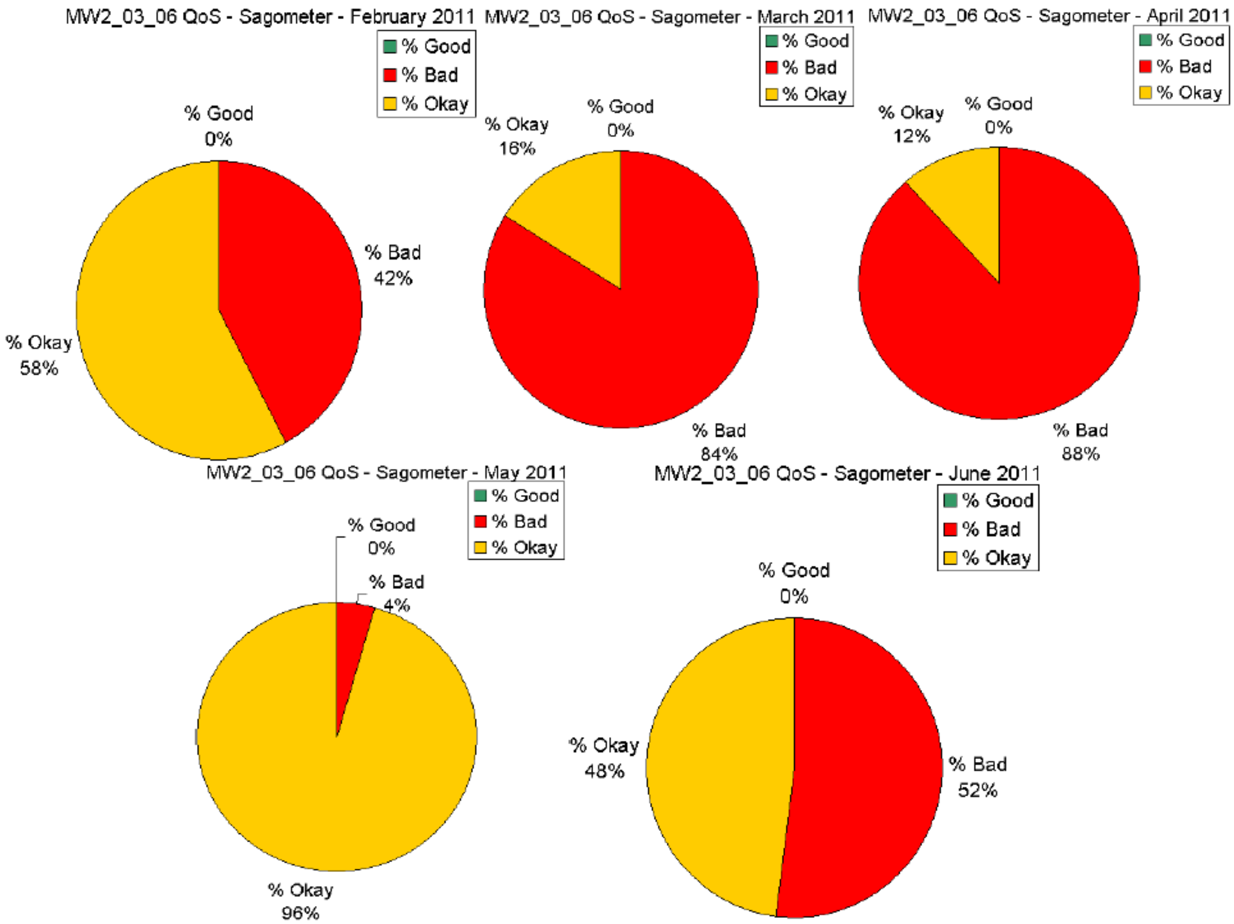


Figure 6-20 Equipment usability Sagometer camera

The pie charts shown below in Figure 6-21 are based on the EPRI sensors rating calculations at site MW2-03/06. The rating calculations are based on numerous data inputs, if anyone of the inputs are not available the rating calculation becomes invalid as represented in the pie charts. The plot covers the months from February to June 2011.

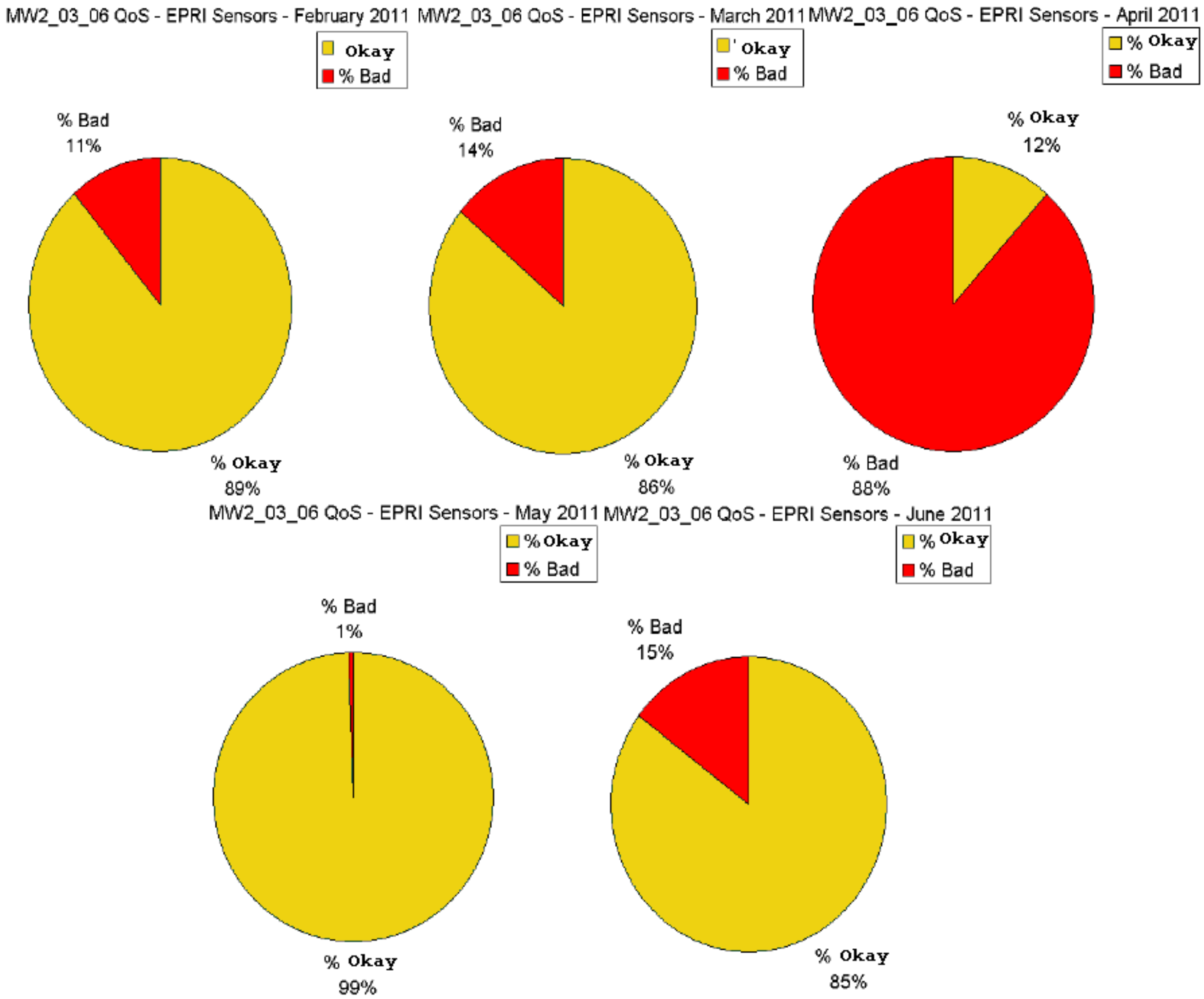


Figure 6-21 Equipment usability EPRI sensors

The plot shown below in Figure 6-22 is the calculated rating data from the Sagometer weather station at MW2 36/04. The plot shows the normal, long-term emergency, short-term emergency and extreme short-term emergency ratings as calculated for the month of June, 2011. Gaps in the graph are a result of bad or missing data.

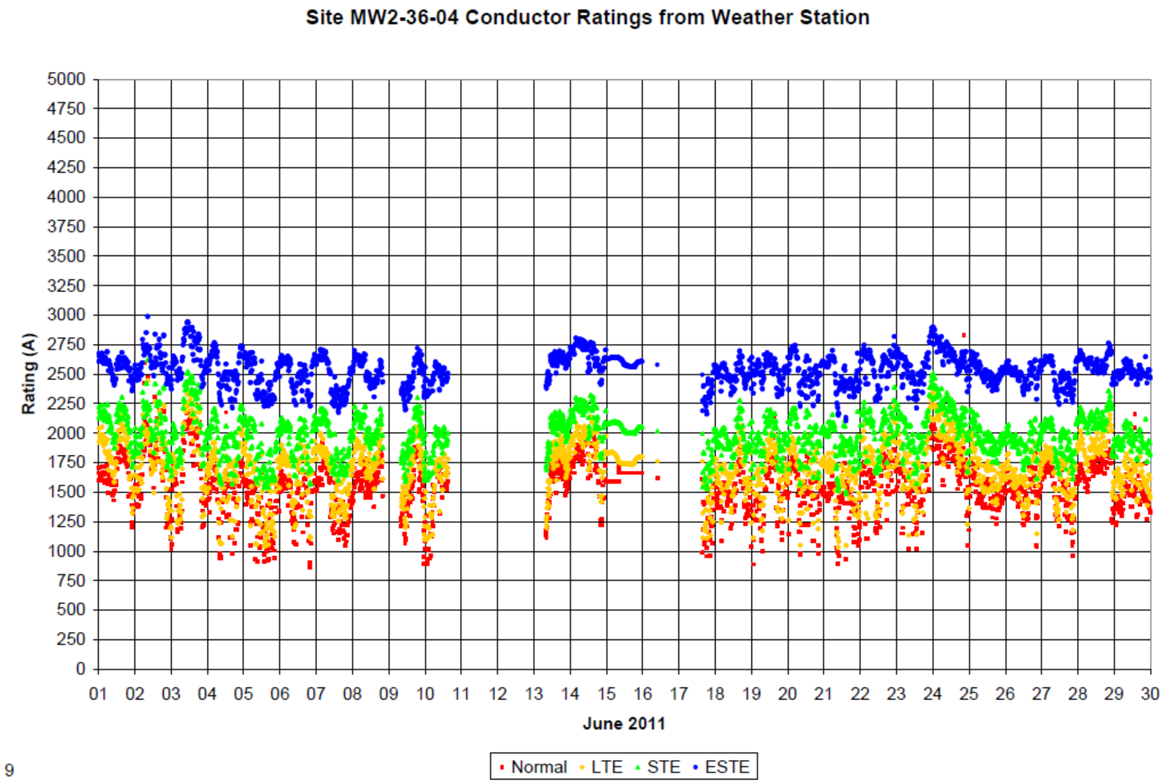


Figure 6-22 Ratings weather station

The plot shown below in Figure 6-23 is the calculated rating data from the airport weather station for site MW2 36/04. The plot shows the normal, long-term emergency, short-term emergency and extreme short-term emergency ratings as calculated for the month of June, 2011. Gaps in the graph are a result of bad or missing data. Data latency results from the update rate of once per hour.

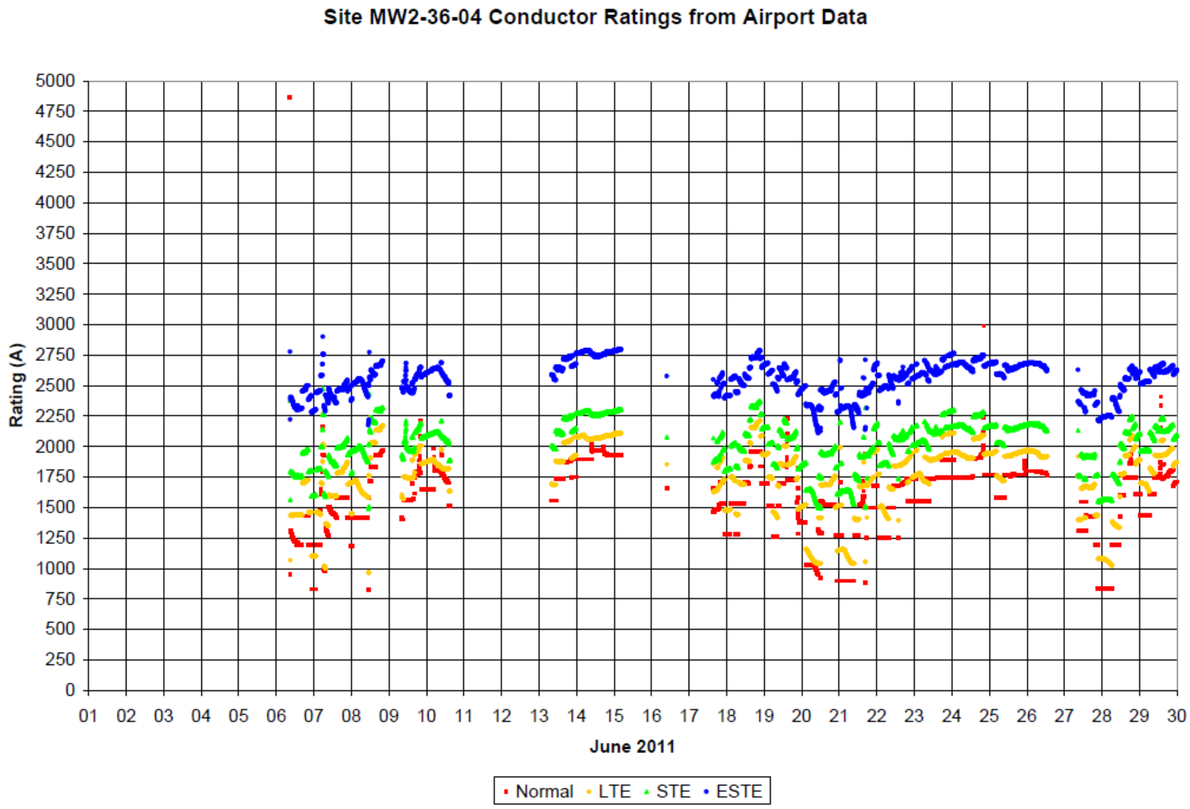


Figure 6-23 Ratings airport weather station

The plot shown below in Figure 6-24 is the calculated rating data from the ThermalRate system at MW2 36/04. The plot shows the normal, long-term emergency, short-term emergency and extreme short-term emergency ratings as calculated for the month of June, 2011. Gaps in the graph are a result of bad or missing data.

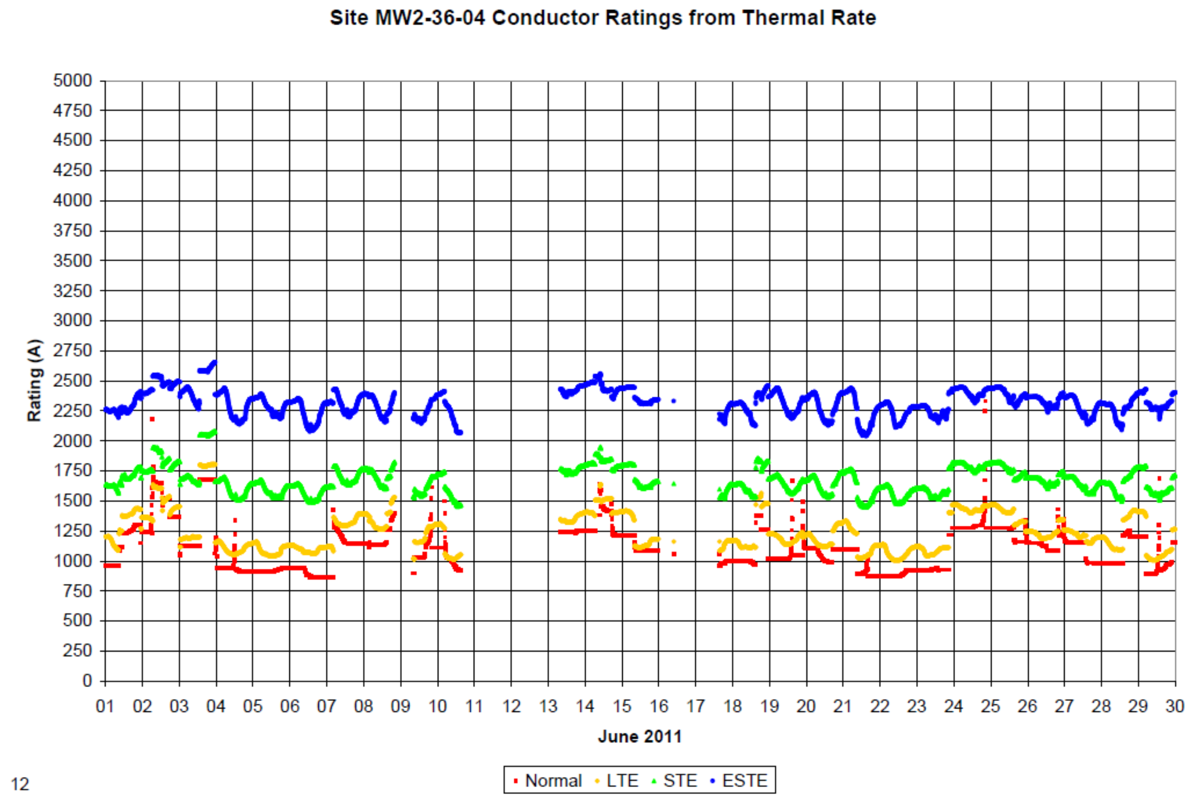


Figure 6-24 Ratings ThermalRate

The plot shown below in Figure 6-25 is the calculated rating data from the Sagometer at MW2 36/04. The plot shows the normal, long-term emergency, short-term emergency and extreme short-term emergency ratings as calculated for the month of June, 2011. Gaps in the graph are a result of bad or missing data.

