Arnold Schwarzenegger
Governor

BIRD STRIKE INDICATOR FIELD DEPLOYMENT AT THE AUDUBON NATIONAL WILDLIFE REFUGE IN NORTH DAKOTA

PHASE TWO

PIER FINAL PROJECT REPORT

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Preface

The Public Interest Energy Research (PIER) Program supports public interest energy research and development that will help improve the quality of life in California by bringing environmentally safe, affordable, and reliable energy services and products to the marketplace.

The PIER Program, managed by the California Energy Commission (Energy Commission), conducts public interest research, development, and demonstration (RD&D) projects to benefit California.

The PIER Program strives to conduct the most promising public interest energy research by partnering with RD&D entities, including individuals, businesses, utilities, and public or private research institutions.

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- Buildings End-Use Energy Efficiency
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- Environmentally Preferred Advanced Generation
- Industrial/Agricultural/Water End-Use Energy Efficiency
- Renewable Energy Technologies
- Transportation

Bird Strike Indicator Field Deployment at the Audubon National Wildlife Refuge in North Dakota is the final report for the Monitoring System for Studying Avian and Wildlife Interactions with Power and Communication Facilities project (contract number 500-01-032) conducted by EDM International, Inc. (EDM). The information from this project contributes to PIER's Energy-Related Environmental Research Program.

For more information about the PIER Program, please visit the Energy Commission's website at www.energy.ca.gov/pier or contact the Energy Commission at 916-654-5164.

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Abstract

The bird strike indicator is an impulse-based vibration sensing and recording tool to detect bird strikes on aerial cables. This project was designed to perform the first field trial of the bird strike indicator on an energized power line. Three power line spans were instrumented with 30 bird strike indicators for parts of two successive years: 2006 and 2007. Ground searches were performed to relate detected carcasses with recorded strikes, and in 2007 visual observations were added to improve the likelihood of getting visual verification of bird collisions detected by the bird strike indicator. In 2006, 71 collisions were recorded and 35 were successfully correlated with ground searches. The bird strike indicators recorded additional collisions that could not be correlated with carcasses found by the surveyors, indicating that some of the carcasses might have fallen outside the search area. In 2006 some bird collisions were likely missed by malfunctioning sensors. During the 2007 field trials, improvements were made to the design of the bird strike indicator sensors based on the lessons learned from 2006. There were 154 detected bird collisions, and three were visually verified. Most collisions (68 percent) were recorded with the top wires (the overhead static wires). There were no false bird collision recordings by sensors during the visual observation period of 446 hours.

Keywords: Avian collisions, power lines, BSI, bird strike indicator, bird searches, accelerometers, vibration recorder

Executive Summary

Introduction

The bird strike indicator is a vibration sensing and recording tool to detect bird strikes on aerial cables such as power lines. It works on the premise that a bird colliding with a wire will induce a stress wave/vibration into the wire that can be monitored and detected using accelerometers inside the bird strike indicator. The system consists of two main components: the bird strike indicator sensors and a base station. The sensors are installed on the wires to be monitored, and report any strike activity to the base station. The base station logs all the data from the sensors for future downloading and analysis. Before this project was conducted, the bird strike indicator was tested in laboratory and field settings, but not on energized lines. A previous Public Interest Energy Research Program project tested the corona effects[1] of the bird strike indicator.

Purpose and Benefits to California

This project was designed to perform the first bird strike indicator field trial on an energized power line. The trials were conducted for portions of two years: 2006 and 2007. The testing period was chosen to coincide with highest incidences of bird use and collisions. The North Dakota study site was selected because it had a documented history of high (~500 per year) bird collision problems and many of the migratory bird species found in North Dakota also occur in California. The project site also offered a unique opportunity because it is located at a national wildlife refuge with staff willing to assist with the field work and with utility partners agreeing to allow installation of bird strike indicators on energized conductors.

Bird collisions with power lines are a growing concern in California and around the world. In the United States bird collisions are a violation of federal law under the Migratory Bird Treaty Act (MBTA). Bird collisions also can occasionally result in electrical outages. Although power line collisions historically have been a low level mortality factor for broad bird populations, power line collisions have been documented for critically endangered species such as the California condor. Successful development of bird strike indicator sensors will help researchers study the level of collision problems and determine the effectiveness of line marking devices in deterring collisions. These monitors can be cost-effectively used in remote locations to capture vital information necessary to minimize the impacts of utility structures on birds. This work is consistent with the PIER Program's mission to develop cost-effective approaches to evaluate and resolve the environmental effects of energy production, delivery, and use in California and to explore how new electricity applications and products can solve environmental problems.

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[1] Corona effect occurs when electricity dischared from the power line passes through the bird strike indicator causing damage to the indicator and subsequently the power line on which it is mounted.

Project Objectives and Methods

The project's objectives were to test the effectiveness of the bird strike indicator in detecting bird collisions with power lines and to evaluate its overall design and performance on energized lines.

The test site chosen for the bird strike indicator field trial is situated near the Audubon National Wildlife Refuge located approximately two miles north of Coleharbor, North Dakota. In 2006 three power line spans known to cause numerous bird collisions were equipped with bird strike indicators to remotely monitor bird strikes. Regular ground searches were performed under the lines to relate carcasses to recorded strikes. The lines were also monitored on site by field personnel at dawn and dusk to record any bird collisions observed during those survey periods. Field tests in 2006 indicated that some design improvements were necessary, so those improvements were made, and the bird strike indicators were re-installed in 2007. Ground searches were complemented with expanded visual observations to help verify strike recordings with actual bird collisions.

Project Outcomes and Conclusions

The field testing of the bird strike indicator sensors at the North Dakota test site has shown that they are able to successfully detect and record bird collisions with power lines. During the 2006 monitoring season, 71 collisions were recorded, and of those 35 were correlated with carcasses from ground searches. The bird strike indicators recorded some collisions that could not be correlated with carcasses found by the surveyors, suggesting that some of the carcasses might have fallen outside the search area, as indicated by some of the observed collisions. Some bird collisions were also missed by the bird strike indicators during the 2006 season. On three occasions they failed to log collisions visually observed by field technicians. In addition, 9 out of 30 sensors failed at some point during this initial field trial and missed recording any collisions after their failure.

Additionally, the 2006 field testing identified some design and fabrication issues affecting the sensors' field performance. The most significant design/fabrication flaw was that accelerometers became detached from the sensors due to glue failure, making them dysfunctional. The sensors installed on the 115 kilovolt (kV) wires also had damaged antenna tips from corona (electrical ionic discharge) activity. However, this damage did not have any effect on the sensors' communication performance.

During the 2007 field trials, design changes were incorporated to solve the problems identified in the 2006 trials. New metallic antennas replaced the plastic antennas, a new switch was used to eliminate moisture intrusion, and accelerometers were allowed to cure for sufficient time before handling, ensuring they developed a strong bond. The 2007 bird strike indicators also had both accelerometers mounted to monitor in the horizontal plane, as opposed to the 2006 models, where both horizontal and vertical signals were recorded. These design changes significantly improved the performance of the sensors in 2007, resulting in no further problems. Lastly, the 2007 trials used a technician to visually monitor spans fitted with bird strike indicators.

Visual observations during the 2007 field trial showed correlation between observed strikes and the bird strike indicator recordings. During 2007, the bird strike indicators detected 154 recorded events versus 101 dead birds found during the field surveys under these same spans. As in 2006, this discrepancy suggests that dead birds are falling outside the search area or striking the wires and continuing to fly off since both scenarios were observed during visual monitoring. It is also important to note that there were no false collision recordings (false positives) by the sensors during the visual observation period of 446 hours over 79 days.

Data from the bird strike indicators suggest that many collisions occur during low visibility, making it impossible to visually observe them with the unaided eye. The maximum number of events occurred just around dusk, between 9 p.m. to 10 p.m. and again around 4 a.m. Very few collisions occurred during daylight hours.

The bird strike indicator results also demonstrate how events may change throughout a season. In the beginning of the monitoring season, bird collisions were being detected more often on Span 2, but later the intensity of bird collisions picked up on Span 6 and continued at the same pace until the end of the season. The sensors also recorded 68 percent of all events on the upper two shield wires.

The battery lasted throughout the six-month trial during both 2006 and 2007 and wireless communication between the sensors and base station was functional. It also was demonstrated that the installation and removal of the bird strike indicator required minimal effort by the Western Area Power Administration line crews.

The findings of the field testing are encouraging, especially results from the 2007 season, considering that this was the first installation of the bird strike indicator sensors on energized power lines at such a complicated test environment as encountered at the North Dakota test site.

Recommendations

The specific recommendations after the 2006 field trials were as follows:

1. Install the sensors closer to the middle of the span to improve the range and sensitivity of collision detection. This location could reduce the sensors' sensitivity to traffic induced vibrations by putting the sensors farther from the towers.
2. Install the accelerometers to ensure they are permanently attached, and investigate using accelerometers that can be mounted without glue.
3. Reinforce antenna tips or find an alternate metallic antenna with no sharp tips, to minimize corona effects.

4. Use greater precaution during fabrication to ensure that the area around each switch is properly sealed to prevent moisture intrusion.
5. Increase the duration of visual observations to increase the chances of direct verification of bird collisions with bird strike indicator-detected collisions.

Items 1 through 5 were successfully incorporated into the 2007 field trials.

Additional testing is recommended to further prove the effectiveness and sensitivity of the bird strike indicator sensors to detect bird collisions. More on the sensitivity of detecting bird collisions is still needed. Detecting a collision includes several variables such as the bird size and flight speed, span length, size of the wire, mounting position, and accelerometer sensitivity setting. Controlled bird strike trials using simulated birds or bird carcasses projected at instrumented spans would provide useful information on the overall detection sensitivity. Finding another study site with less confounding factors but with high documented bird collisions would also be beneficial.

Another recommendation from both the 2006 and 2007 season is the need to develop and incorporate a digital filter in the firmware of the sensor to filter out wind-induced vibrations being recorded by the sensors.

1.0 Introduction

1.1. Background

Bird collisions with power lines are a growing concern in California and around the world. In the United States bird collisions are a violation of federal law under the Migratory Bird Treaty Act (MBTA). The MBTA, (16 U.S.C. 703-712; Ch. 128; July 13, 1918; 40 Stat. 755 and Amendments) applies to the vast majority of birds in the United States (See 50 Code of Federal Regulations [CFR] § 10.13) with the exception of a few species, such as the introduced house sparrow, European starling, rock pigeon, and monk parakeet. The MBTA states that, unless permitted by regulation, it is unlawful to "pursue, hunt, take, capture, kill, possess, sell, barter, purchase, ship, export, or import any migratory birds alive or dead, or any part, nests, eggs, or products thereof." Migratory bird collisions violate the misdemeanor provisions of the MBTA. For misdemeanors, the penalties include fines up to $15,000 per organization and up to six months imprisonment. Bird collisions also can occasionally result in electrical outages.

The extent of bird collision throughout the world is unknown although some estimates have been developed by taking numbers from existing studies and extrapolating values to total miles of power lines. However these estimates are not reliable because the potential risk of birds colliding with lines depends on a complex set of site specific items, such as habitat type, line orientation to foraging flight patterns, number of migratory and resident bird species, species' composition and area familiarity, visibility and weather patterns, types of human-related disturbance, and line design. Although power line collisions historically have been a low level mortality factor for broad bird populations (Brown, 1993; Olendorff and Lehman, 1986), power line collisions have been documented for critically endangered species such as the California condor.