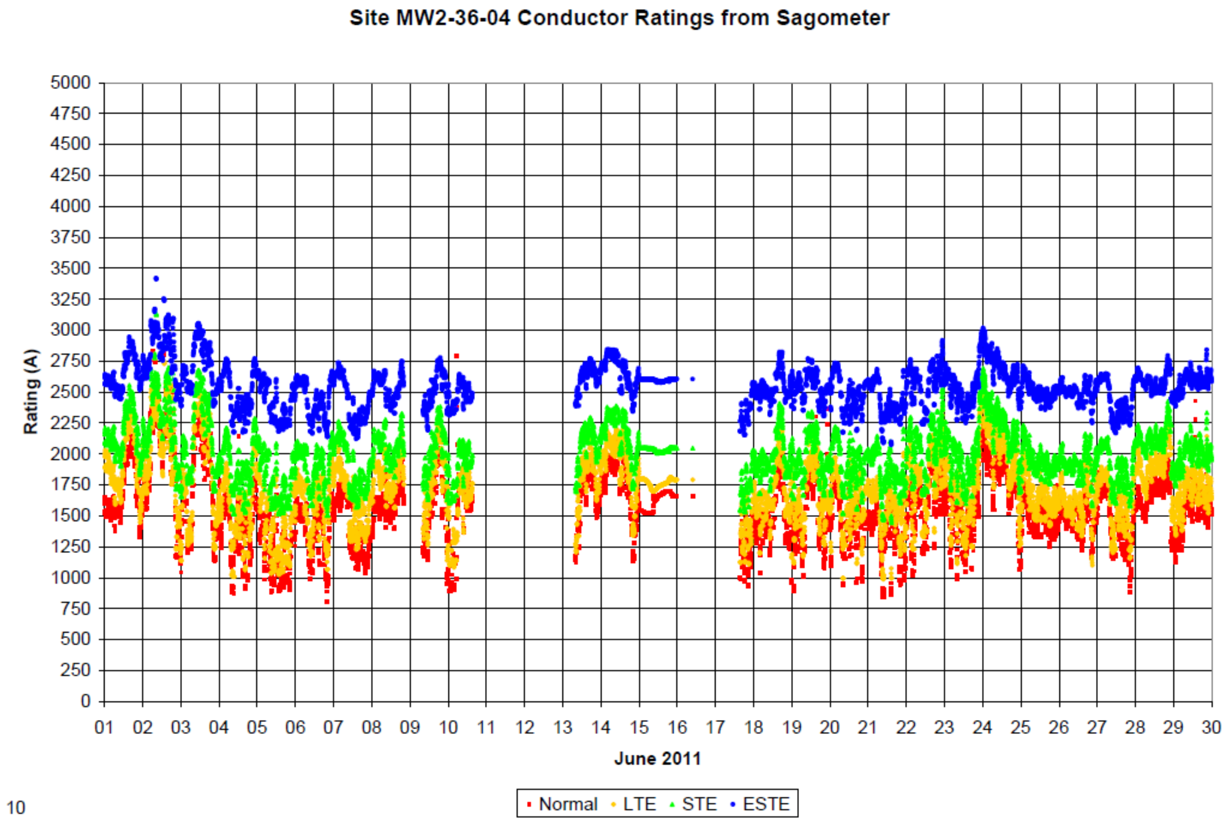


Figure 6-25 Ratings Sagometer

The plot shown below in Figure 6-26 is the calculated rating data from the EPRI Sensor System at MW2 36/04. The plot shows the normal, long-term emergency, short-term emergency and extreme short-term emergency ratings as calculated for the month of June, 2011. Gaps in the graph are a result of bad or missing data.

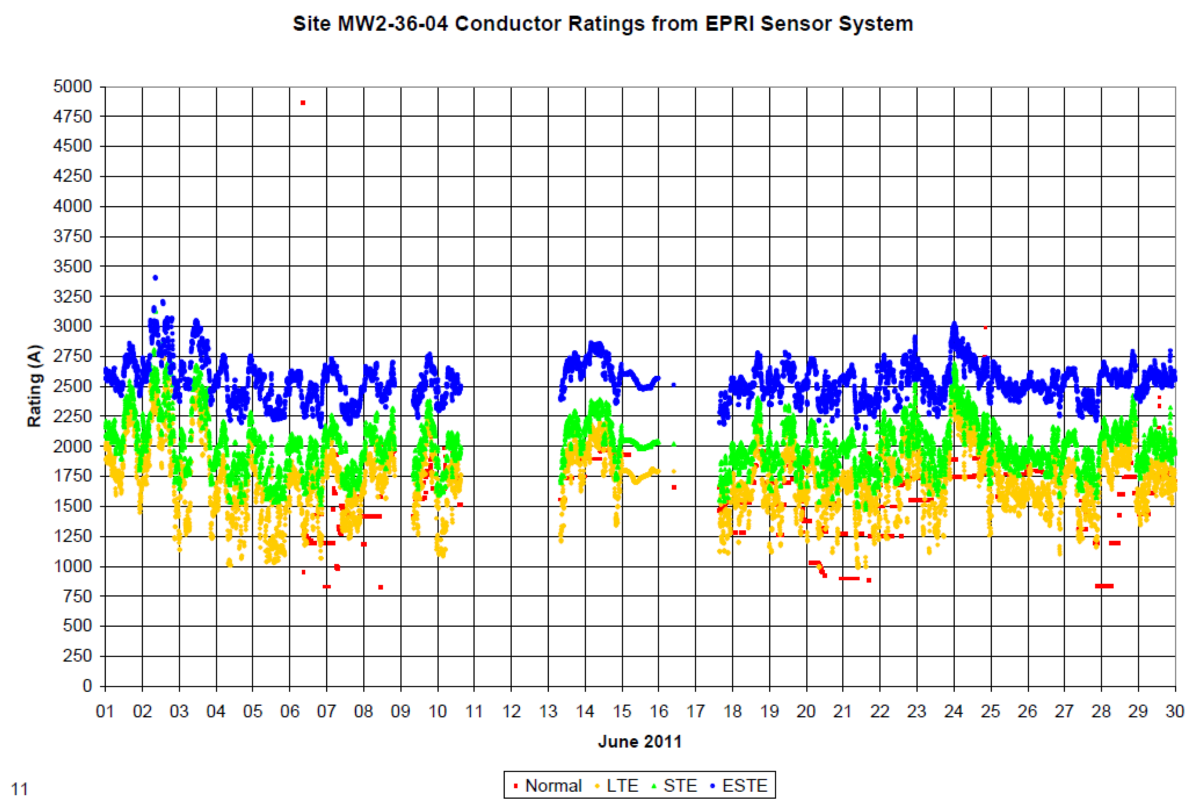


Figure 6-26 Ratings EPRI sensors

The plot shown below in Figure 6-27 is the calculated rating from the Airport Data, EPRI Sensor System, Sagometer, ThermalRate and Sagometer Weather Station the for MW2 36/04. The plot shows the normal ratings as calculated for the month of June, 2011. Gaps in the graph are a result of bad or missing data. Do to data timing issues between the NYPA EMS system and the ThermalRate system results are not useable over this period.

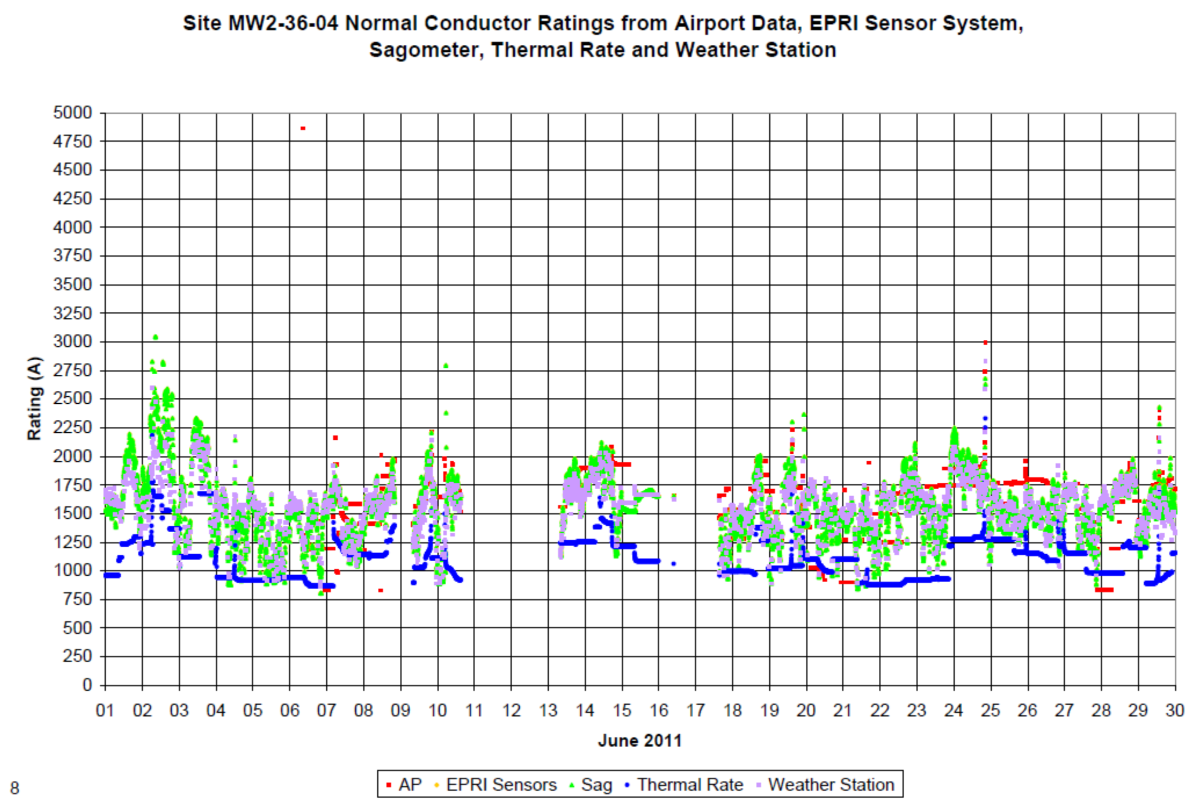


Figure 6-27 Ratings all

The cumulative distribution plot shown below in Figure 6-28 is the calculated rating from the Airport Data, EPRI Sensor System, Sagometer, ThermalRate and Sagometer Weather Station the for MW2 36/04. The plot shows the normal ratings as calculated for the month of June, 2011. Do to data timing issues between the NYPA EMS system and the ThermalRate system results are not useable over this period.

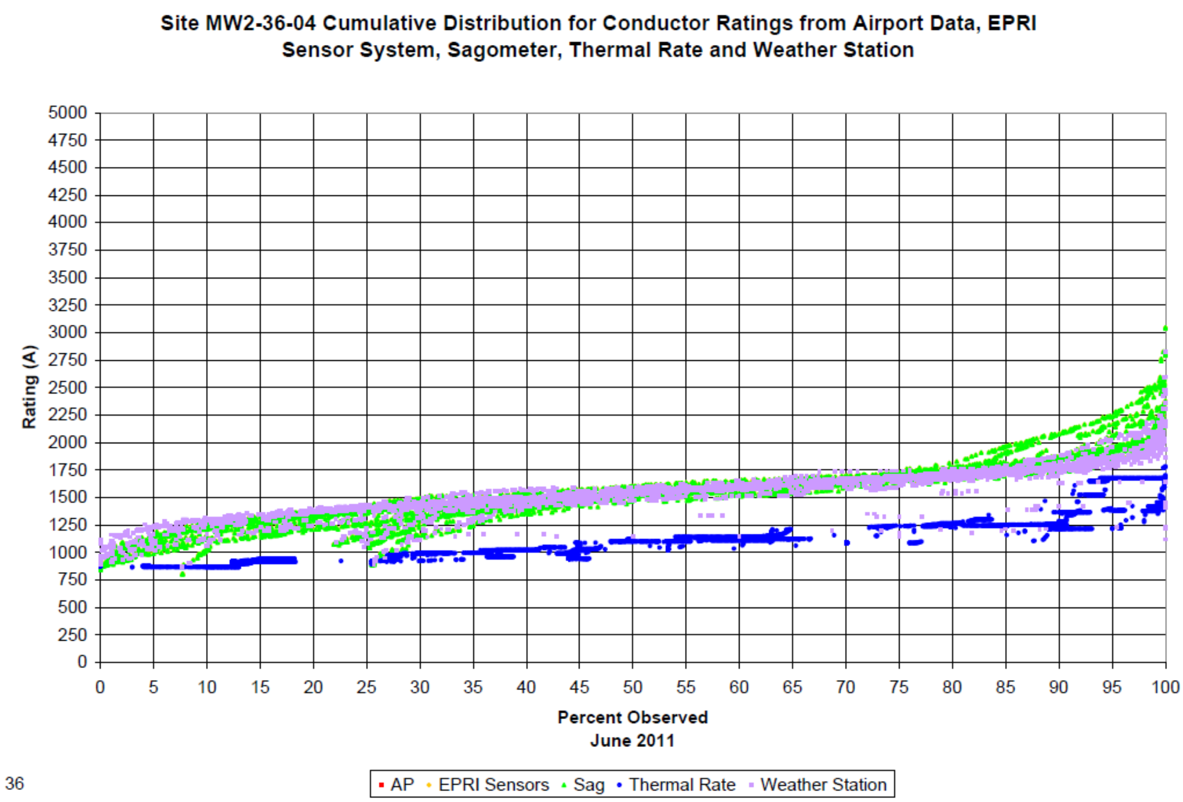


Figure 6-28 Cumulative distribution all

7 CONCLUSIONS

As part of its on-going research in this area, EPRI has developed monitors, rating calculation methodologies, the Dynamic Thermal Circuit Rating (DTCR) software, workshops, and other products. Prior to undertaking capital intensive activities—such as building new lines, reconductoring, raising structure heights, replacing transformers, putting lines underground, etc.—utilities can use this technology to maximize power throughput of existing assets, defer capital expenditures, and simultaneously increase safe and reliable operation of their assets.

The main objective of this project is to demonstrate how EPRI's Dynamic Thermal Circuit Rating (DTCR) Technology can be effectively deployed, and practically integrated, into transmission system engineering, operations, and planning of the New York Power Authority (NYPA). Another objective is to assess the technical and operational feasibility of the DTCR Technologies, and the expected improvement of system and market efficiency due to increased circuit utilization or reliability, particularly during periods when power from wind turbines is high. This demonstration project should serve as a good model for other transmission utilities in NY ISO and other areas in the U.S.

Of the Eleven Tasks identified in the Statement of Work, we have completed Task 1 through 6, though certain components of Task 4 (Maintenance of Field Instrumentation) and Task 6 (Physical Modeling of Lines, Development of Sag-Temperature Equations) are ongoing. Task 9 (Instrumentation, Rating, and Weather Data Analysis) has been started but await the accumulation of field data before completion.

Though the project is still in the early stages of some of the work, it is possible to draw several preliminary conclusions:

- The flexible design of the DTCR software, which allows the software to calculate dynamic thermal line ratings for any of the major types of line monitors, has been very valuable. In the early stages of this project it allowed the comparison of line temperatures and ratings based on various monitors. When integrated into operations, it will ensure the reliability of dynamic line ratings by using multiple sources of real-time data.

- The use of multiple high quality weather stations in the transmission right-of-way is essential to ensure the continual flow of dynamic line rating estimates to operations and to verify the accuracy of dynamic line ratings calculated on the basis of real-time data from various types of line monitors. It is likely that the use of such weather data will serve the role of state estimator tools in power system analysis – filling in for missing data and providing continual sanity checks.

Circuit Ratings

The lines chosen for this study have single 795 kcmil, 26/7 Drake ACSR conductor per phase. So far in the study, the line currents at the three monitoring locations have been quite low. The maximum current at WP2-01/02 is in the range of 200-300 amps. At these low current levels it is difficult to produce accurate dynamic ratings using the temperature or the sag monitors and the ratings produced typically show a good deal of volatility. Any periods of higher current can be very helpful in refining the sag-temperature equations needed to produce thermal ratings from the Sagometer data.

Wind data from the ultrasonic anemometers and the ThermalRate devices seem promising. The average perpendicular effective wind speed appears to be in the range of 15 ft/sec, much higher than the NY ISO worst-case assumption of 3 ft/sec. For the month of June, while the ISO static LTE rating is about 1300 amps, the dynamic LTE rating is usually well above that, though there are times, especially at night, when the dynamic LTE rating is below 1300 amps. Based on weather station real-time data, the daytime line rating is typically above 1500 amps in June.

The dynamic ratings calculated by DTCR parallel the NYISO normal and emergency ratings. The dynamic 4-hour LTE line rating is directly comparable to the NYISO LTE rating but is generally higher due to the use of actual rather than worst-case weather conditions. The NYISO normal rating is not directly comparable to the 24-hour normal rating that DTCR calculates since the NYISO normal rating is intended to be valid for an entire season whereas the DTCR rating varies with weather conditions and is valid only for the next 24 hours.

DTCR Software

The DTCR software has been tested extensively, especially off-line. In this project it has served the purpose of providing a common platform for dynamic line rating calculations from the variety of monitoring approaches being tested.

As shown below, each of the three 230 kV line segments is modeled as five different DTCR elements, each depending on a different source of real-time data. This allows a direct comparison of calculated conductor temperatures and dynamic ratings based on the different instruments.

Table 7-1
DTCR Model Elements

Site	Model	Model	Model	Model	Model
WP2 01-02	Weather Sagometer Sensors	Weather ThermalRate Sensors	Sag based Sagometer Camera	Sag based EPRI Sensor Conductor T	Weather Air Port Sensors
MW2 36-04	Weather Sagometer Sensors	Weather ThermalRate Sensors	Sag based Sagometer Camera	Sag based EPRI Sensor Conductor T	Weather Air Port Sensors
MW2 03-06	Weather Sagometer Sensors	Weather ThermalRate Sensors	Sag based Sagometer Camera	Sag based EPRI Sensor Conductor T	Weather Air Port Sensors

So far, the DTCR software has not been used to develop real-time ratings but only to analyze historical field data. It is anticipated that there will be a significant challenge in integrating the real-time ratings results into NYPA's system operations and in communicating these effectively to the NYISO operators.

Field Instruments

All the field instruments were successfully installed, both in a full-scale laboratory setting at the EPRI facility in Lenox, Massachusetts, and at the three field sites in upper New York. In all cases the installations proceeded without any serious problems. The line-crew mastered the installation process quickly, and believe that there is no problem with installing such instruments in general.

The performance of the instruments was inconsistent overall. A significant amount of technical problems occurred and had to be resolved. In some cases, the hardware providers needed to modify their designs. As a result, it is fair to say that this field trial has resulted in further developments and improvements to the instruments, and this will provide a significant benefit to the industry and the public.

The weather stations provided the most consistent performance overall for two reasons. Weather stations don't require any particular load level in the conductors – as do sag, tension, or conductor temperature measurements – to be able to provide useful data for rating calculations, and weather sensors are, in general, very rugged and reliable. Overall, useful rating calculations were available from the weather stations about 90% of the time for the duration of the project thus far, and the performance is improving.

The Video Sagometer systems have not performed as well as would be needed for reliable rating calculations. Overall, reliable sag measurements were available about 50% of the time, and the vendor had to return to the site several times to make modifications. At this moment, all the Video Sagometer systems are fully operational, so hopefully something was learned and the instruments performance improved during the course of this project. In addition, the current in the conductors essentially never got to the magnitude where sag measurements would be able to be used for ratings. While the latter doesn't indicate anything wrong with the hardware, it is something to consider for future applications.

Two of the three ThermalRate systems never really functioned properly. These systems normally require an RTU link to the utility's EMS to get load data and to function properly. It took several months before the RTU's were connected at the substation, and when they were, the data rate was set so high that the systems malfunctioned. There was a long delay in getting this situation corrected, and it was corrected just prior to this report being issued. The vendor claims that this process is usually quite fast and simple, and this was a special case. More will be learned about this in the upcoming months. The third ThermalRate system, which was not configured with an RTU-EMS integration, has performed well overall.

The EPRI sensor systems have performed quite well, providing useful data about 85% of the time. These instruments are the only ones of the project that are not commercialized, and are still undergoing significant R&D. Several changes were made as a result of what was learned during this project, and the NYPA sites have all been upgraded with the latest prototypes. However, being based on measuring conductor temperature, the data cannot be used for rating calculations at the low levels encountered by the NYPA lines of the project.

The EPRI sensors are also designed to provide load data. The instruments were calibrated using data provided by the NYPA EMS, and subsequent measurements compared favorably.

The DOE Project and Goals

The goals of this project are to demonstrate how EPRI's Dynamic Thermal Circuit Rating (DTCR) Technology can be effectively deployed, and practically integrated, into transmission system engineering, operations, and planning of the New York Power Authority (NYPA). Another objective is to assess the technical and operational feasibility of the DTCR Technologies, and the expected improvement of system and market efficiency due to increased circuit utilization or reliability, particularly during periods when power from wind turbines is high. This demonstration project should serve as a good model for other transmission utilities in NY ISO and other areas in the U.S.

A
APPENDIX

VPN Settings

Server

HP server lights out management:
Address: Ilomx2034005y.epri.com (while at epri lenox lab)
User: Administrator
PW: ZFFDFH43

Server:
Address: nypa_dtcr
User: Administrator
PW: nypa_DTCR1
Groups: administrators
User: eprilenox
PW: eprilenox1
Groups: Power Users, Remote Desktop Users, Users

Roles installed:
File Server
Application Server
Remote Access/VPN Server
DNS Server
DHCP Server
WINS Server

IIS Setup:
Disabled all web sites
Enabled FTP server with root directory c:\DTCR_DATA
FTP anonymous access disabled

REMOTE MODEM CROSS REFERENCE

Table Appendix A 7-2 Modem to vpn assignments

Box	ESN(hex)	ESN(dec)	Modem IP	Server Modem IP	VPN Gateway	VPN IP	Logger Serial Port
S/N 007	6083AF36	09611775796	166.143.191.120	166.154.25.189	192.168.14.31	192.168.1.50	3001
S/N 008	6083AE82	09611775618	166.143.191.123	166.154.25.189	192.168.14.31	192.168.2.50	3001
S/N 009	6083AF6C	09611775852	166.143.188.210	166.154.25.189	192.168.14.31	192.168.3.50	3001
E114	6067B705	09606797061	166.142.073.102	166.141.233.133	192.168.10.31	192.168.4.50	9999
E115	6067B7CE	09606797262	166.142.073.103	166.141.233.133	192.168.10.31	192.168.5.50	9999
E116	6067B970	09606797680	166.142.073.104	166.141.233.133	192.168.10.31	192.168.6.50	9999

Raven xt evdo modems
Modem firmware update status
Backscatter boxes: raven xt current version 4.0.7.003
166.143.191.120 – 4.0.7.003
166.143.191.123 – 4.0.7.003
166.143.188.210 – 4.0.7.003

NYPA_DOE1(007)	166.143.191.120(413-441-4685)	3001
NYPA_DOE2(008)	166.143.191.123(413-464-2485)	3001
NYPA_DOE3(009)	166.143.188.210(413-464-2726)	3001

Datalogger Information

Datalogger Name: NYPA1(007) - CR1000
Datalogger Type: CR1000

IP Port Connection
IP Address: 166.143.191.120:3001

Datalogger Settings
PakBus Address: 1
Security Code: 0
Extra Response Time: 2s
Max Time Online: 0d 0h 0m

Collection Schedule
Base Date: 10/19/2010 12:09:00 AM
Normal Schedule: 0d 0h 10m 0s
Primary Retry Schedule: 0d 0h 2m 0s
Primary Retry Count: 3
Secondary Retry Schedule: 1d 0h 0m 0s

Datalogger Information
Datalogger Name: NYPA2(008) - CR1000
Datalogger Type: CR1000

IP Port Connection
IP Address: 166.143.191.123:3001

Datalogger Settings
PakBus Address: 1
Security Code: 0

Extra Response Time: 3s
Max Time Online: 0d 0h 0m

Collection Schedule
Base Date: 10/19/2010 12:09:00 AM
Normal Schedule: 0d 0h 10m 0s
Primary Retry Schedule: 0d 0h 2m 0s
Primary Retry Count: 3
Secondary Retry Schedule: 1d 0h 0m 0s

Datalogger Information
Datalogger Name: NYPA3(009) - CR1000
Datalogger Type: CR1000

IP Port Connection
IP Address: 166.143.188.210:3001

Datalogger Settings
PakBus Address: 1
Security Code: 0
Extra Response Time: 3s
Max Time Online: 0d 0h 0m

Collection Schedule
Base Date: 10/18/2010 12:09:00 AM
Normal Schedule: 0d 0h 10m 0s
Primary Retry Schedule: 0d 0h 2m 0s
Primary Retry Count: 3
Secondary Retry Schedule: 1d 0h 0m 0s

Modem firmware update status

Sagometers – raven x current version 4.0.7.001
166.142.073.102 – 4.0.7.001 oob-enabled
166.142.073.103 – 4.0.7.001 oob-enabled
166.142.073.104 – 4.0.7.001 oob-enabled

Here are the modem IP's and ESN's for the three Sagometers:
Raven x modems
09606797061 166.142.073.102
09606797262 166.142.073.103
09606797680 166.142.073.104

Modem lan side 192.168.0.1
Internal devices:
.250 – datalogger, port 6785
.251 - ?
.252 – camera?

All: set passwords and vpn keys
Pw = nypaepri12345
Ipsec key = nypaepri12345SierraWireless

Screenshots for sagometer server
Change 192.168.10.* to 192.168.14.* for backscatter setup
Change 192.168.6.* to appropriate local ip for the remote modem, see crossreference table

Modem firmware update status
Server: raven xt current version 4.0.7.003
166.141.233.133 – 4.0.7.003
166.154.25.189 – 4.0.7.003

Table Appendix A-7-3

Server Modem	ESN(hex)	ESN(dec)	Modem IP	USB Device IP
Backscatter	608A6E21	09609072161	166.154.25.189	192.168.14.31
Sagometer	60B3EE5F	09611791967	166.141.233.133	192.168.10.31