The bird strike indicator (BSI) is an impulse-based vibration sensing and recording tool to detect bird strikes on power lines. It is based in part on an earlier bird strike instrument developed by Pacific Gas and Electric Company (PG&E) (CEC 2000), with the basic premise that a bird colliding with a wire will induce a stress wave/vibration into the wire that can be monitored and detected using accelerometers inside the BSI. The system consists of two main components: the BSI sensors and a base station. The sensors are installed on the wires to be monitored, and they report any strike activity to the base station. The base station logs all the data from the sensors for future downloading and analysis (Figure 1). Successful development of the BSI will help researchers study the level of collision problems and determine the effectiveness of line marking devices in deterring collisions. These monitors can be cost-effectively used in remote locations to capture vital information necessary to minimize the impacts of utility structures on birds.

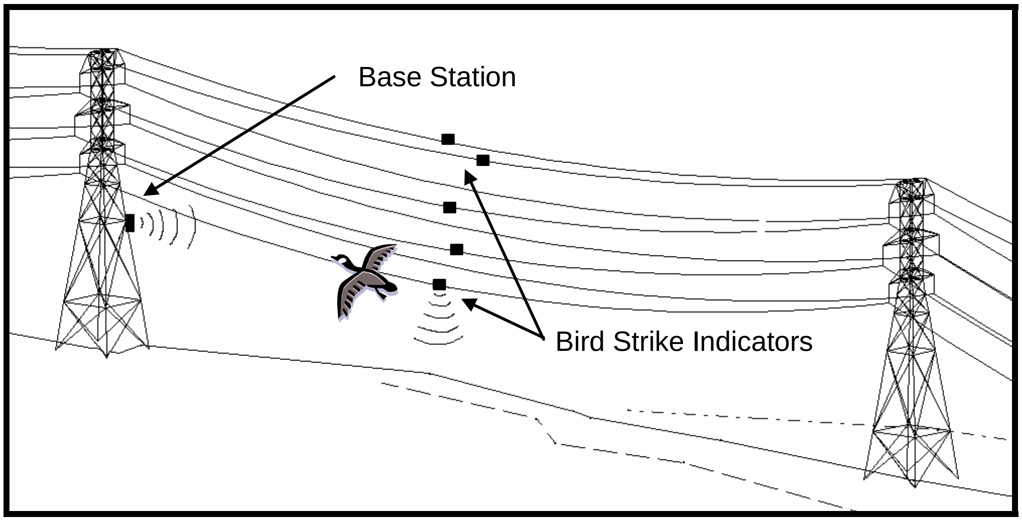


Figure 1. Schematic showing attachment locations for bird strike indicators and their associated base station on a power line

The BSI and base station were developed and lab tested as part of a previous project (CEC 2003). The BSI has been tested in Alaska on United States Coast Guard (USCG) Differential Global Positioning System (GPS) tower guy wires (EPRI 2006) and was shown to operate successfully in a harsh weather environment. Placing devices on power lines can result in corona discharge, resulting in radio interference. Initial testing on the possible impact of BSI corona discharge was conducted, and at 115 kilovolts (kV) the BSI generated low corona levels (CEC 2004).

This study's purpose was to field test the BSI on energized lines and to evaluate the performance of the BSI at a site known to have numerous bird collisions (CEC 2003). This project was co-funded by the California Energy Commission's Public Interest Energy Research (PIER) Program, the Western Area Power Administration (Western), and the Avian Power Line Interaction Committee (APLIC). The BSI is patented by the Electric Power Research Institute (EPRI). The following organizations are past contributors to the BSI development:

- EPRI
- Bonneville Power Administration (BPA)
- NorthWestern Energy – Butte, Montana
- Otter Tail Power Company – Fergus Falls, Minnesota
- PG&E - San Francisco, California
- Salt River Project (SRP) – Phoenix, Arizona
- Southern California Edison (SCE) – Rosemead, California
- Southwest Research Institute, Inc. (SwRI) – San Antonio, Texas
- Tri-State Generation & Transmission Association (Tri-State G&T) – Denver, Colorado
- United States Fish and Wildlife Service (USFWS) - Washington D.C.

1.2. Project Objectives

This project was designed to perform the first BSI field trials on an energized power line. The objectives were to test the BSI effectiveness in detecting bird collisions with power lines and to evaluate the overall BSI design and performance on energized lines.

2.0 Methods

Three power line spans known to cause numerous bird collisions were instrumented with BSIs (Figure 2) to remotely monitor bird strikes. Daily ground searches were performed under the lines to relate detected carcasses with recorded strikes. The instrumented lines also were monitored on site by field personnel at dawn and dusk to record any bird collisions observed during those survey periods. Three spans of line were equipped in 2006 and 2007. The first year tested the technology and correlated the results with the daily field searches. The second year the BSIs were modified in response to lessons learned from 2006, and additional visual observations were emphasized. Section 3 provides a detailed description of the 2006 study; Section 4 provides the 2007 study results.

Figure 2. BSI sensor installed on a wire

2.1. North Dakota Test Site

The test site chosen for this research is situated near the Audubon National Wildlife Refuge, located approximately two miles north of Coleharbor, North Dakota (Figure 3). The triple-circuit line extends along the Audubon Causeway and parallels U.S. Highway 83 (Figures 3 and 4), which bisects Lake Sakakawea and Lake Audubon. This site was selected because it has a history of known bird collisions. Pedestrian surveys for avian fatalities along the causeway were conducted in 2001 and 2002, documenting 885 bird carcasses, representing over 90 species (CEC 2003). The unusual abundance of bird fatalities coupled with the diverse array of area species provide an opportunity to collect sample sizes adequate for data evaluations and comparisons. The North Dakota study site was selected because it had a documented history of bird collision problems and many of the migratory bird species found in North Dakota also occur in California. The project site also offered a unique opportunity because it is located at a national wildlife refuge with staff willing to assist with the field work and with utility partners agreeing to allow installation of bird strike indicators on energized conductors.

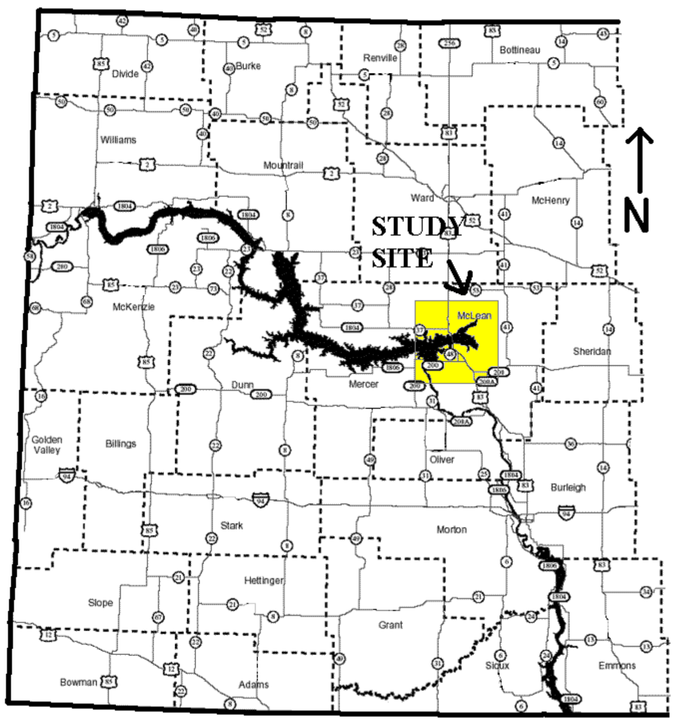


Figure 3. Study site location in western North Dakota

Figure 4. Photograph of the North Dakota test site, looking north

There are 13 transmission spans, each approximately 1000 feet in length, crossing the causeway. Each span consists of 11 wires, as shown in Figure 5. The top two wires are shield wires for lightning interception, the next two sets of three vertical wires are the double-circuit, 115 kV transmission line. The bottom three horizontal wires are a 41.6 kV circuit. In this report, the spans are numbered from 1 to 13, beginning at the south end of the causeway (Figure 6). The numbering begins with Western's structure 12/5, indicating this structure is the fifth structure in Mile 12. Western's numbering continues north to structure 14/6, the sixth structure in Mile 14. The causeway also supports a railroad line, paralleling the highway.

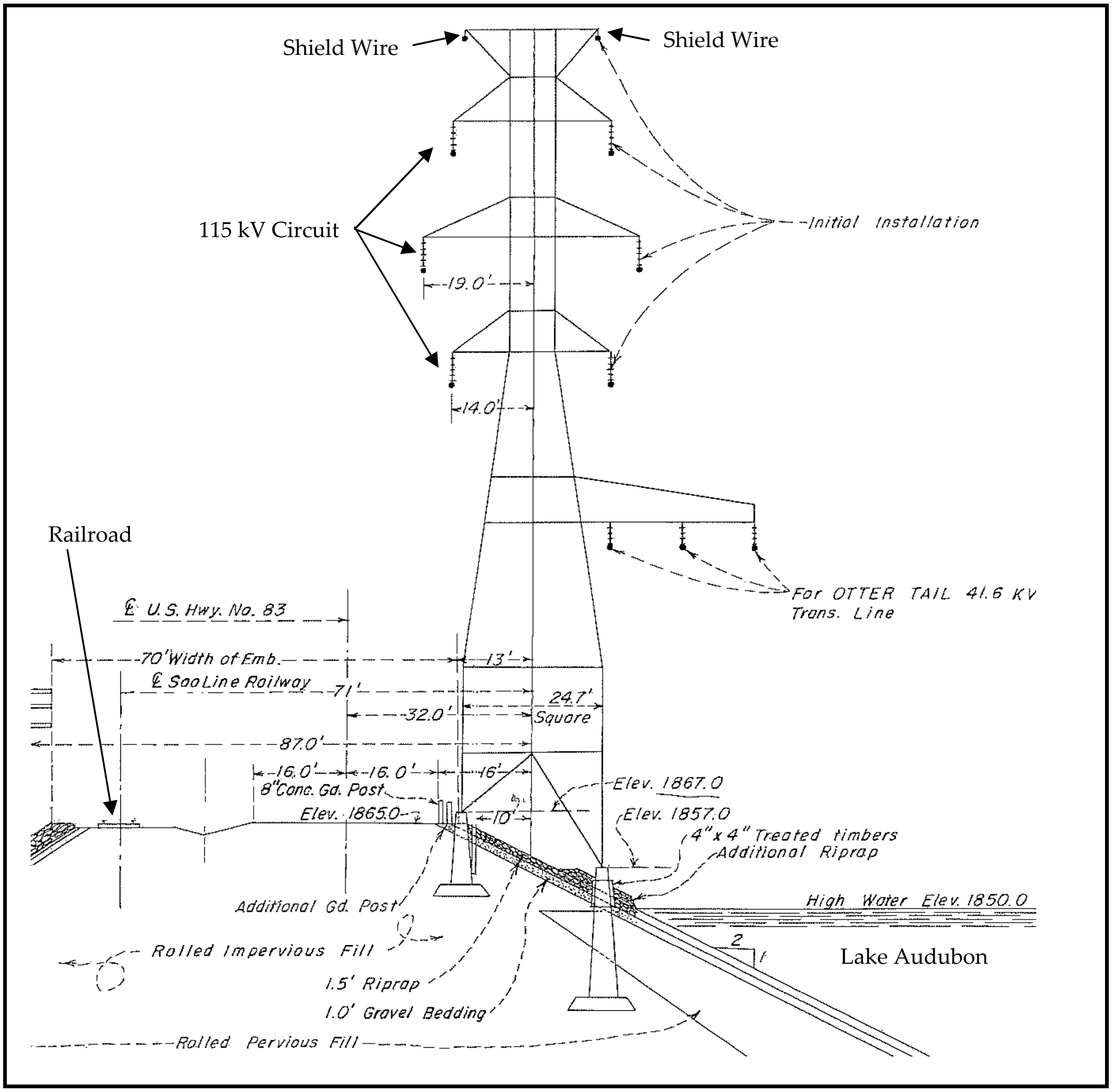


Figure 5. Cross-sectional diagram of the transmission line looking north
(Courtesy of Western)