Ace Manager Settings

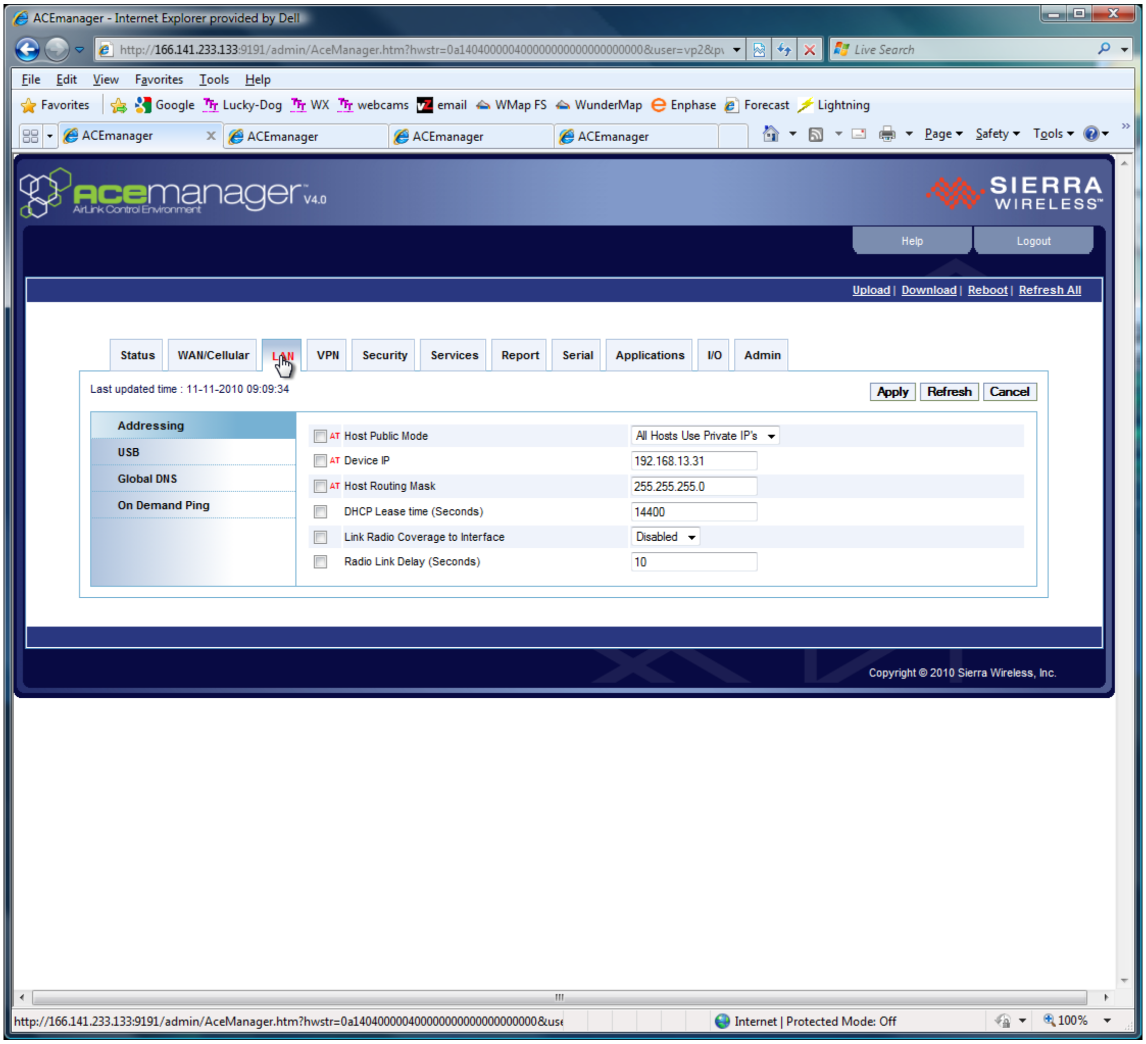


Figure Appendix A 7-1 Ace Manager settings – LAN Addressing

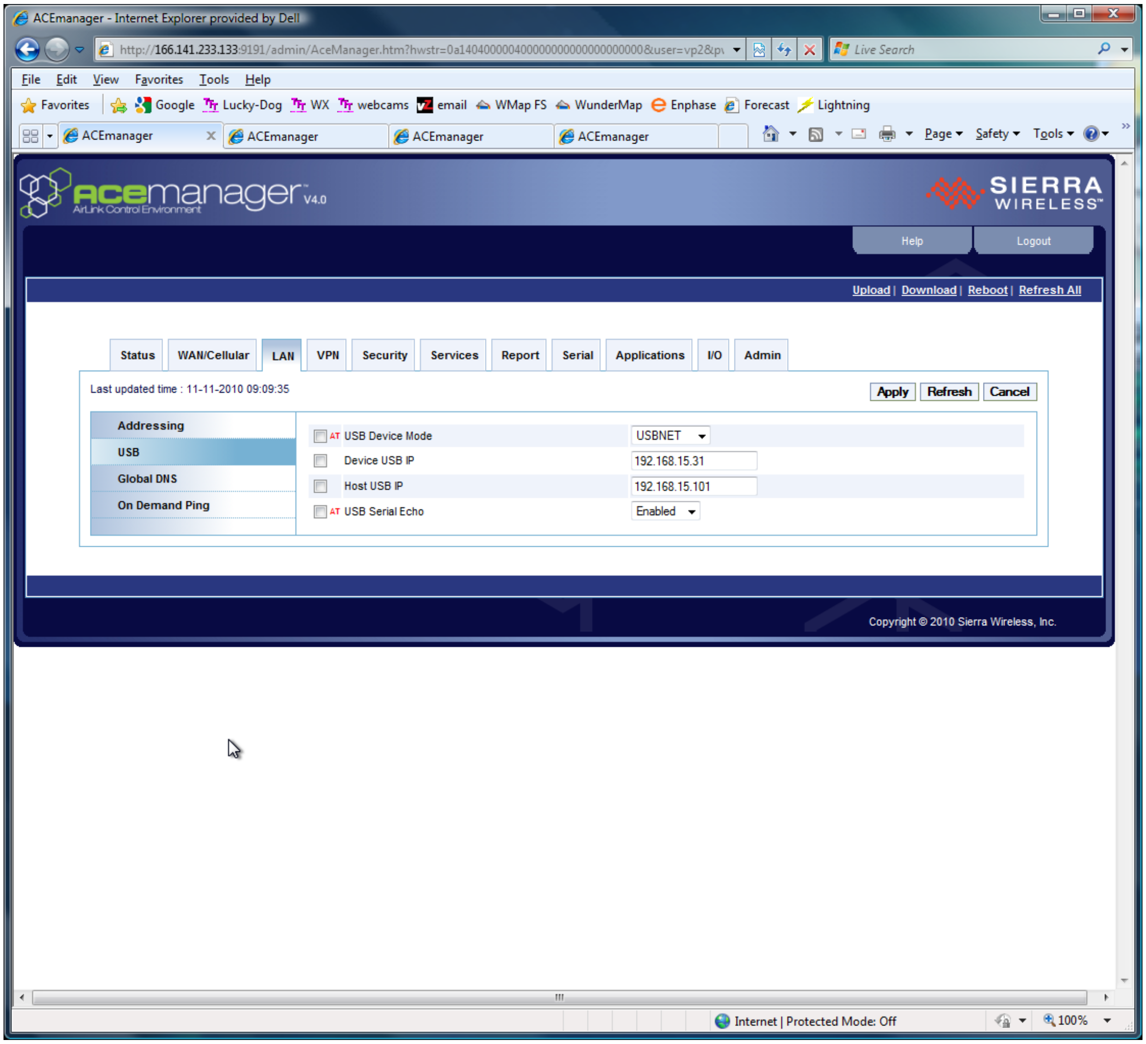


Figure Appendix A 7-2 Ace Manager settings – LAN - USB

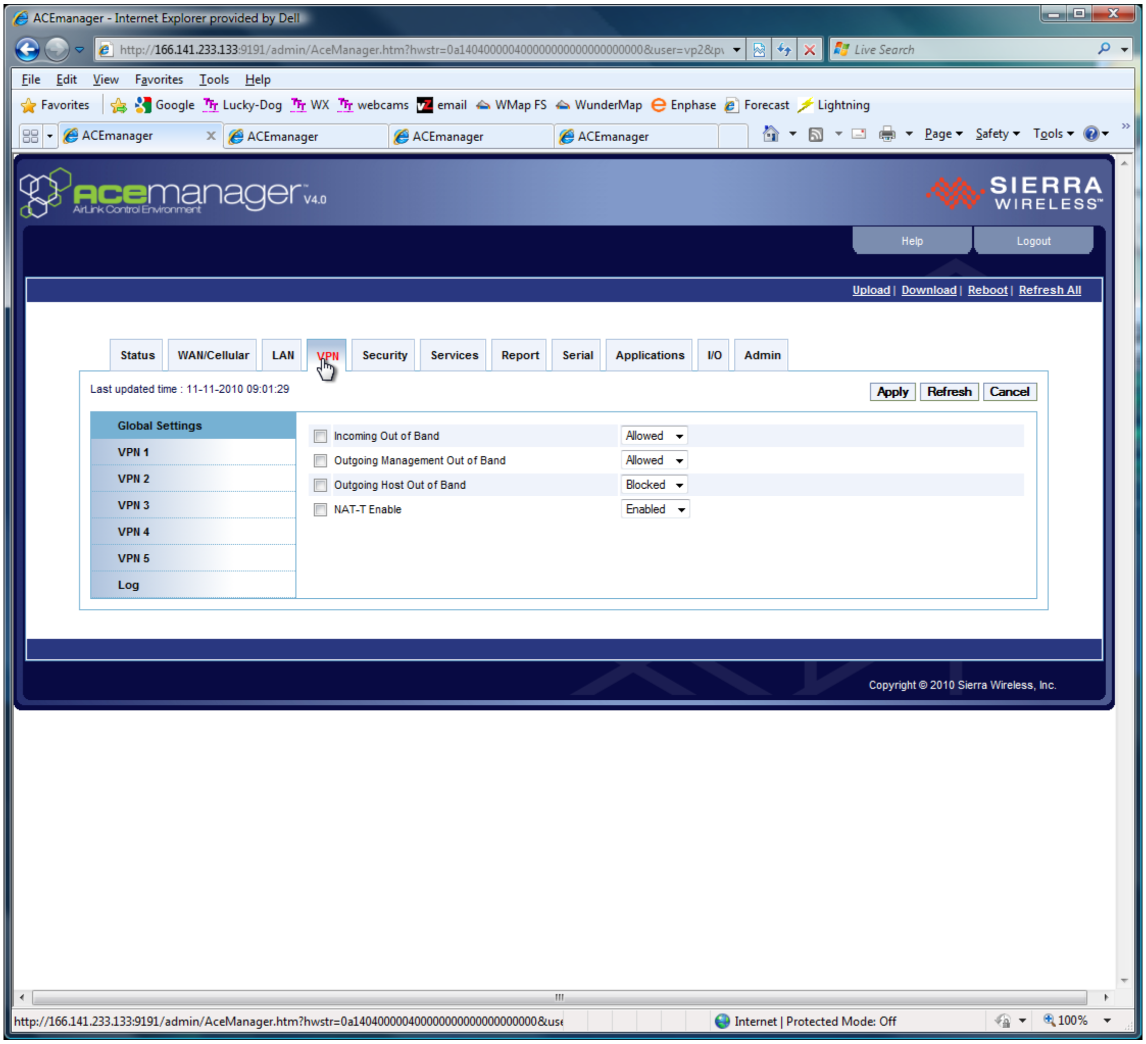


Figure Appendix A 7-3 Ace Manager settings – LAN – Global Settings

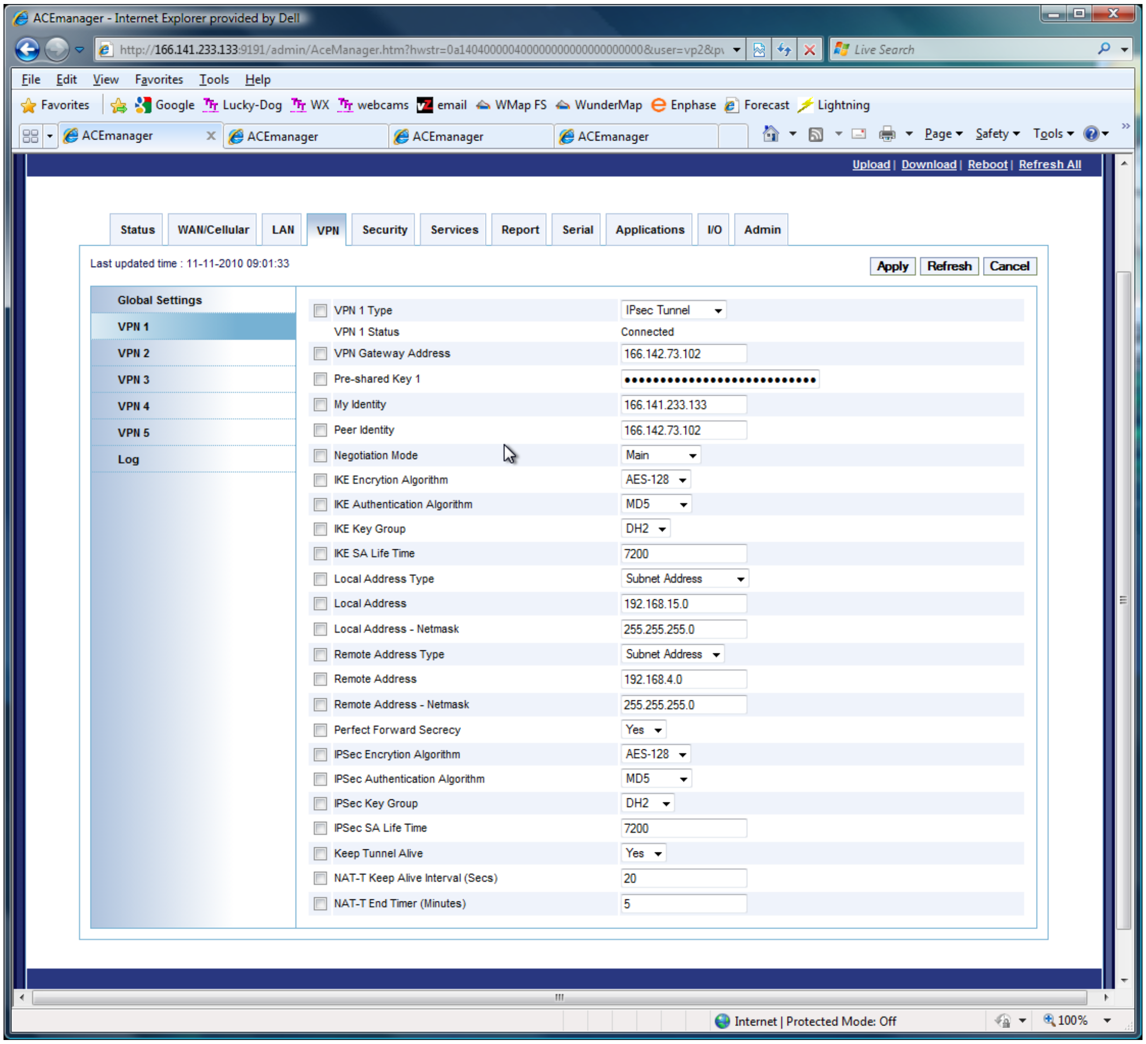


Figure Appendix A 7-4 Ace Manager settings – VPN – VPN1

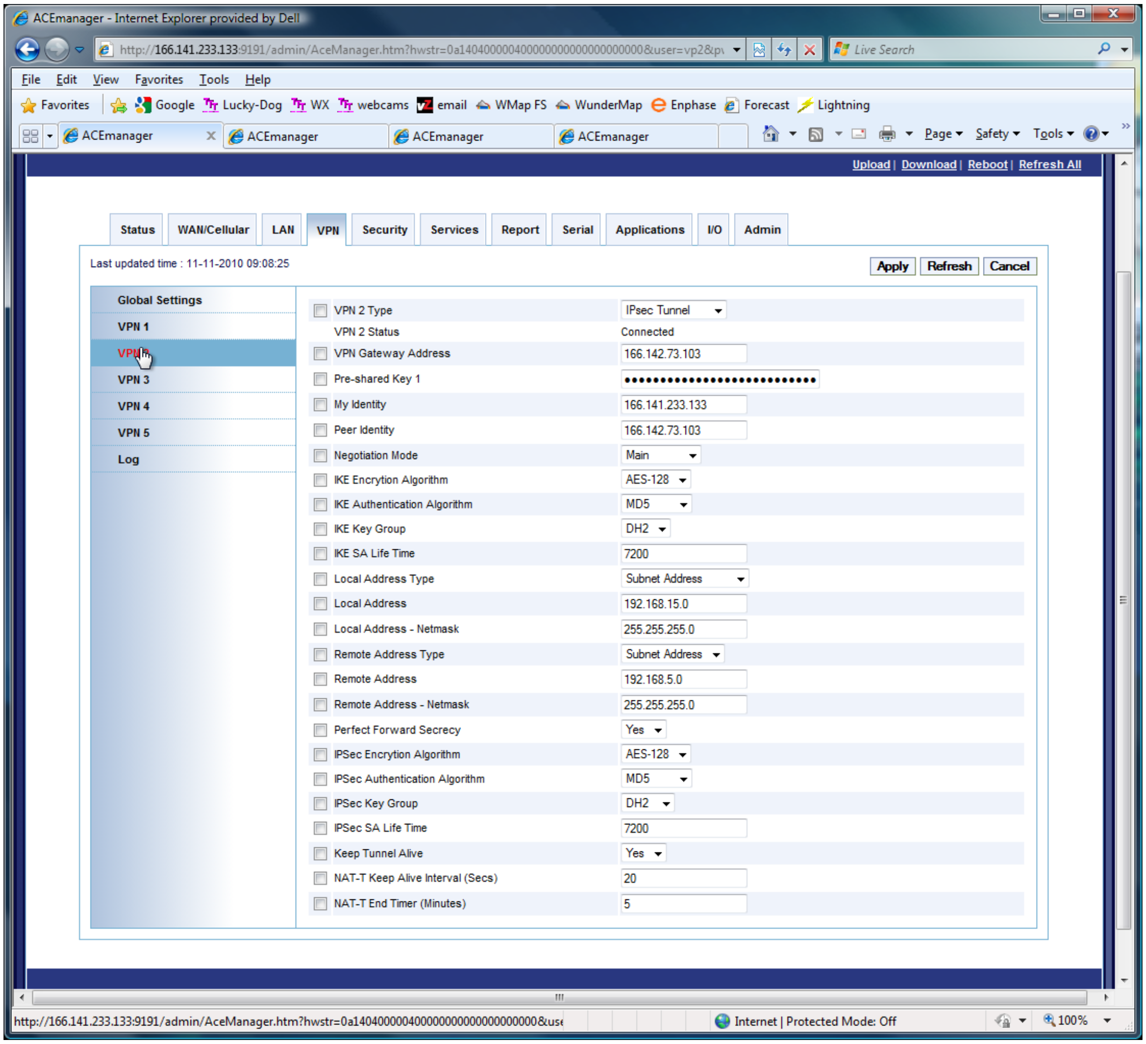


Figure Appendix A 7-5 Ace Manager settings – VPN – VPN2

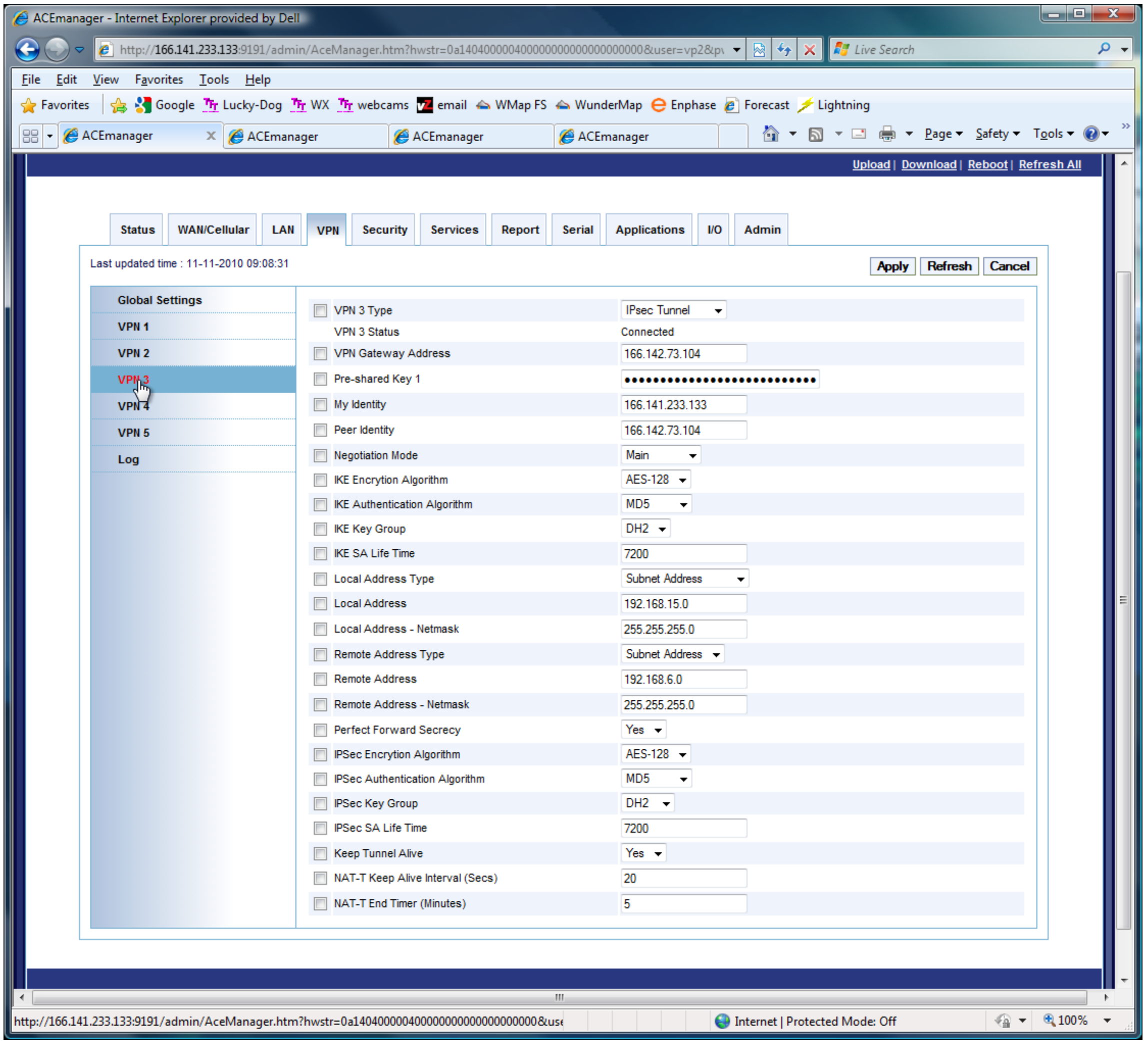


Figure Appendix A 7-6 Ace Manager settings – VPN – VPN3

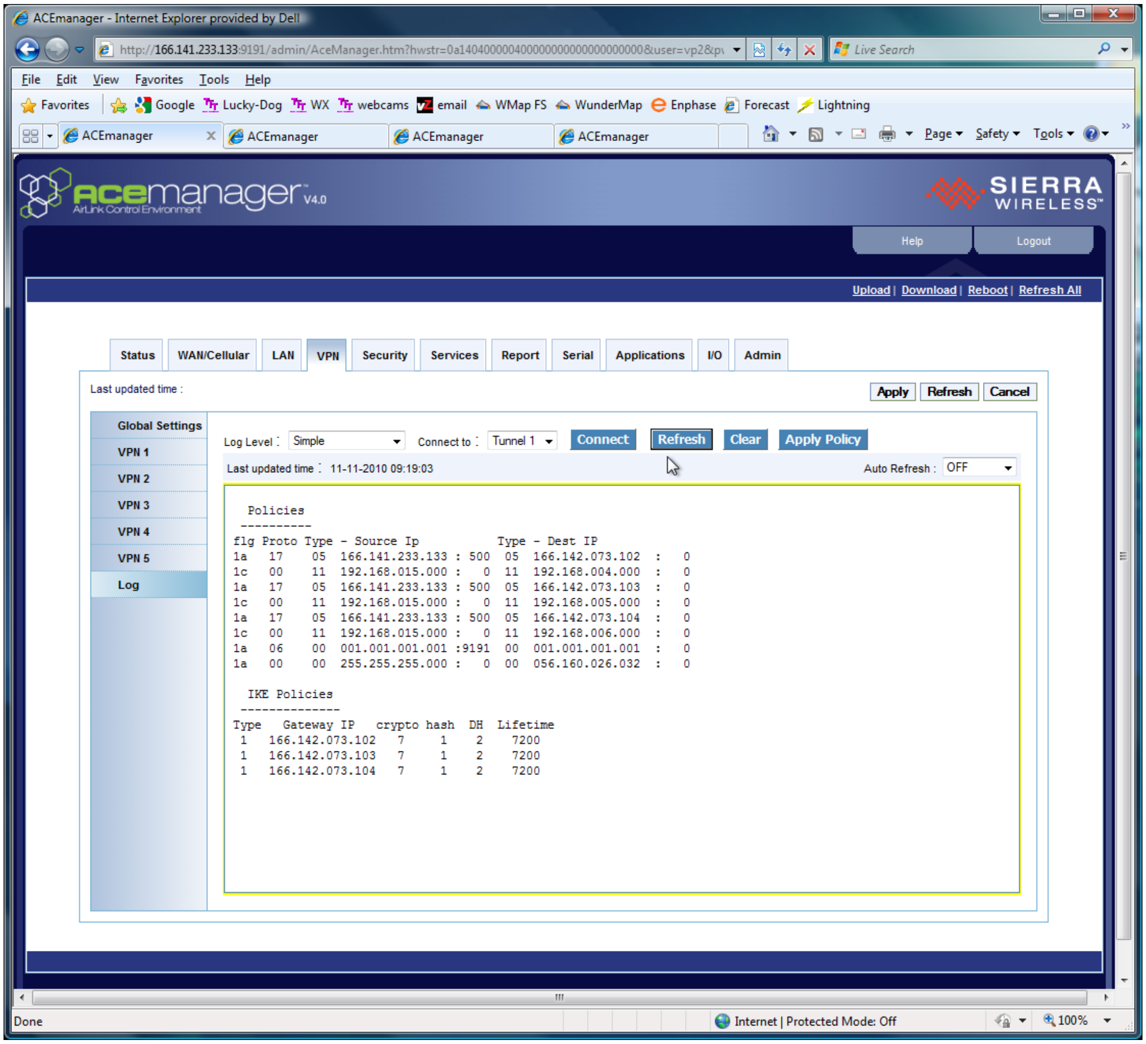


Figure Appendix A 7-7 Ace Manager settings – VPN – Log

Setup for first sagometer
Change 192.168.10.* to 192.168.14.* for backscatter
Change 192.168.4.* to appropriate local device ip, see crossreference table
Change port 9999 to 3001 for backscatter