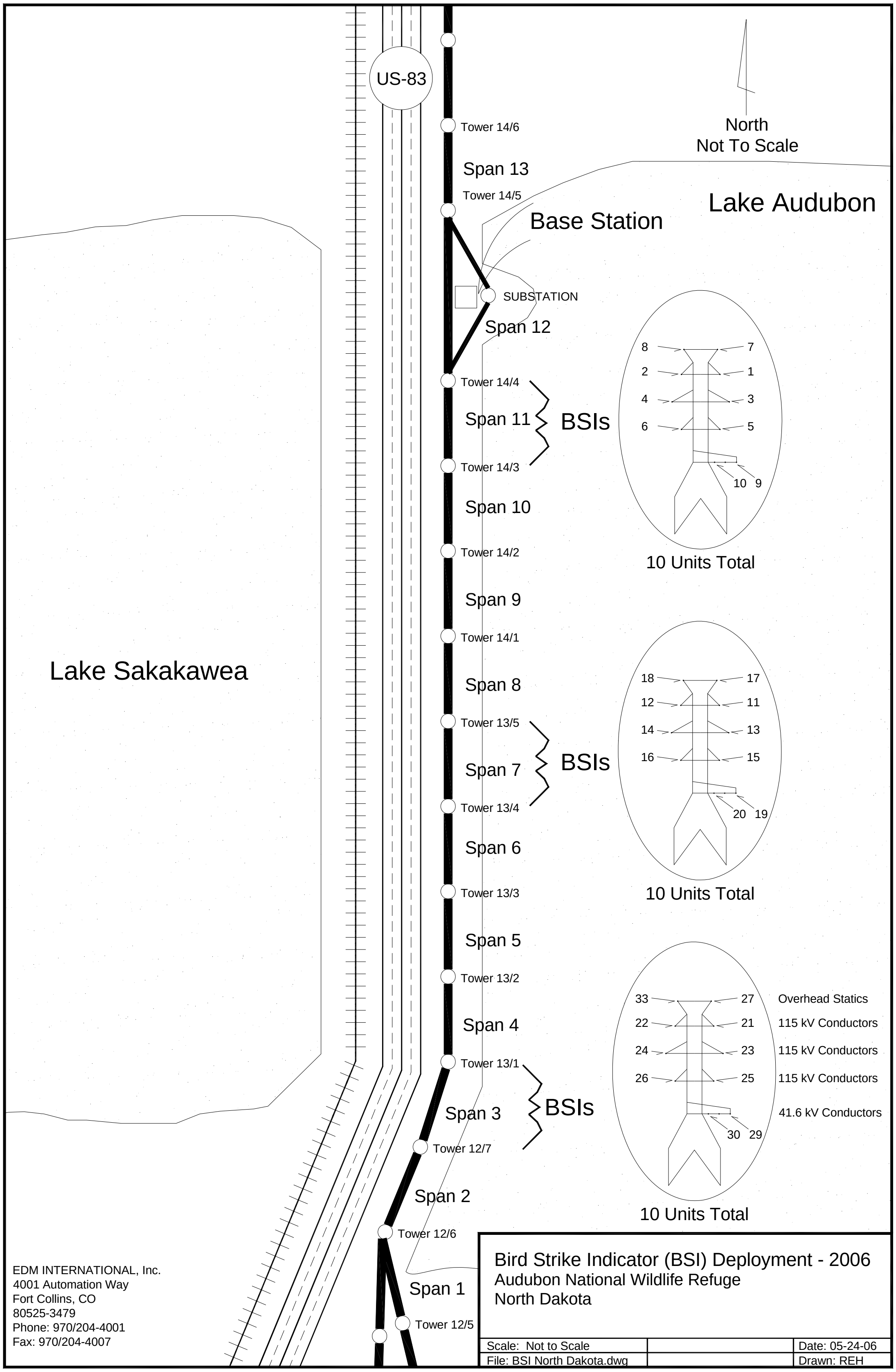


Figure 6. BSI sensor installation detail for the North Dakota field trials

2.2. BSI Fabrication and Installation

Bird strike indicator prototypes were first developed and tested by PIER-sponsored projects with PG&E and EPRI. EPRI later obtained a patent for the BSI. For this project EPRI licensed 30 BSI sensors and one base station to EDM International. EDM fabricated, calibrated, and tested the sensors and a base station from late 2005 to early 2006.

Each BSI sensor has two low power consuming accelerometers for monitoring vibration. These accelerometers are similar to ones used to trigger airbags in automobiles. Each of the BSI sensors also incorporates a small wireless radio to transmit the recorded vibration data to a base station. Bird strike indicator sensors are powered using four size-D primary lithium (non-rechargeable) batteries. There are two analog filters built into the sensor to filter 60 hertz (Hz) noise and also to remove very low-frequency signals. In addition, BSI firmware filters certain weather related events, such as precipitation falling directly on the sensor, which produces a very unique signature. These events are filtered out and are not recorded or transmitted by the sensors to the base station. The units are fitted with proper hotline clamps based on the wire diameters. The sensors for the six 115 kV transmission wires require a bigger clamp compared to the other wires because of their larger diameter.

A base station consists of a laptop computer with an uninterruptible power supply (UPS), wireless radio, and high gain Omni-directional antenna. A graphical user interface (GUI)-based application is used on the laptop to communicate with the BSI sensors and to log all the collected data. The primary function of the base station is to receive strike signals. If and when any vibration data exceeding a set threshold is detected by the sensors, the information is automatically transmitted to the base station and logged. Each vibration record is time stamped and logged by sensor ID and date on the computer. Additionally, the base station receives and logs daily health reports from each BSI sensor, indicating the sensor parameters and their battery health. The base station keeps the clock on each sensor synchronized so the units are never off by more than one minute. Greater detail on the hardware and firmware are provided in a previous report (CEC 2003).

3.0 2006 BSI Field Testing at North Dakota

This study started on April 4, 2006, and ended October 9, 2006. The North Dakota site was selected because of the high rate of bird collisions recorded during previous ground searches (CEC 2003).

3.1. BSI Installation

Thirty BSI sensors were installed on three spans of the transmission lines at the North Dakota study site. The BSI sensors were installed on the 10 wires from a bucket truck using a hot stick, as shown in Figure 7. The BSI sensor was designed to be installed using a hot stick, eliminating the need for initiating a power outage. However, because of the configuration of the wires and the limited access to all wires from only one side along the causeway road, it was necessary to take an outage to install these devices. In addition to the power outage, two road lanes had to be closed for the sensor installation.

Figure 7. Installation of BSI sensors using a bucket truck and hot stick

The three spans selected for monitoring were the third, seventh, and eleventh span from the south end of the causeway (Figure 8). These three spans were selected so that the monitored spans were evenly dispersed on the causeway. The selected spans also had a high likelihood for bird collisions, based on the bird search data collected in the years 2001 and 2002 (CEC 2003), which showed a wide range of bird species previously affected. The three study spans were separated by line sections designed to be used as buffer spans for a future line marking study.

A BSI sensor was installed on 10 of the 11 wires in each span. The only wire not instrumented was the middle wire on the bottom 41.6 kV circuit, shown in Figure 5. This middle wire is parallel to the two outer conductors that were instrumented, and the middle conductor's position minimizes the likelihood of avian collisions. In 2006 all BSI sensors were installed approximately 15 feet north of the existing vibration dampers located on the north side of each structure. This location was selected because of concerns that a sensor mounted in the middle of a span might act as a marking device or bird deterrent, reducing the number of collisions. Figure 8 shows a typical span with all the sensors installed. Installation of the 30 sensors went smoothly and was completed in less than three hours.

After installation, each sensor was turned on and checked to make sure each unit communicated with a mobile base station, as the permanent base station was not yet installed. Once the BSI sensor was turned on, it immediately initiated communication with the base station, received configuration parameters, and synchronized its clock. The strike monitoring command was turned on for each sensor by sending a command automatically from the base station. Although 30 sensors were installed, the sensor numbering is not sequential (Figure 6). Sensor number 28 was the only sensor that did not communicate properly after turning on, and a spare sensor (sensor number 33) was substituted.

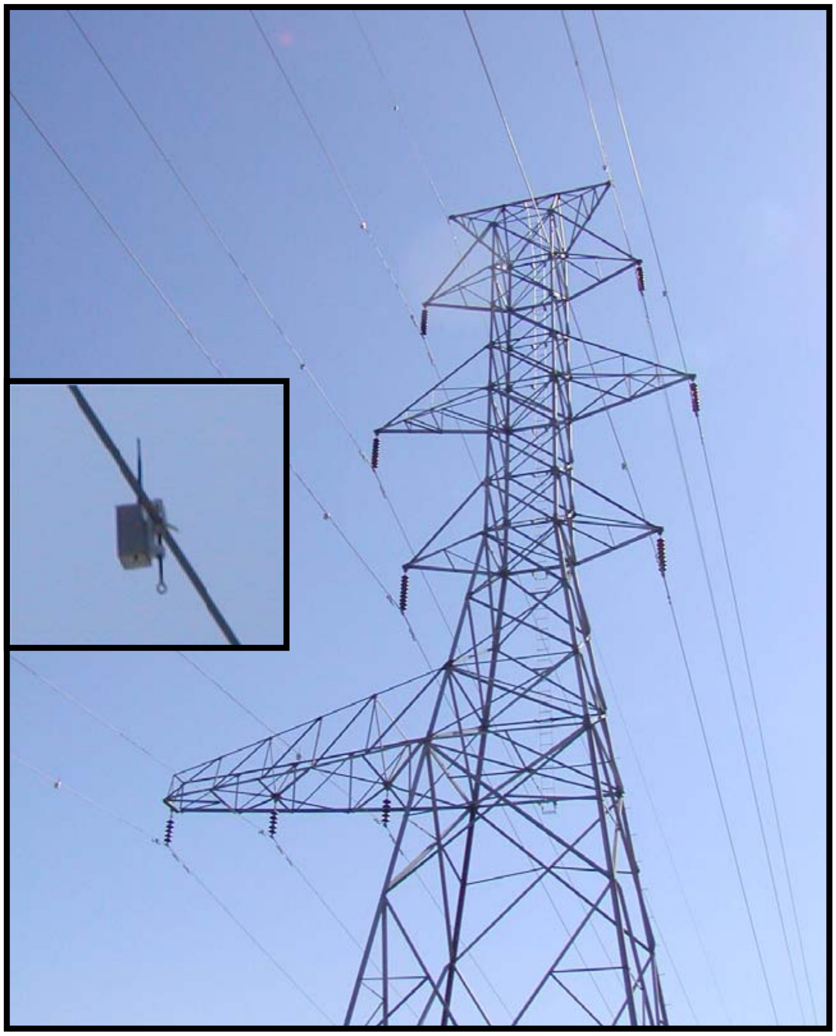


Figure 8. Sensors installed on a typical span at the North Dakota test site

The permanent base station was installed in an insulated communication shack located immediately north of the fenced perimeter of the Snake Creek Embankment Substation (Figure 9). The distance to the farthest sensor was approximately two miles from the base station. The laptop computer, along with the wireless radio and UPS, was placed inside the shack. The omnidirectional antenna was installed on a pipe attached to the nearby fence to increase the height. A dedicated phone line was connected to the laptop for remote access and data retrieval. Software was used to remotely access the base station via the phone line, allowing for complete remote control of the base station and retrieval of the logged data.

Figure 6. Communication shack housing the BSI base station

3.2. Monitoring and Troubleshooting

The BSI sensors are designed to continuously monitor vibrations of instrumented transmission line sections. They detect, record, and then transmit collision data to the base station when a vibration signal at the sensor location exceeds a set threshold. First, a summary of the detected collision information consisting of the date, time, sensor number, and the maximum signal on the two monitored axes is sent to the base station. Immediately following the strike summary data, the actual vibration data in both axes perpendicular to the wire also are transmitted. These vibration data are collected for a one-second duration and are ideal for troubleshooting and to determine if the signal actually represents a bird strike.

In addition to reporting detected collisions, each sensor reports its health to the base station daily at a preset time. The health report includes the parameters set for monitoring collision, the clock time, and battery voltages. The health report is used to ensure the sensors are operating properly, synchronizing their clock, and monitoring each sensor's battery life. As stated, each sensor's clock is kept synchronized to within one minute of the base station clock.

During this test, the base station was linked to a phone line to allow for remote access connection. This link was used to monitor and troubleshoot the BSIs at least weekly and frequently daily. The remote link was regularly used to download logged data for further analysis.

The remote link proved to be particularly useful immediately following BSI installation. During the first week, the BSI sensors detected numerous vibrations with a unique waveform signature not consistent with bird collisions. It was determined these signals were caused by heavy truck and train traffic along Highway 83. The BSIs have a built-in capability to reprogram the parameters for monitoring vibration remotely and the threshold for detecting collision was raised to 750,[1] from the normal threshold of 500 for a three-week period in an attempt to minimize traffic vibrations (the maximum possible amplitude for detecting a vibration is 2048, which corresponds to approximately 10 *g* of acceleration). It was subsequently determined that bird collisions were still detectable even with ambient traffic vibrations because of the bird collisions' unique signature; therefore, the threshold was dropped back down to 500, which also ensured the ability to detect smaller collision events.

3.3. Field Survey Methods

Dead bird searches and scavenger removal surveys were conducted in tandem with the remote BSI monitoring. Visual flight observations of bird flights were recorded at dusk and dawn to document any actual collisions occurring during these low-light periods. The protocols for the field surveys were similar to that used in the 2001 and 2002 study, as described in a previous report (CEC 2003).

3.3.1. Dead Bird Searches

During previous field surveys, all 13 spans were searched for bird carcasses. In the 2006 study described in this report, Spans 1 and 13 were not included. Access to the previously searched area beneath Span 13 was denied. Span 1 had not been mowed or grazed during the previous summer and there were no plans to remove the high vegetation located along the eastern side of this line span during the 2006 field season. Since the grass height would decrease searcher efficiency, Span 1 was not included in the study, as it would likely result in artificially low carcass observation and collision numbers. The elimination of these two terminal spans allowed for the field observations to be condensed into a three-day cycle (A, B, and C). Cycle A included Spans 2, 3, 4, and 5; Cycle B included Spans 6, 7, 8, and 9; Cycle C included Spans 10, 11, and 12.

3.3.2. Scavenger Removal Study

To estimate the effects of survey biases from both scavenger removal and searcher observations, bird carcasses retained for this purpose were marked and placed in areas beneath the transmission line typically surveyed by the field personnel. The planted birds were monitored by field personal to determine how many are removed by scavengers. The method for planting birds for the 2006 scavenger removal study season was originally designed to follow the protocols outlined in a previous report (CEC 2003). However, this protocol was altered because of two factors: high on-site scavenging rates and a lack of on-site staff.

The primary factor was directly linked to high on-site scavenging rates. After the initial carcasses were planted using random times and locations , the pedestrian surveyors failed to recover any planted birds. A concentrated effort was then initiated to recover the remaining planted birds using a Trimble global positioning system (GPS) unit. Despite these efforts, no planted carcasses were found or recovered. It was assumed the high rate of removal was from predator scavenging; therefore replanting birds would be of limited value. Additionally, a high

[1] These numbers are a relative amplitude of vibration.

scavenging rate would affect carcass retrieval from birds colliding with the line during the 2006 field surveys.

The second factor was the lack of additional on-site staff to continue the steady rate of carcass planting. The time required to replant the carcasses using the same methods was too substantial to meet the project requirements with the given staff. Consequently, bird carcass planting was discontinued and methods to trap area scavengers were developed.

After obtaining authorization from the Audubon Refuge staff, trapping began on June 19, 2006, and ended October 9, 2006. Five raccoon and two mink traps were placed around areas with signs of scavenged birds and area predators (e.g., scat or tracks). Traps were placed along Spans 2, 7, 9, 11, 12, and at an offsite location, Schaeffer Pond. Various types of baits were used, including sardines, jackal, fish oil, "Plum Crazy," and carp. On average, the traps were baited once every work cycle. Table 1 presents a trapping summary.

Table 1. Trapping summary

Date	Trap Number	Species Caught	Bait used
6/21/06	1	Raccoon	Jackal
7/3/06	2	Raccoon	Sardines
7/8/06	2	Beaver	Sardines
7/15/06	6	Skunk	Carp
7/16/06	5	Skunk	Carp
8/8/06	3	Skunk	Carp
10/3/06	2	Raccoon	Carp
10/8/06	1	Feral cat	Carp

After scavenger trapping was initiated, all planted birds were recovered by the pedestrian surveyors. The trapping reduced the scavenging rate of bird carcasses along the causeway and allowed the pedestrian surveyors to search for and recover planted birds for the surveyor bias study. The placement of the planted birds followed the October 2003 Interim Report (CEC 2003) protocols, but the frequency of planting was altered, as well as the numbering system. Summer staff at the refuge was trained to plant birds according to a specific schedule. After the trapping, no carcasses were removed due to scavenging, reducing the bias to zero.

3.3.3. Necropsy Technique

Necropsies were performed on all recovered carcasses, excluding those carcasses that were uncollectible (i.e., flattened by vehicles, feather spots, or decayed beyond recovery). The techniques used to perform the necropsies were the same as those used in the 2003 Report (CEC 2003).

3.4. BSI Removal

The BSI sensors were removed prior to winter, after being operational for approximately six months. When the Western line crew was able to remove all sensors, the BSIs were shipped back to EDM for analysis.

3.5. BSI Performance

There are several parameters used to determine the mechanical/electrical performance of the BSI sensor system. These parameters are classified into four categories: installation/removal requirements, physical performance on energized wires, sensor communications, and battery life.

3.5.1. Installation/Removal Requirements

This study of the BSI sensor system was the first to be completed on an energized power line. Prior to this project, the BSI sensors had been tested only on communication tower guy wires. The installation of 30 BSI sensors on the power line went very well and was accomplished in less than three hours by Western's line crew using a bucket truck and hot stick. An outage was taken to install the BSIs, because of the unique right-of-way (ROW) configuration limiting access along both sides of the lines. Normally an outage would not be necessary. EDM participated in the installation; however, Western's crews independently removed the sensors.

3.5.2. Physical Performance on Energized Wires

The sensors were on the North Dakota lines for approximately six months. Immediately after receiving the sensors back from the field, their physical condition was examined for any damage. The inside of each box also was examined for moisture, damage, or deterioration.

The overall physical condition of the sensors was very good, with no sign of external damage except for the tips of the plastic antennas. The antenna tips on the 18 sensors installed on the energized 115 kV wires, as well as the tip on one other unit, were noticeably degraded. The degradation did not have any effect on the performance of the sensors in the field, as the sensors continued to communicate with the base station throughout the entire monitoring season. The cause of damage on 18 sensors was likely due to electrical corona activity on the energized conductors. The magnitude of corona increases with increasing voltage, which would explain the damage to the 18 sensors installed on the 115 kV wires. This type of damage was not noted on units mounted on the shield wires or on the lower voltage 41.6 kV wires. One sensor installed on the lower 41.6 kV wire showed some damage, but it was different from the other antenna damage. Whereas the antennas on the 115 kV wires showed significant fraying on the antenna tips, the unit on the 41.6 kV wire had a small break at the tip. The cause of this break is unknown. Based on these results, any BSI unit to be installed on a line equal or greater than 115 kV should have a metal antenna with no sharp tips, e.g., an antenna with a small spherical ball at the top. An alternative is to use a plastic antenna with a reinforced tip.

Four out of the 30 sensors showed some sign of condensation in the inside bottom of the box. Two of the four had very light condensation, consisting of a light fogging with no visible water droplets. The remaining two had moderate condensation consisting of a few small water droplets. Moisture may have entered around the switch mounted at the bottom of the sensor. Greater precaution during future fabrication should ensure the area around each switch is properly sealed.

After the sensors were removed they were subjected to a recalibration test to evaluate their sensitivity in detecting strikes after the six-month deployment. Ten sensors had low sensitivity in one or both axes. Although the accelerometers were attached to the box using specialized glue designed for very high temperatures, investigation showed that in some accelerometers the glue had failed. In four BSIs both accelerometers had become unglued. Six sensors had one of their two accelerometers unglued. Of these six units, four of the unglued accelerometers were units measuring vibration in the horizontal axes. This is a significant factor, because the primary axis for detecting bird collisions is the horizontal axis. Therefore, a total of eight out of the 30 sensors stopped monitoring collisions at some point after the accelerometers became detached. Table 2 provides a list of the sensors where the glue failed on the accelerometers.

Although the glue was designed for high temperatures, nine of the 10 units with detached accelerometers were mounted on the high voltage, 115 kV wires. The remaining unit was on the 41.6 kV circuit. None of the units on the static wires experienced glue failure.

Table 2. BSI sensor accelerometer condition summary

BSI Sensor No.	Accelerometer Condition			Last Day of Strike Reporting		
	Horizontal Axis	Vertical Axis	Total Recorded Strikes	Sensor Location	No. Days after Installation	Date
3	Unglued		0	115 kV Wire		
5		Unglued	0	115 kV Wire		
10	Unglued	Unglued	3	41.6 kV Wire	120	8/2/2006
12	Unglued	Unglued	0	115 kV Wire		
13	Unglued		0	115 kV Wire		
15		Unglued	0	115 kV Wire	4	4/8/2006
21	Unglued	Unglued	0	115 kV Wire		
22	Unglued		7	115 kV Wire	144	8/26/2006
23	Unglued		0	115 kV Wire		
24	Unglued	Unglued	0	115 kV Wire		

The strike data log was searched to determine the last day any of the sensors listed in Table 2 reported a strike event. This was done because the accelerometers likely became detached either on or after this day. Of the three sensors that reported strikes, one sensor reported strikes only during the week of installation. Two sensors reported strikes as late as August. The remaining seven sensors never reported any strike events. However, this does not mean the sensors were defective from the beginning of the project, as other sensors with properly glued accelerometers similarly never reported strikes. Other than the two sensors that reported strikes in August, it is not possible to determine when the accelerometers might have become detached and thus stopped monitoring collisions.