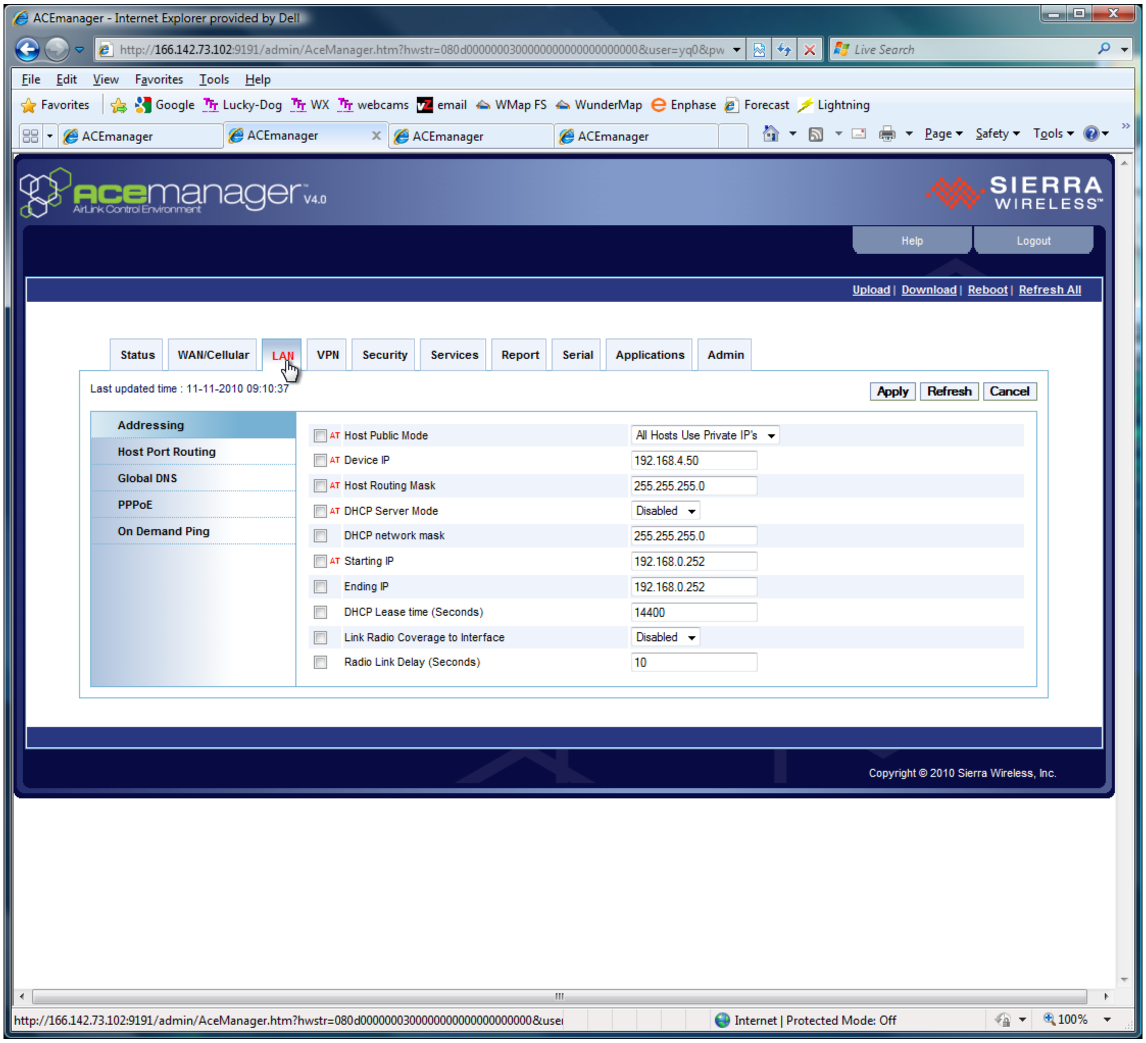


Figure Appendix A 7-8 Ace Manager settings – LAN - Addressing

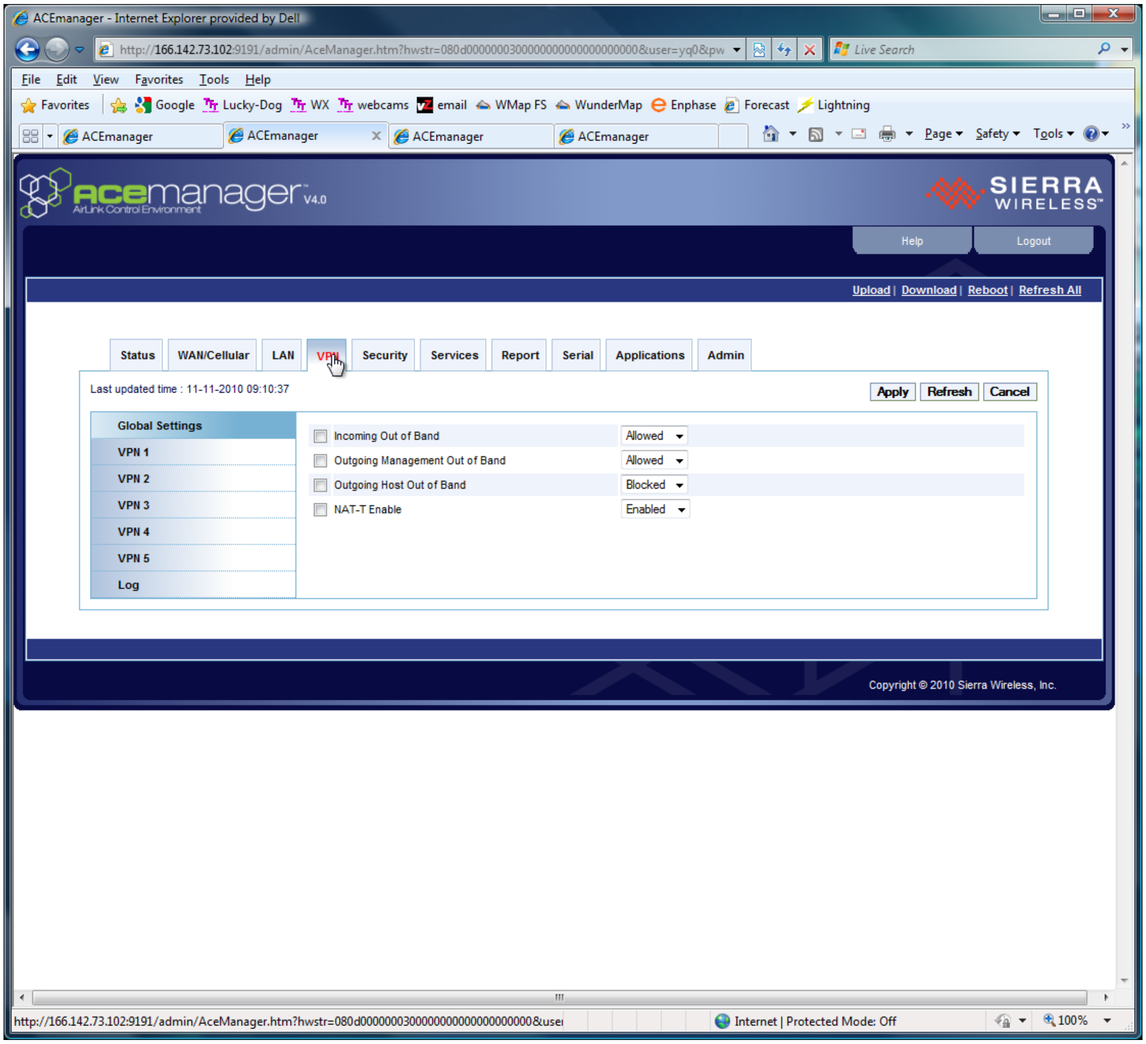


Figure Appendix A 7-9 Ace Manager settings – VPN – Global Settings

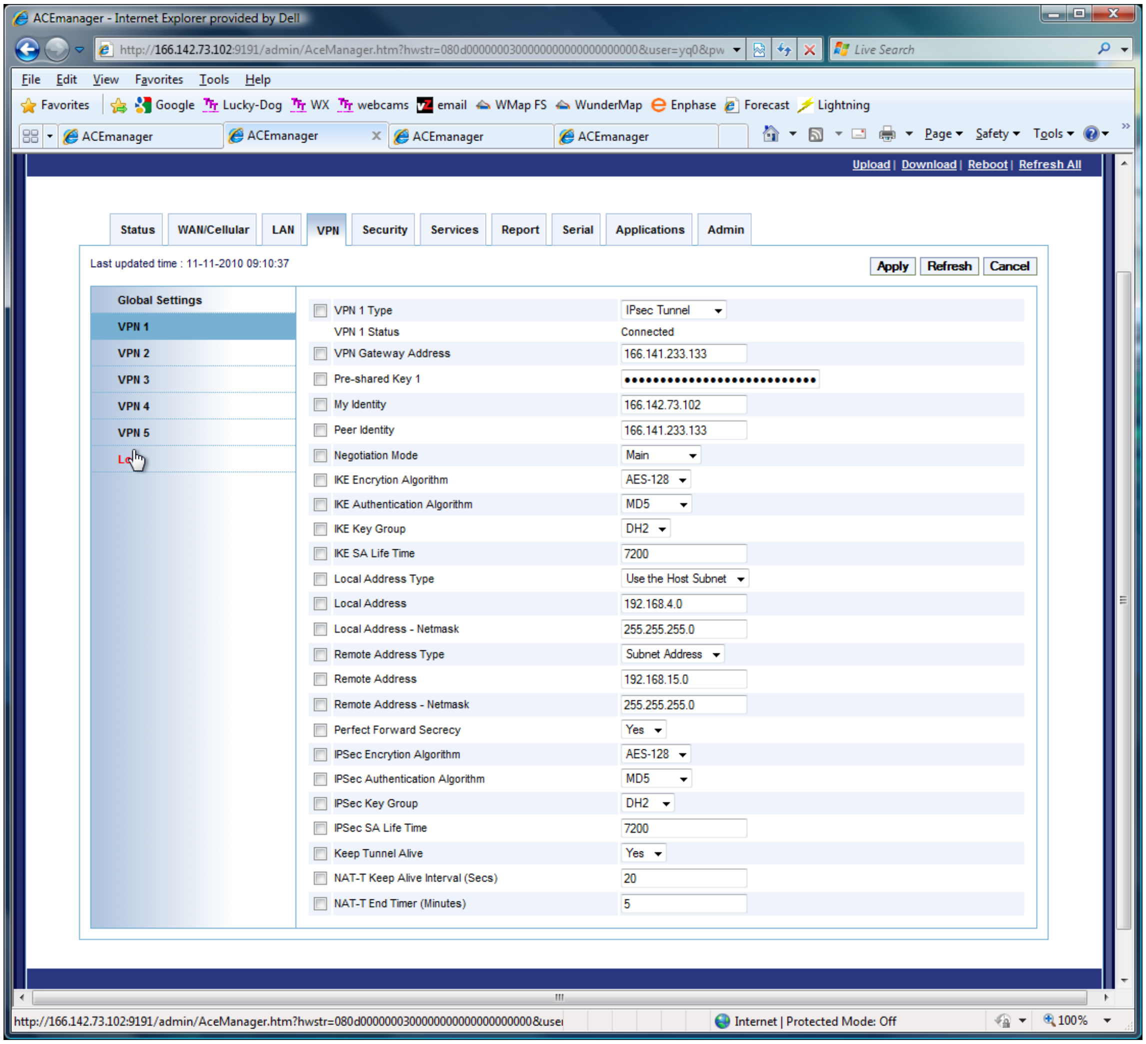


Figure Appendix A 7-10 Ace Manager settings – VPN – VPN1

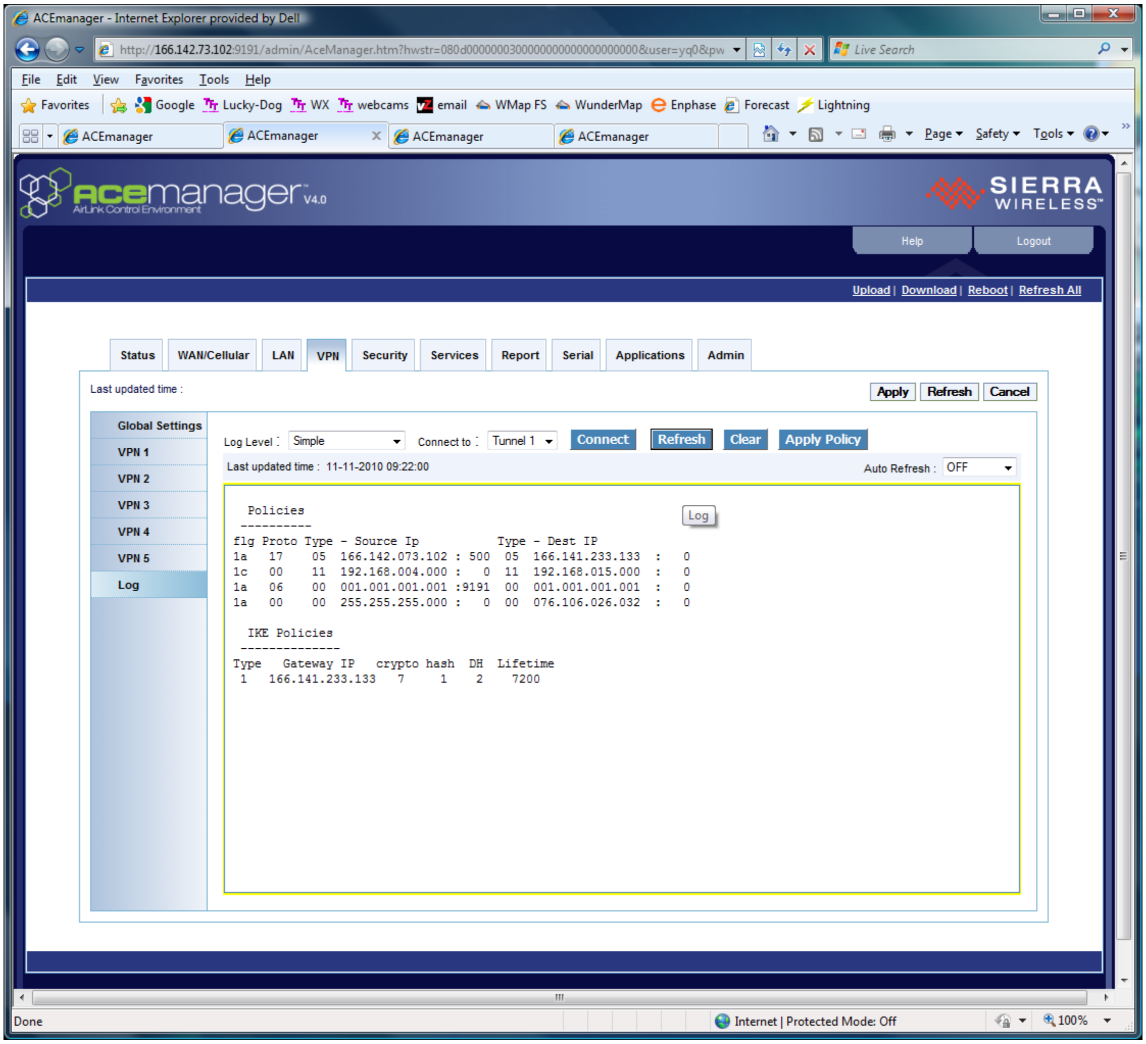


Figure Appendix A 7-11 Ace Manager settings – VPN – Log

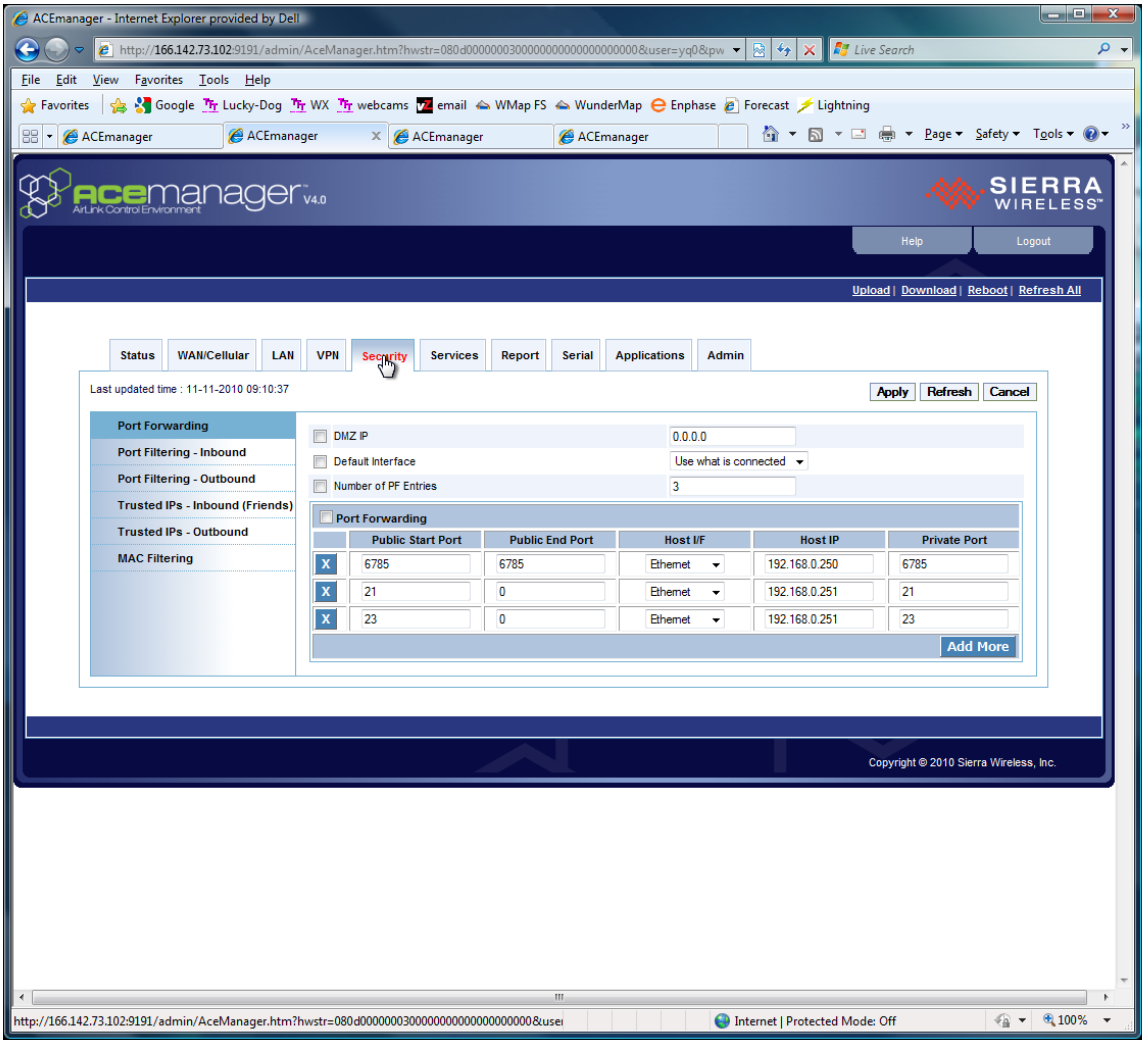


Figure Appendix A 7-12 Ace Manager settings – Security – Port Forwarding

These are only for sagometers, backscatter port forwarding should be empty.

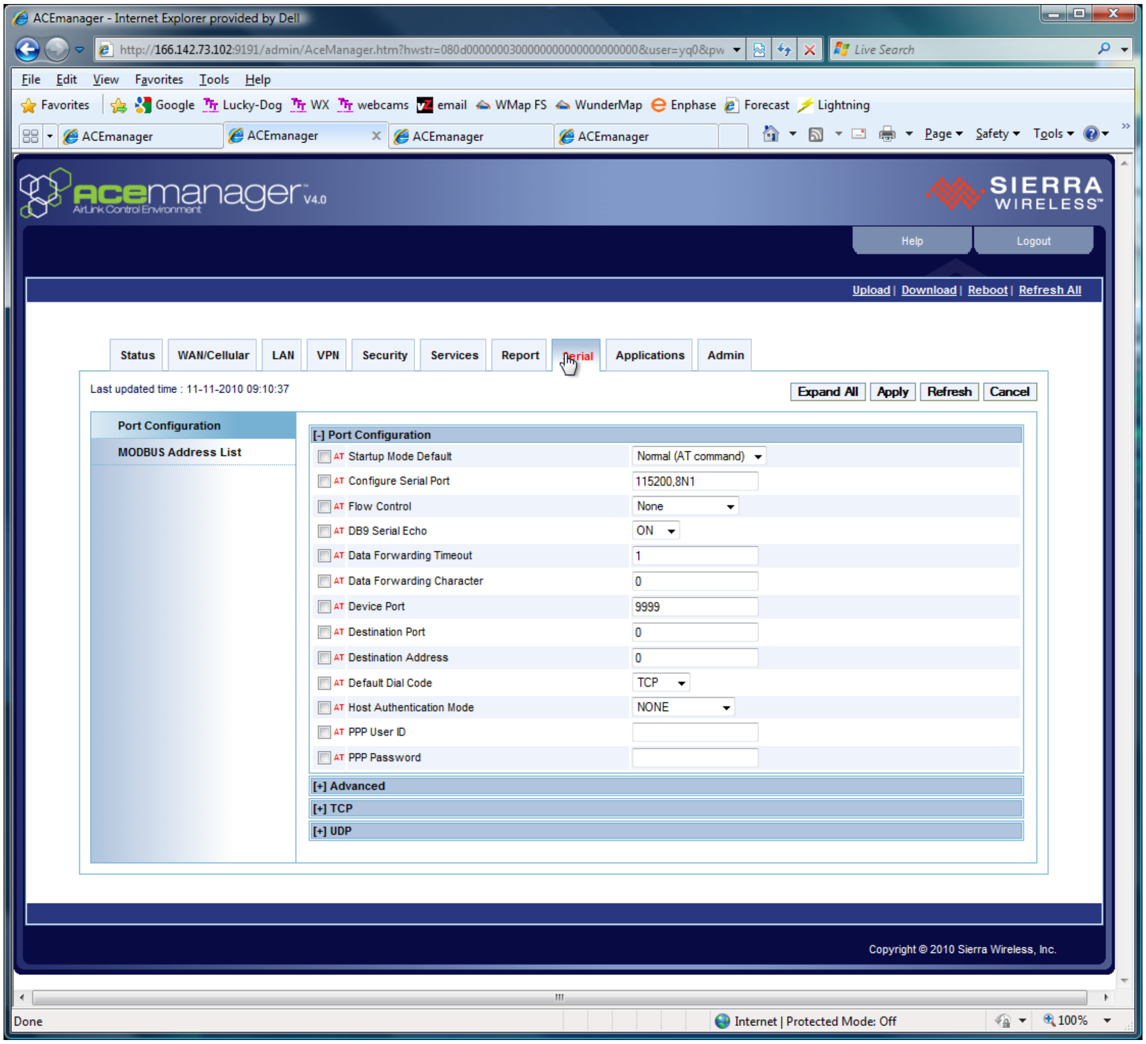


Figure Appendix A 7-13 Ace Manager settings – Serial – Port Configuration

Clearance to Temperature Conversion

Figure Appendix A 7-14 Survey

This section of the appendix provides the clearance to temperature conversion methodology.

Instructions for Creating Sag vs. Conductor Temperature Equations

--------------------Step 1: The Survey Sheets--------------------

Required:

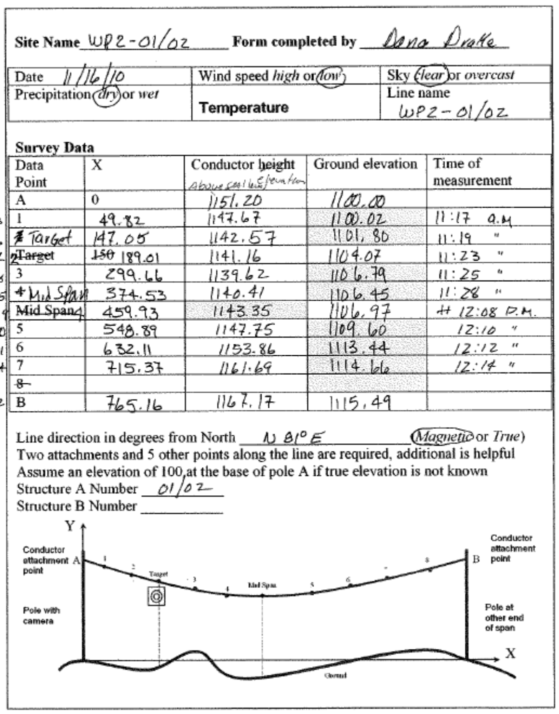
Microsoft Excel

Survey Sheet (PDF)

EDM Spread Sheet (Excel)

For the Survey Crew

Typical project sheet



Site Name WP2-01/02 Form completed by Dana Drake

Date 11/16/10	Wind speed high or low	Sky clear or overcast
Precipitation dry or wet	Temperature	Line name WP2-01/02

Survey Data

	Data Point	X	Conductor height (Above sea level elevation)	Ground elevation	Time of measurement
101	A	0	1151.20	1100.00	
103	1	49.82	1147.67	1100.02	11:17 a.m
106	~~3~~ Target	147.05	1142.57	1101.80	11:19 "
107	2 ~~Target~~	~~150~~ 189.01	1141.16	1104.07	11:23 "
108	3	299.66	1139.62	1106.79	11:25 "
105	~~4~~ Mid Span	374.53	1140.41	1106.45	11:28 "
109	~~Mid Span~~ 4	459.93	1143.35	1106.97	12:08 P.M.
110	5	548.89	1147.75	1109.60	12:10 "
111	6	632.11	1153.86	1113.44	12:12 "
104	7	715.37	1161.69	1114.66	12:14 "
	~~8~~				
102	B	765.16	1167.17	1115.49	

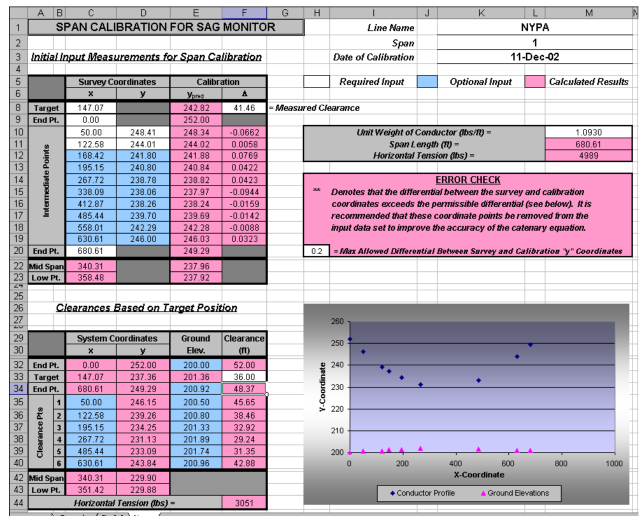
Line direction in degrees from North N 81° E (Magnetic or True)

Two attachments and 5 other points along the line are required, additional is helpful

Assume an elevation of 100 at the base of pole A if true elevation is not known

Structure A Number 01/02

Structure B Number



SPAN CALIBRATION FOR SAG MONITOR

Line Name: NYPA
Span: 1
Date of Calibration: 11-Dec-02

Initial Input Measurements for Span Calibration

Required Input | Optional Input | Calculated Results

	Survey Coordinates x	Survey Coordinates y	Calibration y_{pred}	Calibration Δ
Target	147.07		242.82	41.46 = Measured Clearance
End Pt.	0.00		252.00	
Intermediate Points	50.00	248.41	248.34	-0.0662
	122.58	244.01	244.02	0.0058
	168.42	241.80	241.88	0.0769
	195.15	240.80	240.84	0.0422
	267.72	238.78	238.82	0.0423
	338.09	238.06	237.97	-0.0944
	412.87	238.26	238.24	-0.0159
	485.44	239.70	239.69	-0.0142
	558.01	242.29	242.28	-0.0088
	630.61	246.00	246.03	0.0323
End Pt.	680.61		249.29	
Mid Span	340.31		237.96	
Low Pt.	358.48		237.92	

Unit Weight of Conductor (lbs/ft) =	1.0930
Span Length (ft) =	680.61
Horizontal Tension (lbs) =	4989

ERROR CHECK

** Denotes that the differential between the survey and calibration coordinates exceeds the permissible differential (see below). It is recommended that these coordinate points be removed from the input data set to improve the accuracy of the catenary equation.

0.2 = Max Allowed Differential Between Survey and Calibration "y" Coordinates

Clearances Based on Target Position

		System Coordinates x	System Coordinates y	Ground Elev.	Clearance (ft)
End Pt.		0.00	252.00	200.00	52.00
Target		147.07	237.36	201.36	36.00
End Pt.		680.61	249.29	200.92	48.37
Clearance Pts	1	50.00	246.15	200.50	45.65
	2	122.58	239.26	200.80	38.46
	3	195.15	234.25	201.33	32.92
	4	267.72	231.13	201.89	29.24
	5	485.44	233.09	201.74	31.35
	6	630.61	243.84	200.96	42.88
Mid Span		340.31	229.90		
Low Pt.		351.42	229.88		
Horizontal Tension (lbs) =					3051

1. Make a note of the "Conductor height" value for point "A" and point "B" from the Survey Sheet. These are the start and end point heights. They will be used later to calculate an average (midspan) elevation. Also make a note of the "X" value for point "B" from the Survey Sheet. This is the Actual Span distance. Also make a note of "Temperature" (°F).
2. Copy the data from the "X" column on the Survey Sheet to the "X" column under "Survey Coordinates" on the EDM Spread Sheet.
3. Copy the data from the "Conductor height" column on the Survey Sheet to the "y" column on the EDM Spread Sheet under the Survey Coordinates section.
4. Now copy the data from the "Ground Elevation" column on the Survey Sheet to the "Ground Elev." column on the lower left portion of the EDM Spread Sheet. Make sure to align the elevation value with the proper x value.
5. In the "Clearance" column corresponding to the "Target" row on the EDM Spread Sheet enter the value from delta (Δ) in the top portion of the EDM Spread Sheet.
6. Copy the data from the "Ground elevation" column on the Survey Sheet to the "Ground Elev." column on the lower left portion of the EDM Spread Sheet. Notice that there are only 5 data points here that correspond the "Clearance" (on the left). Choose the 5 data points (from the Survey Sheet) that best cover the entire range of the span. Make sure you enter the Ground Elevation that corresponds to each of the chosen data points.
7. From the Survey Sheet: subtract the Ground elevation for the Target from the Conductor Height for the Target. This is the delta (Δ) for the Calibration column of the EDM Spread Sheet.
8. Once this data has been entered into the EDM Spread Sheet, make a note of the "Horizontal Tension (lbs)" reported by the EDM Spread Sheet.