There are several possibilities to explain why the accelerometers became detached where glued. The first involves the process of installing the accelerometers. Inadequate surface preparation and curing time prior to installation may have contributed to the failures. The second possibility is that aeolian vibration in the power line might have caused the failures. This line may also have experienced high thermal loading over the summer months. However, these causes cannot be confirmed. Nonetheless, future installations will need to be rigorously inspected to minimize the likelihood of this failure type. Using accelerometers that can be mounted without glue also should be investigated.

3.5.3. Sensor Communication

The BSI sensors are designed to communicate to the base station daily to report their health, synchronize their clocks, and communicate whenever they detect any strike signals. Bird strike indicator sensor communications worked very well throughout the monitoring season, with 28 sensors reporting their health daily, as programmed. Two sensors (BSIs 4 and 24, mounted on 115 kV wires) unexpectedly stopped communicating with the base station 19 days after installation. At the end of the project the batteries for both these sensors tested positive. Additionally, they communicated properly after being taken down from the lines and rebooted. These two sensors likely experienced a firmware lockup and could not be remotely restarted by the firmware, as designed. These two sensors required a hard reset by turning the power off and then on, which is not typically feasible when installed on overhead lines without mobilizing line crews. It also should be noted that sensor 24 was one of the four units where both accelerometers became unglued for unknown reasons. Additionally, although both these units were on different towers, they were both located on the same 115 kV circuit wire.

In addition to reporting their health, the sensors also transmitted strike signatures consisting of both horizontal and vertical axes vibration data. The sensor communications during strike reporting worked very well, especially considering the large amount of strike data that needed to be transmitted during these communications.

3.5.4. Battery Life

Each sensor contains two sets of batteries. One set powers the radio; the second set powers the other electronics, including the accelerometers. The BSI sensors were designed with a battery life of six months. All sensors' radio batteries exceeded the six-month design life and were still operational when the sensors were removed from the North Dakota site. The average battery life for the accelerometer batteries was 5.8 months, with 10 of the 30 sensors still showing battery capacity to continue working past the day of planned removal of the sensors from the site. Table 3 summarizes the battery performance for all the BSI sensors. Battery voltages highlighted in red in the table indicate low voltage. Sensor 4 and 24 had firmware lockup 19 days after installation and are also highlighted in red.

Table 3. Battery performance of the BSI sensors

BSI Sensor No.	Last Day of Health Reporting		Days since installation	Reported Battery Voltage	
	Day	Date		Accelerometer	Radio
1	252	9/9/2006	158	**2.81**	3.44
2	283	10/10/2006	189	3.54	3.58
3	260	9/17/2006	166	**2.82**	3.53
4	**113**	4/23/2006	**19**	3.47	3.54
5	258	9/15/2006	164	**2.86**	3.56
6	283	10/10/2006	189	3.53	3.56
7	267	9/24/2006	173	**2.93**	3.59
8	266	9/23/2006	172	**2.92**	3.53
9	263	9/20/2006	169	**2.96**	3.62
10	235	8/23/2006	141	**2.82**	3.23
11	252	9/9/2006	158	**2.94**	3.58
12	257	9/14/2006	163	**2.97**	3.59
13	264	9/21/2006	170	**2.88**	3.53
14	257	9/14/2006	163	**2.98**	3.63
15	258	9/15/2006	164	**2.97**	3.58
16	265	9/22/2006	171	**2.93**	3.60
17	283	10/10/2006	189	3.51	3.55
18	283	10/10/2006	189	3.51	3.55
19	283	10/10/2006	189	3.51	3.56
20	283	10/10/2006	189	3.54	3.58
21	259	9/16/2006	165	**2.95**	3.62
22	283	10/10/2006	189	3.53	3.58
23	254	9/11/2006	160	**2.82**	3.45
24	**113**	4/23/2006	**19**	3.56	3.60
25	256	9/13/2006	162	3.04	3.38
26	283	10/10/2006	189	3.51	3.54
27	283	10/10/2006	189	3.41	3.43
29	262	9/19/2006	168	**2.95**	3.55
30	283	10/10/2006	189	3.50	3.55
33	259	9/16/2006	165	**2.80**	3.54

Note: Red indicates a low battery level or firmware lockup.

3.5.5. Summary of BSI Performance Affecting Strike Monitoring

In summary, nine out of the 30 BSI sensors, listed in Table 4, stopped monitoring strikes at some point during the monitoring season. The majority of these failures were a result of accelerometers coming unglued, thus rendering the sensors dysfunctional. Two sensors stopped functioning 19 days into the monitoring season as a result of a firmware lockup. All of the remaining sensors functioned properly until batteries became depleted on 11 units near the very end of the monitoring season. September 9 was the first date a functional BSI experienced a low battery level (158 days after installation). Sensor 10 had a low battery after 141 days but it was not properly functioning after 120 days due to an unglued accelerometer (Refer to Table 4). The damage to antenna tips of the sensors installed on the 115 kV wires and condensation in a few of the sensors did not affect the field performance.

Table 4. BSI sensors not monitoring strikes

BSI Sensor No.	Estimate of No. of Days Properly Functioning	Cause
3		Accelerometer Unglued
4	19	Firmware Lockup
10	120	Accelerometer Unglued
12		Accelerometer Unglued
13		Accelerometer Unglued
21		Accelerometer Unglued
22	144	Accelerometer Unglued
23		Accelerometer Unglued
24	19	Firmware Lockup, Accelerometer Unglued

3.6. BSI Sensor Collision Recording

The BSI sensors frequently recorded wire vibration data. These data included non-bird collision data such as vibrations induced from the railroad and truck traffic traveling along the causeway. There were also a few weather related events recorded. The BSI sensors also recorded 87 bird collisions. Bird collisions were determined by analyzing the vibration signal or signature recorded for each event.

3.6.1. Bird Collision Signals

Bird collisions produce signal signatures that allow a researcher to clearly distinguish a bird collision from other events. Bird collisions with power lines produce vibrations primarily in the horizontal axis (X-axis). As a bird collides with a power line it pushes the wire generating a slow back-and-forth motion into the wire, which quickly ends. This form is depicted by the transient nature of the vibration signal shown in Figure 10. After the initial strike, the wire recovers from the displaced position and slowly goes back to rest. The vibration signal then travels down the wire and disperses and spreads out, depending on the distance it has to travel to the sensor.

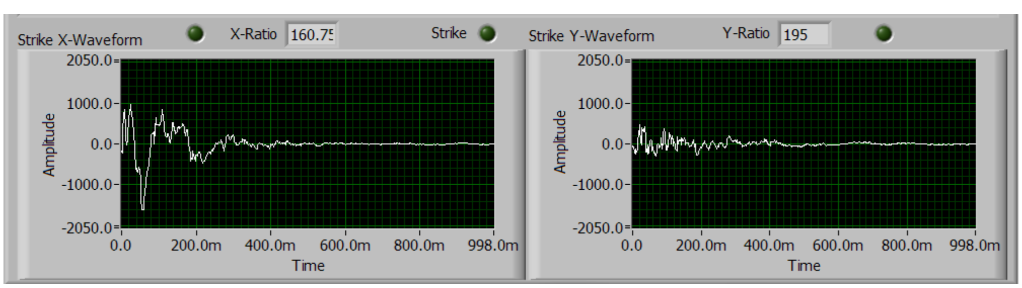
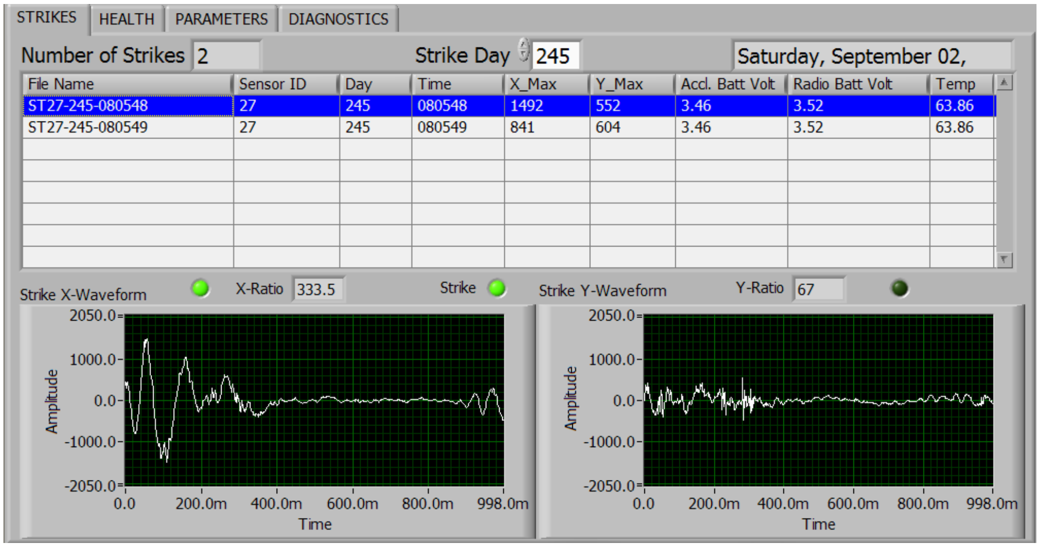
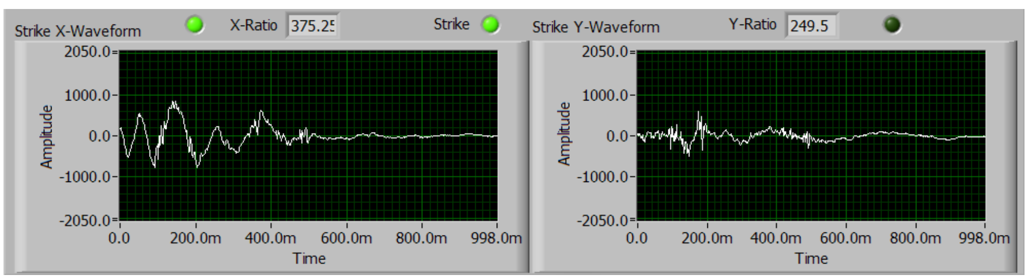


Figure 7. Typical BSI sensor recording for a bird collision with a power line in the X-Axis (left graph) and in the Y-Axis (right graph)

Another example of bird collision recordings is shown in Figure 11, along with a second event recorded within one second of the first event, as shown by the time stamp. The beginning of the second event is initiated at the end of the horizontal (X-axis) vibration signal recording for the first event. The second event could be a second bird colliding with the power line in less than one second after the first collision. However, it is possible the second event was a reflection of the first event from the end of the wire span.



(a) Bird collision recording



(b) Possible second collision within one second or reflection from end of span

Figure 8. Two consecutive recordings by BSI sensor 27

A review of all the collision data identified 87 possible bird collisions recorded by the BSI sensors on the three monitored spans during the six-month monitoring season. A summary of the bird collisions recorded by the sensors is provided in Table 5. Sixteen of the recorded bird collisions occurred within five seconds of a previous event recorded by the same sensor. These sixteen collision recordings could either be a second bird from a flock colliding with the same wire or a reflection from the original bird collision.