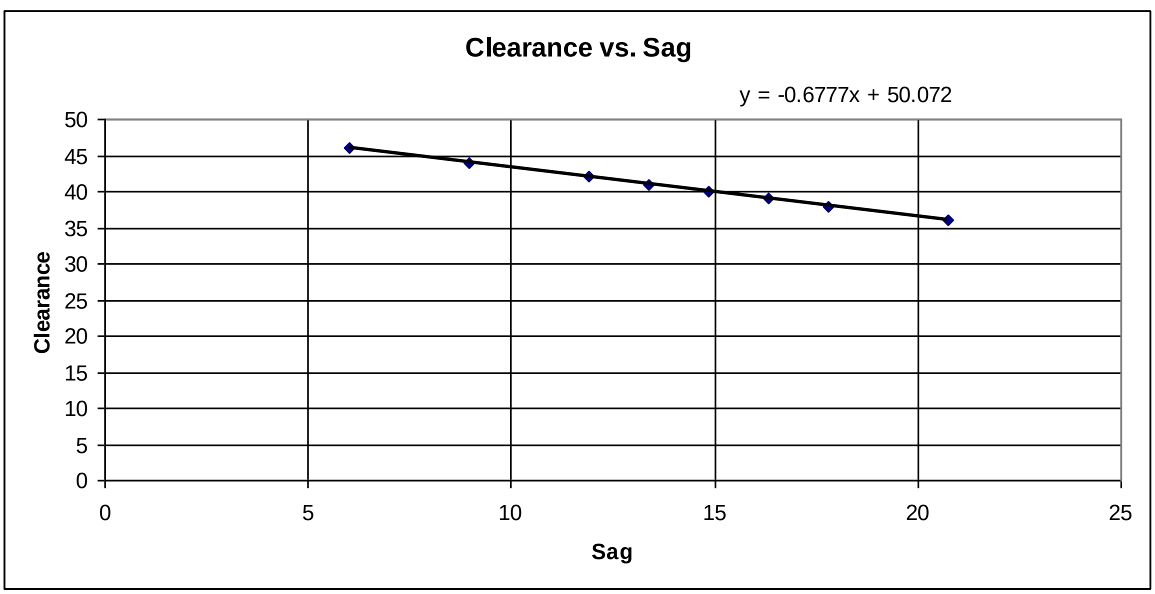
9. Now vary the “Clearance (ft)” on the EDM Spread Sheet. Use logical values and whole foot intervals. Make a chart of the Clearance entered and the corresponding “Mid Span” “y” value from the “System Coordinates” portion of the EDM Spread Sheet. The table should look something like this:

Clearance	Elev
46	244.66
44	241.7
42	238.75
41	237.28
40	235.8
39	234.33
38	232.85
36	229.9

10. Now average the two “Conductor height” values (noted in the first step). Once you have a midspan elevation, subtract each “Elev” value (from the previous step) from the midspan elevation. This is the sag of the conductor. Note each of these values, and append them to the previous table. The result should look similar to this:

Clearance	Elev	Sag
46	244.66	6.005
44	241.7	8.965
42	238.75	11.915
41	237.28	13.385
40	235.8	14.865
39	234.33	16.335
38	232.85	17.815
36	229.9	20.765

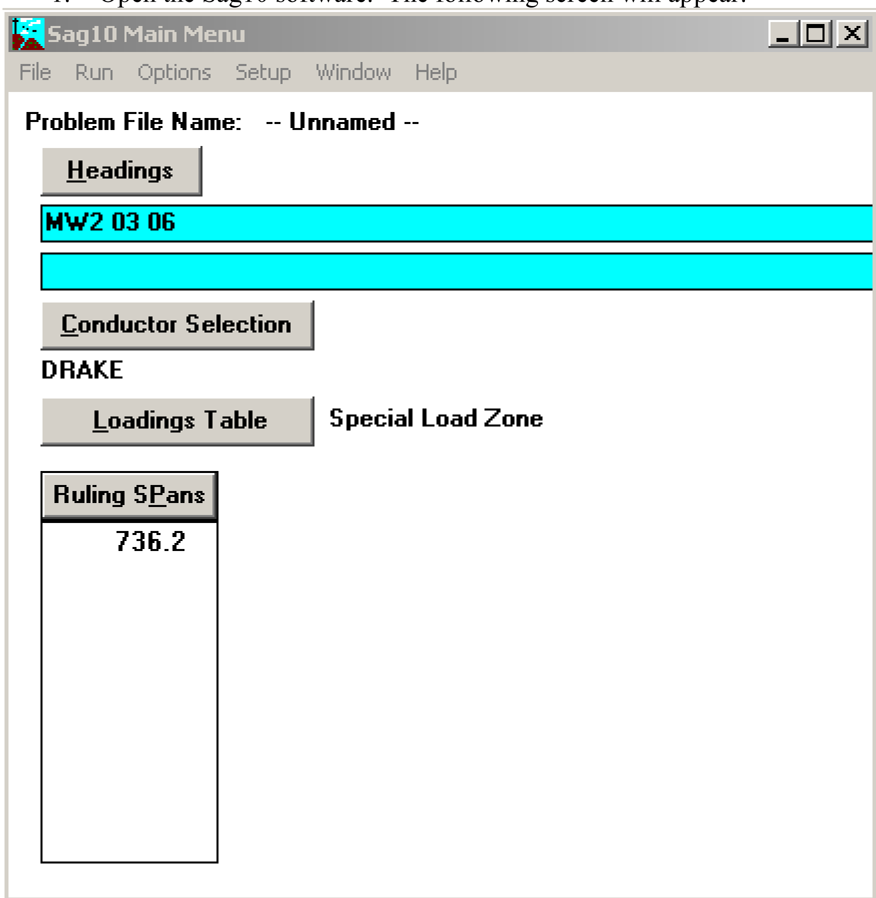
11. Now create a Clearance vs. Sag plot using the above values. Add a linear trend line to the plot and have Excel display the equation for the trend line. Note the equation of the trend line. The result should look similar to this:



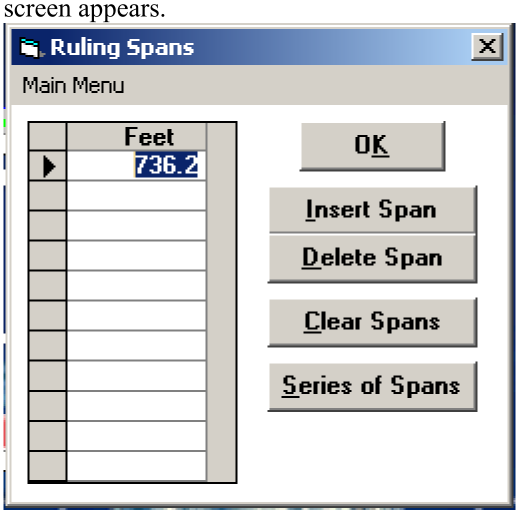
**Note: All values for Clearance, Elevation, and Sag are in feet (ft).*

-------------------Step 2: The Sag10 Software-------------------
Required:
Sag10 Software, data from Step 1, NYPA Information Sheet, Microsoft Excel

1. Open the Sag10 software. The following screen will appear:



Enter the line name ("MW2 03 06" in this case) and then click the "Ruling SPans" button. The following screen appears.



Enter the ruling span (as provided by the owner of the transmission line, in this case the NYPA Commonwealth Associates) and click the "OK" button.

Below is a sample of the NYPA Commonwealth Associates information sheet for a transmission line:

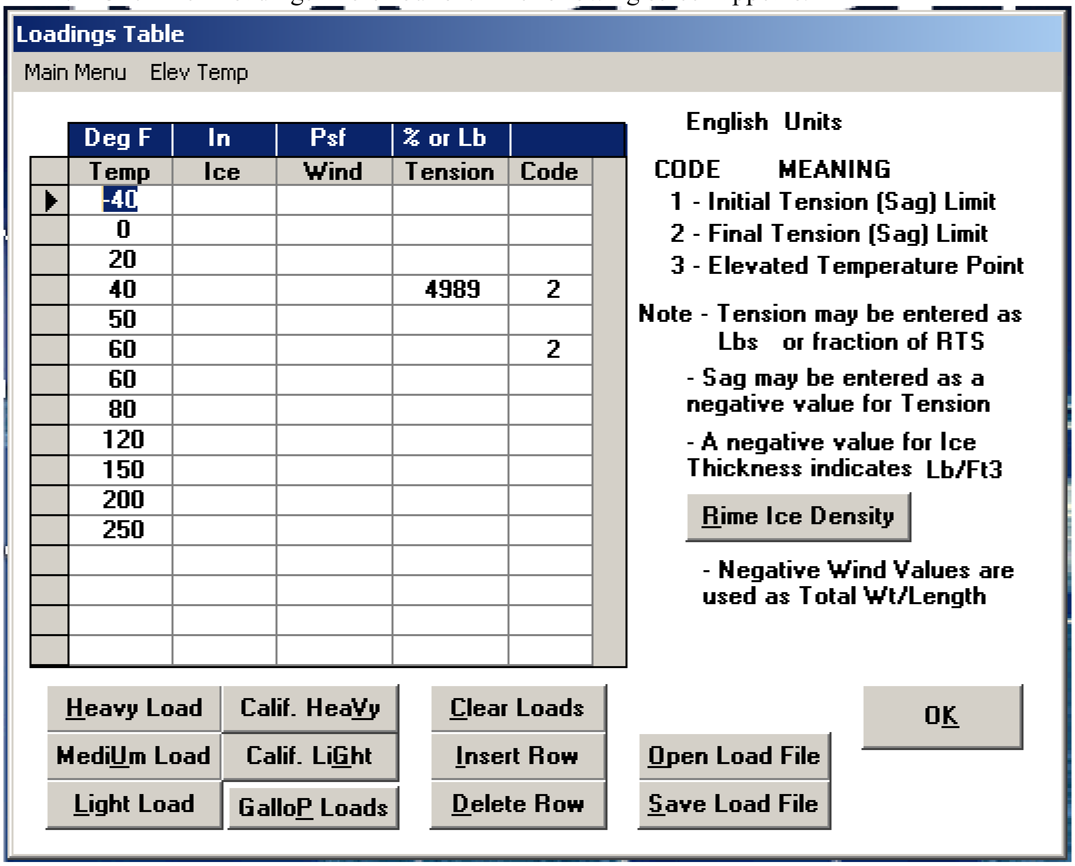
MW2 3_06

Commonwealth Associates, Inc. Page 1/2
PLS-CADD Version 10.40x64 8:34:37 AM Tuesday, November 02, 2010
Commonwealth Associates, Inc.
Project Name: 'm:\pls\clients\nypa\projects\moses_willis.DON'
Criteria notes:
Notes:
Due to the file size of this model some actions have been taken to ensure a useable file size.
In some cases points were left in a separate location, not attached to the PLS-CADD file.
These were points that are not necessary to operate the file but if needed can be inserted.
The following "external" survey files existing in the "Survey" subfolder:
.tin
The tin model is currently attached to the PLS-CADD file.
building.xyz
The building xyz points are currently attached to the PLS-CADD file.
ground.xyz
The ground xyz points are not attached to the PLS-CADD file.
There is no need to have these points in the file if the .tin and interpolated points are attached.
interpolated-points.xyz
The interpolated-points xyz points are currently attached to the PLS-CADD file.
obstructions.xyz
The obstructions xyz points are currently attached to the PLS-CADD file.
structure.xyz
The structure xyz points are currently attached to the PLS-CADD file.
tree.xyz
The tree xyz points are not attached to the PLS-CADD file.
For rating analysis purposed these points are not necessary.
wire.xyz
The wire xyz points are currently attached to the PLS-CADD file.
SURVEY PROJECTION INFORMATION
Projection: NAD83 3101 New York East (NJ)
Type: Transversal Mercator
Ellipsoid: GRS-80
Datum: NAD-83
Units: feet (us survey foot)

Section Sagging Data

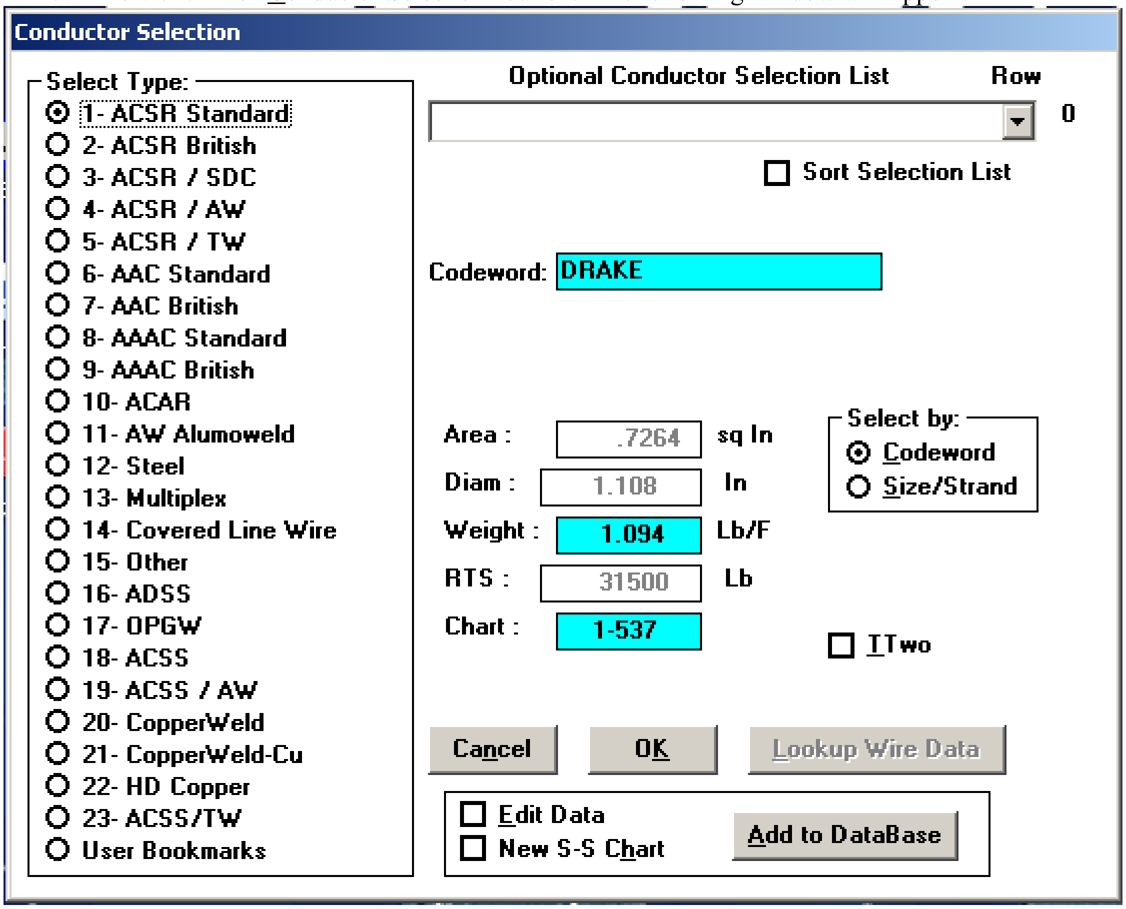
Sec. No.	Cable File Name	From Str.	To Str.	Voltage (kV)	Ruling Span (ft)	Sagging Data Condition	Temp. (deg F)	Catenary Constant (ft)	Horiz. Tension (lbs)	Display Catenary Constant (ft)
55	drake_acsr.wir	2/5	19/5	230	736.2	Creep RS	70.0	4189.0	4582.8	4292.9
56	7#8_alumoweld.wir	2/5	19/5	0	736.1	Creep RS	66.0	6567.0	1719.2	4379.5
57	7#8_alumoweld.wir	2/5	19/5	0	736.2	Creep RS	66.0	6567.0	1719.2	4379.5

2. Click the "Loadings Table" button. The following screen appears.



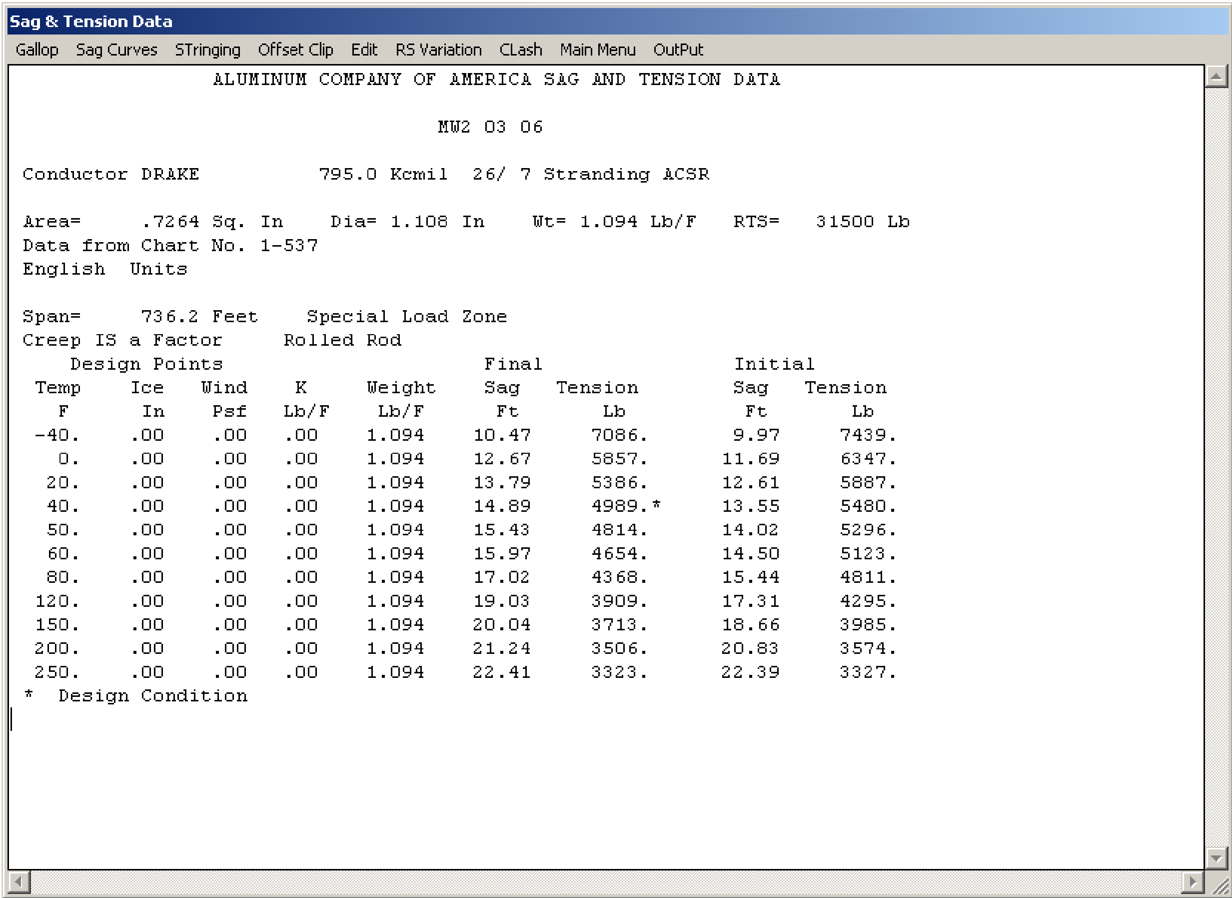
Populate the "Temp" column with a series of values. Since these are temperatures, and can thusly be applied to all conductors, a standard assortment is recommended. Use the values above if you are not provided with other values. Make sure to enter the tension value corresponding to the conductor temperature (as reported in the EDM Spread Sheet and Survey Sheet, respectively). Next to this value, place a "2" in the "Code" columns. This tells the Sag10 software what to do. The "2" in the 60 degree row should be placed automatically by the Sag10 software. When finished, click the "OK" button.