Table 5. Summary of bird collisions recorded by the BSI sensors

Span	BSI Sensor No.	Wire Type	No. of Collisions	Possible Reflection from Span End
11	8	Shield Wire	3	2
11	10	41.6 kV	3	2
7	17	Shield Wire	17	1
7	18	Shield Wire	26	3
7	20	41.6 kV	3	1
3	22	115 kV	7	1
3	27	Shield Wire	24	5
3	30	41.6 kV	4	1
Total			87	16

Ninety-two percent of the bird collisions (n=80) recorded by the BSIs were on the upper and lower wires (the overhead shield wires and the underbuild). Sensor 22, which is one of the top 115 kV wires immediately below the overhead shield wire on Span 3 (see Figure 12), recorded the remaining seven events. Although detecting most strikes on the upper and lower wires is supported by the observational flight data, these results are confounded by BSI failures on the 115 kV wires at some point of time during the field trials (BSIs 3, 4, 10, 12, 13, 21, 22, 23, and 24). Figure 12 is a graphical representation of the strike summary with the number of strikes in brackets. Units with stars indicated failures at some point in the field season.

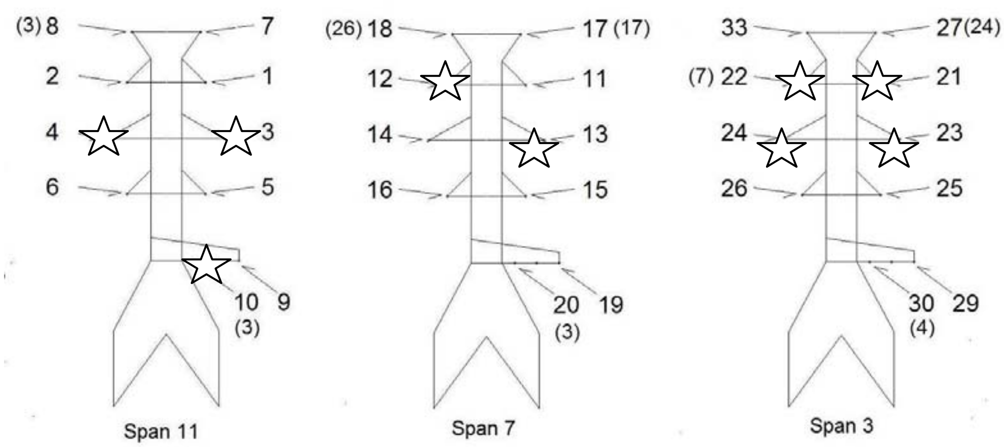


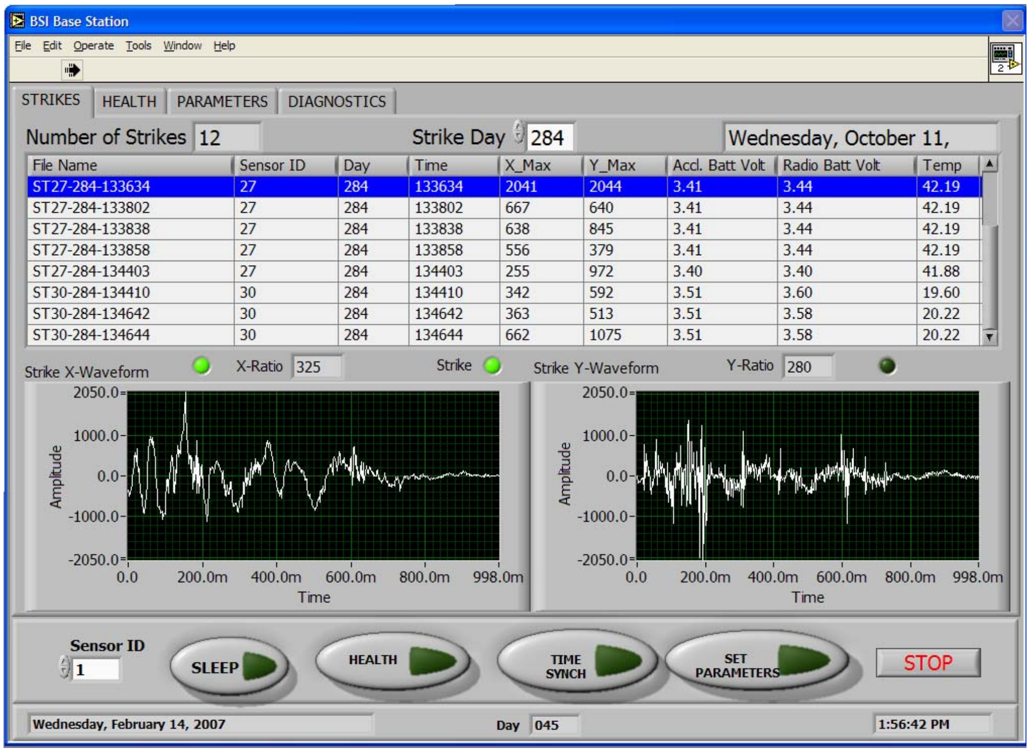
Figure 9. Representation of BSI sensors recorded strikes (number in parenthesis is the number of bird collisions recorded by that sensor). Stars represent units that failed at some point during the field trials.

The pattern of recorded events supports the dawn and dusk line observations. The visual observations noted that birds often responded to the lines with one of two behaviors: (1) to fly over the wires, or (2) to fly under the wires. This response would put the birds at the highest risk as they begin their ascent or descent, and it relates well with collisions recorded by the BSI sensors.

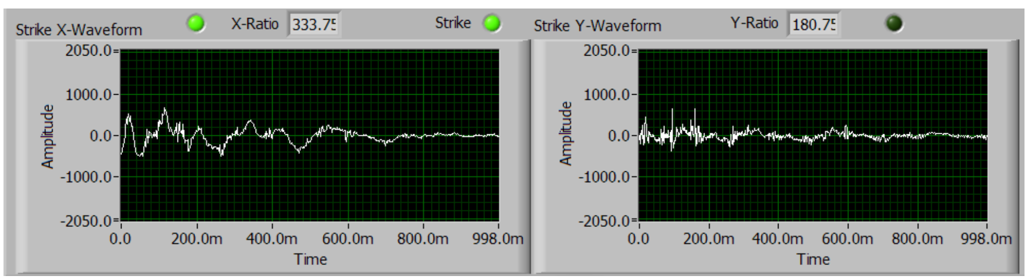
3.6.2. Simulated Strikes

At the end of the project, artificial strikes were initiated to determine if the BSI sensors were capable of detecting collisions at the opposite end of a 1000 ft span. These tests were performed in early October, just before the BSI sensors were removed. Different strike magnitudes were created by hitting the wires with a hot stick. These tests occurred on Span 3 with the wires instrumented with BSI sensor no. 27 (static wire) and BSI sensor no. 30 (41.6 kV wire). It should be noted hot stick strikes are similar but not exactly the same as bird collisions because hot sticks are much stiffer than birds.

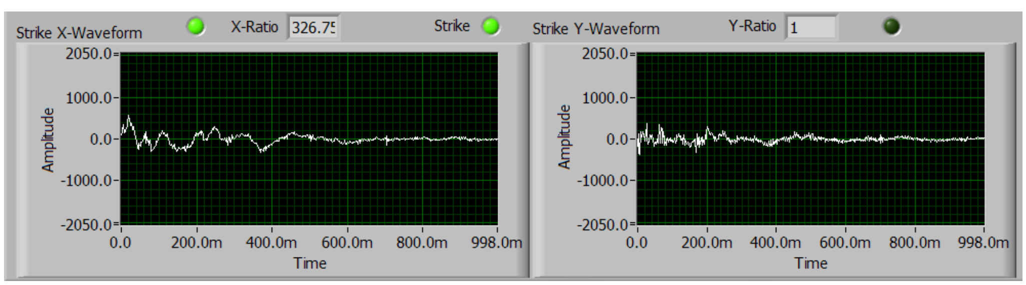
Figure 13 illustrates the simulated strike signals propagated by two different strike levels. The strongest hot stick strike produced a very large vibration signal in magnitude, exceeding the upper scale value. The following two moderate strikes produced consistent results in both strength and vibration magnitude. The moderate strikes, which are closer to what might be expected from bird collisions, resulted in vibration at the sensor with a maximum magnitude of 667 and 638 in the horizontal (X-axis) direction. The threshold above which the sensors were set to detect collisions was 500. This indicates that sensors are capable of detecting events similar in magnitude to a moderate hot stick strike a full span apart from the impact. In contrast, a very light hot stick strike, barely touching the wire with the hot stick, was not detected by the BSI sensors located 1000 feet from the simulated strike, as was expected.



(a) Strong hot stick strike



(b) Moderate hot stick strike



(c) Another moderate hot stick strike

Figure 10. Recorded signals from simulated strikes

3.6.3. Traffic-Induced Vibrations

The North Dakota test site is located parallel to a four lane highway and a railroad track (Figure 6). As discussed in Section 3.2, soon after the BSI installation, traffic-induced vibrations produced numerous vibration recordings. Because the BSIs use batteries to transmit strike data, there was concern these traffic events could drain the batteries before the end of the six-month project period. Therefore it was decided to reset the strike threshold to minimize these events. Accordingly, the threshold for collision detection was increased from 500 to 750. The higher threshold did significantly reduce the highway traffic-induced recordings but did not eliminate the infrequent railroad traffic-induced collision recordings. After three weeks of field examinations and comparisons, it was decided to reset the BSIs back to 500, which was used for the reminder of the monitoring season.

Train-induced vibrations were separated from bird collision events by analyzing the strike signatures. The signature of train traffic was continuous in nature, resulting in a back-and-forth movement of the wire throughout the one-second recording duration (Figure 14). In contrast to a bird strike, which tapers off after an initial impact, the train caused vibrations continued as long as the set threshold was exceeded.

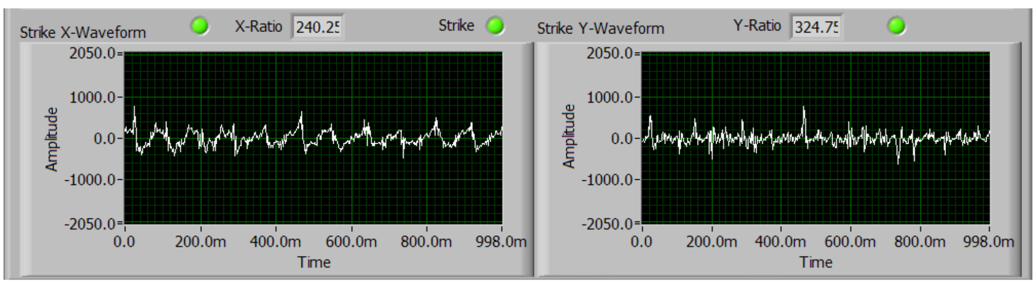


Figure 14. A typical train-induced vibration recording

Bird collisions with wires that were receiving traffic-induced vibrations could result in a difficult-to-interpret combined signature. Not all the BSIs at the study site were affected in the same way by passing traffic. Some sensors were positioned in such a way that they did not record the train-induced vibrations, and bird strikes were even detected during traffic periods. Although this traffic could mask bird collisions, the railroad traffic was limited in duration and on limited days.

Because of the unique nature of the traffic vibration signature, a digital filter could be designed and programmed into the firmware of the BSI sensor to eliminate or at least minimize these traffic-induced recordings. However, most monitoring sites may not have the same traffic problem found at the causeway.

3.6.4. Weather-Related Strikes

Severe weather events, such as hail and extreme high winds, also can produce "strikes" detected by the sensors. Hail hitting the wire or the sensor typically produces a signature primarily in the vertical (Y-axis) direction (Figure 15). These signals are very transient and may just produce a sharp blip.

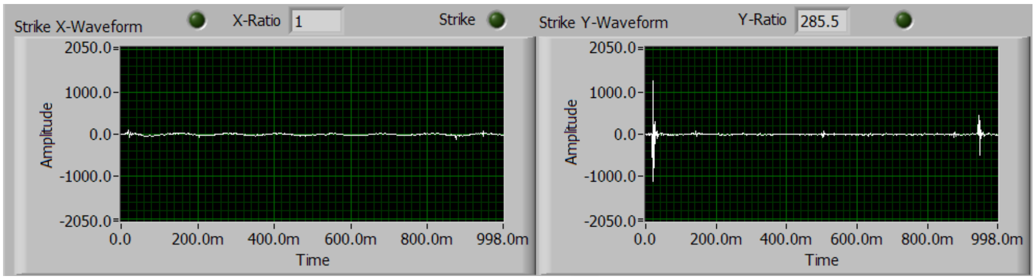


Figure 15. Vibration signature likely produced by hail

Light to moderate winds do not affect the BSI sensors and typically do not result in any vibration recordings. Light winds are 2 or less on the Beaufort Wind Scale (7 mph or less). Moderate winds are 3 to 4 on the Beaufort Wind Scale (8–18 mph). Higher winds can produce vibrations, but a wind-induced vibration signal is transient in nature with very different frequency content than those for bird collisions. As expected, high wind vibrations were noted on the North Dakota site. The day the BSI sensors were to be removed, the causeway was very windy, with wind gusts above 30 to 40 miles per hour (mph) (7 on the Beaufort Wind Scale). Only when wind gusts were extreme did the BSI sensors record any wire vibration (Figure 16). Wind-induced vibrations also have a very different signature, with a higher frequency content.

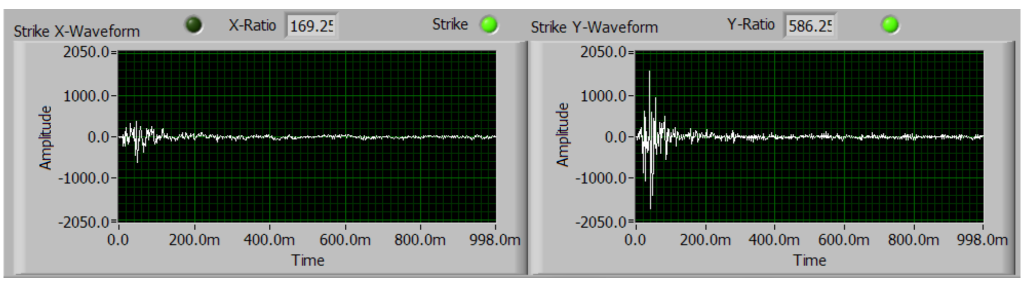


Figure 16. Vibration signature produced by extreme wind gusts exceeding 30 to 40 mph

3.7. Field Survey Results

The 2006 field season began with the installation of the BSIs on April 4, 2006, and ended with the last day of pedestrian survey data collected on October 9, 2006. The field season consisted of 135 days of pedestrian survey data and 180 days of BSI data. A total of 429 bird carcasses were recovered along the causeway during the 2006 field season.

The single species with the greatest number of individuals recovered was the American coot (*Fulica americana*), with a total of 76 carcasses recovered. Table 6 summarizes the 67 known birds species recovered in 2006. Overall, passerines represented the largest species diversity, while waterfowl and shorebirds accounted for the largest carcass sample. The nine most abundant species recovered are listed in bold in Table 6.

Table 6. Bird fatalities recorded during the 2006 field season

Species	Wt. Grams	Number Found	Species	Wt. Grams	Number Found
American coot	**650**	**76**	Longspur sp.	-	1
American white pelican	7,500	6	Mallard	1,100	3
American wigeon	720	1	Marbled godwit	370	2
Bank swallow	**13**	**11**	Mourning dove	120	5
Black tern	62	4	Nelson's sharp-tailed sparrow	17	1
Blackbird sp.	-	2	Northern flicker	130	1
Blue-winged teal	380	1	Northern pintail	800	1
Bobolink	43	4	Northern waterthrush	18	1
Brown-headed cowbird	44	6	Orange-crowned warbler	9	2
California gull	610	8	Pied-billed grebe	450	2
Canada goose	4,500	9	Purple martin	56	2
Canvasback	1,220	1	Rail sp.	-	2
Cedar waxwing	32	3	Redhead	1,050	3
Clay-colored sparrow	12	4	Red-winged blackbird	52	4
Cliff swallow	**21**	**11**	**Ring-billed gull**	**520**	**31**
Common grackle	**115**	**25**	Ring-necked pheasant	1,150	4
Common loon	4,100	1	Sandpiper sp.	-	1
Common tern	**120**	**19**	**Savannah sparrow**	**20**	**14**
Common yellowthroat	10	3	Semipalmated sandpiper	25	2
Double-crested cormorant	**1,700**	**18**	Sharp-tailed grouse	880	1
Downy woodpecker	27	1	Song sparrow	20	3
Duck sp.	-	1	**Sora rail**	**75**	**18**
Eared grebe	300	6	Sparrow sp.	-	7
Eastern kingbird	40	2	Swainson's thrush	31	2
Forester's tern	160	2	Swallow sp.	-	3
Franklin's gull	280	4	Swamp sparrow	17	2
Gadwall	910	6	Tern sp.	-	5
Grasshopper sparrow	17	4	unknown	-	10
Grebe sp.	-	1	Vesper sparrow	26	6
Green-winged teal	350	1	Warbling vireo	12	1
Grey catbird	37	1	Western grebe	1,500	4
Gull sp.	-	3	Western meadowlark	97	1
Harris's sparrow	36	1	White-crowned sparrow	29	2
House finch	21	1	Wilson's phalarope	60	5
Killdeer	95	6	Yellow warbler	9	6
Lapland longspur	27	1	Yellow-bellied flycatcher	11	1
Least flycatcher	10	3	Yellow-headed blackbird	65	7
Lesser scaup	830	1	Yellow-rumped warbler	12	3
Lesser yellowlegs	80	2			

The 429 bird fatalities, encompassing 67 species, recorded during the 2006 field season was roughly the same number of fatalities as the 2001 season (451 dead birds, 63 species) and 2002 season (434 dead birds, 77 species). The species composition is roughly equivalent as well. This parallel may suggest that avian dynamics have remained approximately the same at the site during the four-year period from 2002 to 2006.

3.7.1. Necropsy Technique

The nature of the causeway makes it difficult to discern the cause of death for many of the retrieved birds. Secondary injuries sustained from vehicles may mask power line collision injuries. This uncertainty increases the complexity of correlating collision signatures recorded by the BSI sensors to carcasses on the ground. Whenever possible, necropsies were completed on carcasses collected in 2006. Table 7 presents necropsy results by span, along with numbers of bird collisions recorded by the BSI sensors.

Table 7. Necropsy results by span

Span ID	Spans with BSIs	No. of Strikes Detected by BSIs	Total Number of Bird Fatalities per Span	Cause of Death		
				Power Line	Vehicle	Unknown
2			42	8	18	16
3	**BSIs**	**35**	**49**	**11**	**16**	**22**
4			39	9	17	13
5			28	10	7	11
6			55	17	16	22
7	**BSIs**	**46**	**40**	**9**	**14**	**17**
8			31	4	14	13
9			31	6	13	11
10			44	10	19	15
11	**BSIs**	**6**	**36**	**6**	**19**	**11**
12			34	8	14	12
Totals			**429**	**98**	**167**	**163**
Total for BSI Spans	**BSIs**	**87**	**125**	**26**	**49**	**50**

The distance bird carcasses were detected from each tower was recorded in this study to determine the spatial distribution of carcasses. These data indicate a reduced number of detected carcasses closer to towers (Figure 17) and show a general increase in detected carcasses occurring roughly 250 feet from south towers and roughly 100 to 250 feet from north towers. This general trend suggests birds are flying more frequently near the middle span section, perhaps due to the structure visibility. This trend also suggests that installing BSI sensors closer to the middle of the spans on future projects might increase the likelihood of detecting a greater number of bird collisions. It is not clear why the distribution of birds also increased at approximately 850 and 925 feet.

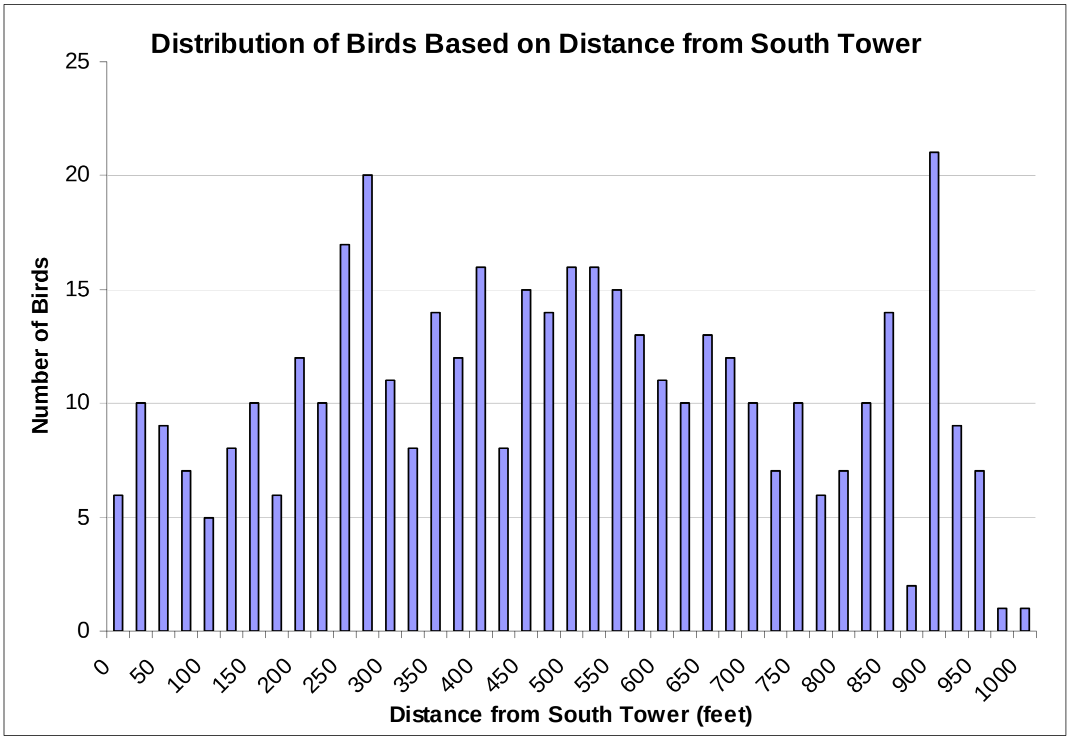


Figure 17. Distribution pattern of dead birds based on distance from tower locations

3.8. Strikes Correlation With Recovered Carcass

3.8.1. Background

The correlation between detected carcasses and BSI strikes are affected by the following factors:

1. Carcass detection biases (searcher bias, scavenger removal bias, habitat bias, crippling bias).
2. Correct diagnosis of cause of death.
3. BSI functionality and sensitivity.