3. Now click the "Conductor Selection" button. The following window will appear.



In the list on the left, select the category of conductor that is being used. Then, from the drop-down list at top select the specific conductor. In this case, "DRAKE" is the conductor in use. Once the proper conductor is selected in both lists, click the "Lookup Wire Data" button. This will populate the appropriate parameters that identify the conductor. Once finished, click the "OK" button.

4. You are now ready to run the calculations using the Sag10 program. At the main screen, select the "Run" menu, then select "Sag & Tension". This will open a new window called "Sag & Tension Data" that looks similar to the one shown below.


Sag & Tension Data

Gallop Sag Curves STringing Offset Clip Edit RS Variation CLash Main Menu OutPut

ALUMINUM COMPANY OF AMERICA SAG AND TENSION DATA

MW2 03 06

Conductor DRAKE 795.0 Kcmil 26/ 7 Stranding ACSR

Area= .7264 Sq. In Dia= 1.108 In Wt= 1.094 Lb/F RTS= 31500 Lb
Data from Chart No. 1-537
English Units

Span= 736.2 Feet Special Load Zone
Creep IS a Factor Rolled Rod

Design Points					Final		Initial	
Temp	Ice	Wind	K	Weight	Sag	Tension	Sag	Tension
F	In	Psf	Lb/F	Lb/F	Ft	Lb	Ft	Lb
-40.	.00	.00	.00	1.094	10.47	7086.	9.97	7439.
0.	.00	.00	.00	1.094	12.67	5857.	11.69	6347.
20.	.00	.00	.00	1.094	13.79	5386.	12.61	5887.
40.	.00	.00	.00	1.094	14.89	4989.*	13.55	5480.
50.	.00	.00	.00	1.094	15.43	4814.	14.02	5296.
60.	.00	.00	.00	1.094	15.97	4654.	14.50	5123.
80.	.00	.00	.00	1.094	17.02	4368.	15.44	4811.
120.	.00	.00	.00	1.094	19.03	3909.	17.31	4295.
150.	.00	.00	.00	1.094	20.04	3713.	18.66	3985.
200.	.00	.00	.00	1.094	21.24	3506.	20.83	3574.
250.	.00	.00	.00	1.094	22.41	3323.	22.39	3327.

* Design Condition

This is a list of the various conductor attributes at each temperature. Note then row that has an asterisk (*) next to the Final Tension value. This is the "Design Condition" (the initial temperature and tension data generated from Step 1). Take note of the value in the "Design Condition" row for Initial Sag (in this case, 13.55ft). This will be used later. Note that the "Final Sag" distance is the final sag of the ruling span. Not the actual span distance.

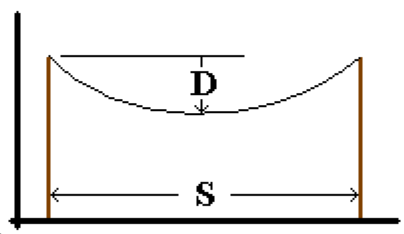
5. Copy the Temp (F) and Final Sag (Ft) columns into and Excel spreadsheet. You will also need the Ruling Span distance (from instruction 1 of Step 2) and the Actual Span distance (from instruction 1 of Step 1). Additional columns for Temp (C), Final Sag (Actual Span), and EDM Spread Sheet Clearance. When finished, the table should be similar to the one below.

RS ft	736.2
span len ft	680.61

Sag 10 Data Temp F	Sag 10 temp C	Sag 10 Fin Sag RS ft	Sag 10 Fin Sag ft	EDM sheet clearance (ft)
-40	-40.0	10.47	8.948530177	44.0075811
0	-17.8	12.67	10.8288326	42.73330015
20	-6.7	13.79	11.78607747	42.0845753
50	10.0	15.43	13.18775746	41.13465677
60	15.6	15.97	13.64928624	40.82187872
80	26.7	17.02	14.54670331	40.21369917
120	48.9	19.03	16.26461598	39.04946975
150	65.6	20.04	17.12784573	38.46445895
200	93.3	21.24	18.15346523	37.76939661
250	121.1	22.41	19.15344425	37.09171083
40		14.89	12.72622869	41.44743482

- To convert from degrees F to degrees C, use the following formula: =CONVERT(%CELL%,"F","C")
  - where "%CELL%" is a reference to the cell containing the temperature in degrees F.
- To calculate Final Sag (Actual Span) from Final Sag (RS), use the following formula (be sure to note the non-intuitive notation used):

$$D = \frac{D_{RS}}{\left(\frac{S_{RS}}{S}\right)^2}$$



where

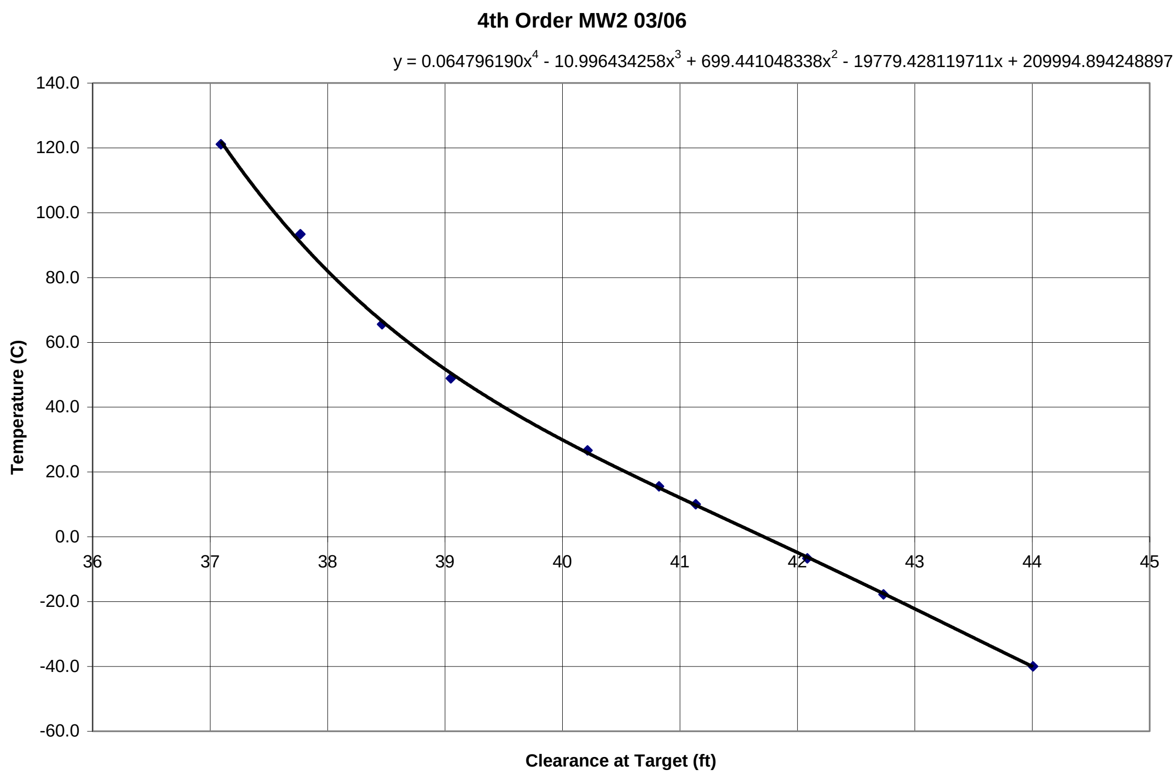
D_{RS} = Sag from the ruling span.
S_{RS} = Actual Span distance (from instruction 1 of Step 1)
S = Ruling Span distance (provided by owner of the line (in this case: NYPA Commonwealth Associates))

- To calculate the "EDM Sheet Clearance" use the equation derived in instruction 11 of Step 1 (the equation for the linear trend line). The value of "x" in this equation should be the Final Sag (Actual Span) value from the table.

-------------------Step 3: 4th Order Polynomial-------------------

Required:
Microsoft Excel, all data from previous step

1. In Excel, create a scatter plot with the following source data:
   x-axis: EDM Sheet Clearance, from the table created in the previous step
   y-axis: Sag10 Temp (C), from the table created in the previous step
   This plot should be created as a new worksheet, *not* as an object in the current worksheet.
2. Assign a Polynomial trend line of the 4th order to this plot's data. Set the trend line to display the equation on the graph.
3. Format the displayed 4th order polynomial to display *at least* 8 decimal places. The finished plot should look similar to the one below.



The equation on this plot is of the utmost importance: it relates the temperature of a conductor to the sag of that conductor. A 4th order polynomial carried to 8 decimal places is used to achieve the greatest accuracy. In case it is not clear from the above image, the equation relating this conductor's temperature to its sag is as follows:

$y = 0.064796190x^4 - 10.996434258x^3 + 699.441048338x^2 - 19779.428119711x + 209994.894248897$

---------------I/O data for MW2 36/04---------------

Survey Data:

Data Point	X	Conductor height	Ground elevation	Temperature(F)
A	0	1057.03	1000	50
1	50	1052.28	1000.65	
2	128.62	1046.19	1001.87	
Target	148.56	1044.55	1001.95	
3	206.74	1041.41	1002	
4	285.86	1038.03	1002.08	
Mid Span	363.42	1035.89	1002.64	
5	443.12	1035.5	1003.05	
6	521.74	1036.36	1002.5	
7	600.36	1038.73	1002.14	
8	679	1042.56	1002.64	
B	729	1045.78	1003.61	
Sensor	181.54	1042.65	1001.94	

Tension: 4751 lbs
Ruling Span: 786.5
Actual Span: 729 ft
Clearance and Sag table:

Clearance	Elev	Sag		
			Evel1	1057.03
46	1041.44	9.965	Elev2	1045.78
44	1038.36	13.045	ElevAvg	1051.405
42	1035.28	16.125		
41	1033.73	17.675		
40	1032.19	19.215		
39	1030.65	20.755		
38	1029.11	22.295		
36	1026.03	25.375		

Equation of Clearance vs. Sag line:
y = -0.6488x + 52.465
Excel Tables (post Sag10):

Sag 10 Data Temp F	Sag 10 temp C	Sag 10 Fin Sag RS Ft	Sag 10 Fin Sag ft	EDM sheet clearance (ft)
-40	-40.0	12.69	10.90232752	45.3915699
0	-17.8	15.02	12.90409452	44.09282348
20	-6.7	16.17	13.8920911	43.45181129
50	10.0	17.85	15.33542524	42.5153761
60	15.6	18.4	15.80794535	42.20880506
80	26.7	19.47	16.72721173	41.61238503
120	48.9	21.53	18.49701431	40.46413712
150	65.6	22.63	19.44205452	39.85099503
200	93.3	23.87	20.50737258	39.15981667
250	121.1	25.09	21.55550808	38.47978636

Equation of 4^{th} Order Polynomial for Temperature(C) vs. Clearance plot:
y = 0.07082855x4 - 12.34434740x3 + 806.55977836x2 - 23432.72668555x + 255592.98910116
Initial Sag: 16.41 ft

Calculated Initial Sag: 14.098 ft
Datasheet Initial Sag: 13.95 ft

---------------I/O data for MW2 03/06---------------

Survey Data:

Data Point	X	Conductor height	Ground elevation	Temperature(F)
A	0	252.09	200	40
1	50	248.41	200.5	
2	122.58	244.01	200.8	
Target	147.07	242.44	200.98	
3	195.15	240.8	201.33	
4	267.72	238.78	201.89	
Mid Span	338.09	238.06	201.72	
5	412.87	238.26	201.69	
6	485.44	239.7	201.74	
7	558.01	242.29	201.4	
8	630.61	246	200.96	
B	680.61	249.24	200.92	
Sensor	168.42	241.8	201.18	

Tension: 4989 lbs
Ruling Span: 736.2 ft
Actual Span: 680.61 ft
Clearance and Sag table:

Clearance	Elev	Sag		
46	244.66	6.005	Evel1	252.09
44	241.7	8.965	Elev2	249.24
42	238.75	11.915	ElevAvg	250.665
41	237.28	13.385		
40	235.8	14.865		
39	234.33	16.335		
38	232.85	17.815		
36	229.9	20.765		

Equation of Clearance vs. Sag line:
$y = -0.6777x + 50.072$
Excel Tables (post Sag10):

Sag 10 Data Temp F	Sag 10 temp C	Sag 10 Fin Sag RS Ft	Sag 10 Fin Sag ft	EDM sheet clearance (ft)
-40	-40.0	10.47	8.948530177	44.0075811
0	-17.8	12.67	10.8288326	42.73330015
20	-6.7	13.79	11.78607747	42.0845753
50	10.0	15.43	13.18775746	41.13465677
60	15.6	15.97	13.64928624	40.82187872
80	26.7	17.02	14.54670331	40.21369917
120	48.9	19.03	16.26461598	39.04946975
150	65.6	20.04	17.12784573	38.46445895
200	93.3	21.24	18.15346523	37.76939661
250	121.1	22.41	19.15344425	37.09171083

40	14.89	12.72622869	41.44743482

Equation of 4th Order Polynomial for Temperature(C) vs. Clearance plot:
y = 0.064796190x4 - 10.996434258x3 + 699.441048338x2 - 19779.428119711x + 209994.894248897
Initial Sag: 13.55 ft
Calculated Initial Sag: 11.58 ft
Datasheet Initial Sag: 11.50 ft

---------------I/O data for WP2 01/02---------------

Survey Data:

Data Point	X	Conductor height	Ground elevation	Temperature(F)
A	0	1151.2	1100	50
1	49.82	1147.67	1100.02	
Target	147.05	1142.57	1101.8	
2	189.01	1141.16	1104.7	
3	299.66	1139.62	1106.79	
Mid Span	374.53	1140.41	1106.45	
4	459.93	1143.35	1106.97	
5	548.89	1147.75	1109.6	
6	632.11	1153.86	1113.44	
7	715.37	1161.69	1114.66	
B	765.16	1167.17	1115.49	

Tension: 4334 lbs
Ruling Span: 778.3 ft
Actual Span: 765.16 ft
Clearance and Sag table:

Clearance	Elev	Sag		
46	1149.12	10.065	Elev2	1167.17
44	1145.9	13.285	ElevAvg	1159.185
42	1142.68	16.505		
41	1141.06	18.125		
40	1139.45	19.735		
39	1137.84	21.345		
38	1136.23	22.955		
36	1133.01	26.175		

Evel1 1151.2

Equation of Clearance vs. Sag line:
y = -0.6206x + 52.246
Excel Tables (post Sag10):

Sag 10 Data Temp F	Sag 10 temp C	Sag 10 Fin Sag RS Ft	Sag 10 Fin Sag ft	EDM sheet clearance (ft)
-40	-40.0	14.17	13.69558	43.74653
0	-17.8	16.46	15.9089	42.37293
20	-6.7	17.57	16.98174	41.70713
50	10.0	19.18	18.53784	40.74142
60	15.6	19.7	19.04043	40.42951
80	26.7	20.72	20.02628	39.81769
120	48.9	22.67	21.91099	38.64804
150	65.6	23.65	22.85818	38.06022
200	93.3	24.86	24.02767	37.33443

250	121.1	26.04	25.16816	36.62664
40	4.4	18.65	18.02558	41.05932

Equation of 4th Order Polynomial for Temperature(C) vs. Clearance plot:
y = 0.05480087x4 - 9.21294018x3 + 580.71858804x2 - 16282.47462093x + 171509.79041319
Initial Sag: 17.93 ft
Calculated Initial Sag: 17.32 ft
Datasheet Initial Sag: 15.74 ft