The carcass detection biases were addressed by planting carcasses to determine searcher efficiency and scavenging rates. After it was determined that there was a high rate of scavenging, animals were trapped to reduce this bias. Although searcher and scavenger biases were taken into account, and floating bird carcasses were recovered when possible, bird fatalities were still observed beyond the project's search zone. When birds fall outside the survey area or fly away injured, they are not detected. This is called the *crippling bias*. The crippling bias at this site also may be a significant factor. In APLIC (1994), crippling rates from 73% to 75% were noted, and Crowder (2000) reported a rate of 81.8% at a 345 kV transmission line located in a wetland complex in southern Indiana. These biases were supported by visual project observations, which consisted of four wire strikes where one bird glanced off the wire and flew away to the lake and another bird fell into the lake, but its carcass could not be retrieved.

Correlating BSI strikes successfully with detected carcasses requires a correct diagnosis of cause of death. The Audubon Causeway is a busy stretch of highway where birds collide with both vehicles and wires. In some cases birds may be striking wires and then getting hit by vehicles or run over on the pavement surfaces. Whenever possible, necropsies were done; however, it is possible that the cause of death in some of these cases may have been wrongly attributed and/or power line collisions might have been masked by secondary vehicle collisions.

Proper correlation also requires the sensors to detect collisions. As noted, the BSI sensors were able to detect bird strikes but also recorded train and vehicle traffic and weather throughout the season. Although each of these events have unique signatures to differentiate them, it is possible that traffic events masked some bird strikes. Additionally, the monitors were placed at the end of the spans to prevent them from acting like line markers (bird diverters) and increasing the visibility of the wire. The placement of the BSIs at the end of the spans makes it difficult to detect light collisions at the opposite end of the span. Placing the BSIs mid-span would be preferable from a detection perspective. Lastly, technical problems with some sensors may have precluded detection of some strikes.

3.8.2. Results

The BSI sensors recorded a total of 87 bird collisions in Spans 3, 7, and 11. Sixteen of these events were either dual bird strikes or strike reflections (the result of a wave generated by a strike reverberating back down the line). Eliminating these possible reflections leaves a total of 71 recorded bird collisions.

These numbers relate well with the overall number of carcasses recovered from the three instrumented spans. A total of 125 carcasses were recovered by the field crews at the three monitored spans, of which 76 were identified as either power line collisions (n=26) or unknown collisions (n=50). The remaining 49 carcasses were determined to be from vehicle collisions.

All strikes detected by the BSIs were compared to the carcasses found under the instrumented spans. Following a strike event, the bird carcass records were reviewed for all carcasses detected within two full search cycles. This method allowed nine days for the pedestrian surveyors to locate all birds. By increasing the search effort to two full search cycles, the opportunity for the surveyors to find carcasses was maximized.

Once the nine-day window was established, the carcass records were searched for dead birds found within the allotted time frame. A viable carcass was defined as one adhering to the following parameters:

1. The carcass was collected after the BSI strike time signature.
2. The necropsy determined the fatality was caused by a power line collision or from an unknown cause of death.
3. The carcass record was not already attributed to another strike event.

Most BSI strike records had at least one or more associated carcasses; however, 13 strike records were eliminated, since they did not relate to carcass retrieval. These birds may have fallen outside the search area into the lake, been crippled and flown off, been scavenged, or avoided detection by the surveyors. In some other cases, more birds were found than recorded by the sensors. The maximum number of birds associated with a single strike event was six. It is possible that these birds hit one of the energized wires without a functioning BSI or hit wires and did not trigger a threshold value. It is possible that some birds may have been the victims of vehicle collisions and not the power lines.

Using this process, 35 collisions detected by field searchers were related to the 71 BSI collisions (Table 8). These associations are conservative because they excluded any carcasses identified as victims of vehicle collisions, some of which could be masking wire collisions.

The carcasses that related between the BSI and field searches included 16 birds where power lines were determined to be the confirmed cause of death or injury. These birds consisted of larger birds, such as coots (n=7), gulls (n=3), cormorants (n=2), and a grebe. They ranged in size from approximately 10 ounces (oz) to 3.7 pounds (lbs). However, three small birds, a least flycatcher and two yellow-headed blackbirds, also were recorded.

The data in Table 8 also includes 19 birds where the cause of death was determined to be unknown. These 19 deaths consist of larger birds, such as coots (n=3), gulls (n=4), terns (n=2), ducks (n=2), one loon, and one grebe. They range in size from approximately 4.2 oz to 9 lbs. However, five small birds consisting of two grackles, a bobolink, a clay-colored sparrow, and a common yellowthroat also were recorded. One unknown species also was recorded.

Because of the location of BSI sensors, it is possible that a bird collision at the very north end of an adjacent south span also could be detected and recorded by the sensors. For example, collisions occurring at the north end of Span 2 were very close to the sensors on Span 3. The transmission wires are continuous through each transmission suspension clamp, and it is possible for vibration signals to travel from one span to another, even though the spans are equipped with vibration dampers. This was observed during the installation of the BSI sensors as the sensors detected Western crews replacing vibration dampers on nearby spans. Including detected carcasses from the north end of the adjacent south span also would increase the association between the recorded bird collisions and recovered carcasses.

Table 8. BSI strikes correlated with bird carcasses recovered on the ground

Span	Sensor	Species
3	22	Common loon
3	22	Double-crested cormorant
3	22	American coot
3	22	American coot
3	27	Yellow-headed blackbird
3	27	Yellow-headed blackbird
3	27	Ring-billed gull
3	27	Lesser scaup
3	27	American coot
3	27	American coot
3	27	American coot
3	30	Common grackle
3	30	Franklin's gull
3	30	Double-crested cormorant
7	17	American coot
7	17	Ring-billed gull
7	17	Common tern
7	17	California gull
7	17	Eared grebe
7	17	American wigeon
7	17	unknown
7	18	Least flycatcher
7	18	unknown gull
7	18	Franklin's gull
7	18	Common tern
7	18	Common grackle
7	18	unknown gull
7	18	unknown grebe
7	18	American coot
7	18	Common yellowthroat
7	18	American coot
7	18	American coot

3.8.3. Visual Collision Observations

Visual monitoring was used as part of the field survey protocol to obtain visual confirmation of bird collisions with the wires. This approach was an attempt to relate strike recordings with the BSI sensors.

During the six-month field survey cycle, only three observed collisions were recorded on the test spans, one on each of the three monitored spans. Many collisions were probably not detected because they occurred in low light conditions or outside the observation periods. Thirty-two percent of the bird strikes recorded by the BSIs were between the hours of 22:00 and 04:45. The three observed collisions are described below:

1. Span 11 (BSI sensor 1): The strike occurred on June 13, 2006, at 21:40 on Span 11, approximately 500 feet from the sensor unit. A Canada goose was observed flying into the uppermost 115 kV line on the east side. After hitting the wire the bird glided/flew to water by a distant island.
2. Span 3 (BSI sensor 21): The strike occurred on July 8, 2006, at 16:10 on Span 3, approximately 650 feet from the sensor unit. A Double-crested cormorant was observed flying into the uppermost 115 kV line on the east side. This bird was part of a larger flock. After hitting the wire the cormorant fell into the water, 50 feet from the shoreline.
3. Span 7 (BSI sensor 16): The strike occurred on August 26, 2006, at 12:30 on Span 7, approximately 300 feet from the sensor unit. A California gull was observed flying into the lowermost 115 kV line on the west side. After hitting the wire the gull fell into the rocks on the east side of the highway.

None of these strike events were recorded by the BSI sensors. Additionally, none of these three sensors recorded any vibrations throughout the field monitoring season (e.g., birds, traffic, and weather). According to the post-study review of the BSIs, sensors 1, 16, and 21 were all communicating properly with base station during the time of the observed collisions, indicating that their batteries were charged. However, both accelerometers in sensor 21 were detached at the end of the project, which could explain why the cormorant collision was not recorded. The collision on Span 11 may have not been recorded because of the great distance between the sensor and the bird (500 feet) and the nature of the collision (a glancing hit). For a collision to be detected by the sensors it needs to produce vibration at the sensor exceeding the set threshold for detection. The collision with sensor 16 should have been recorded by the sensor. In this case a large bird hit the wires and fell straight down approximately 300 feet from the sensor. This suggests that there was a problem with this sensor.

3.9. Summary of BSI Sensor Field Testing: 2006

Table 9 provides an overall summary of the BSI sensor testing at North Dakota. The monitoring season lasted 189 days from installation of the sensors on the line until the day they were taken down. Seventeen of the 30 BSI sensors recorded vibration events, and eight of those seventeen recorded bird collisions. Twenty-eight sensors were operational until close to the end of the monitoring season, with an average battery life of 5.8 months. Two sensors had firmware lockup very early on—19 days after installation—and were not operational after that. X-axis accelerometers on eight sensors came unglued, making them unable to monitor bird collisions.

In addition, all the 18 sensors installed on the 115 kV wires had their plastic antenna tip disintegrate as a result of corona activity. However, this did not affect their performance and the sensors continued to communicate with the base station. Four sensors had some condensation on the inside of the box resulting from moisture ingress through the switch at the bottom of the sensors.

Table 9. Summary of BSI sensor performance and vibration recordings during field monitoring season at North Dakota

BSI Sensor	Wire Voltage	Antenna	Condensation	Accelerometer		Sensor Stopped Functioning		Vibration Recordings	
				X-Axis	Y-Axis	Days since installation	Cause	Bird Collisions	Other
1	115 kV	Tip Broken	Light			158	Low Voltage		
2	115 kV	Tip Broken				189			Yes
3	115 kV	Tip Broken		Unglued		166	Low Voltage		
4	115 kV	Tip Broken	Moderate			19	Firmware Lockup		
5	115 kV	Tip Broken			Unglued	164	Low Voltage		
6	115 kV	Tip Broken				189			Yes
7	41.6 kV					173	Low Voltage		Yes
8	41.6 kV					172	Low Voltage	3	Yes
9	41.6 kV					169	Low Voltage		
10	41.6 kV		Light	Unglued	Unglued	141	Low Voltage	3	Yes
11	115 kV	Tip Broken				158	Low Voltage		
12	115 kV	Tip Broken		Unglued	Unglued	163	Low Voltage		
13	115 kV	Tip Broken		Unglued		170	Low Voltage		
14	115 kV	Tip Broken				163	Low Voltage		
15	115 kV	Tip Broken			Unglued	164	Low Voltage		Yes
16	115 kV	Tip Broken				171	Low Voltage		
17	41.6 kV					189		17	Yes
18	41.6 kV					189		26	Yes
19	41.6 kV	Tip Broken				189			Yes
20	41.6 kV					189		3	Yes
21	115 kV	Tip Broken	Moderate	Unglued	Unglued	165	Low Voltage		
22	115 kV	Tip Broken		Unglued	unglued	189		7	Yes
23	115 kV	Tip Broken		Unglued		160	Low Voltage		
24	115 kV	Tip Broken		Unglued	Unglued	19	Firmware Lockup		
25	115 kV	Tip Broken				162	Low Voltage		Yes
26	115 kV	Tip Broken				189			Yes
27	41.6 kV					189		24	Yes
29	41.6 kV					168	Low Voltage		Yes
30	41.6 kV					189		4	Yes
33	41.6 kV					165	Low Voltage		Yes

4.0 2007 BSI Field Testing at North Dakota

It was decided to continue the BSI tests at the North Dakota causeway in 2007 in coordination with a Western Area Power Administration marking study to further evaluate the performance of the BSI sensors. Prior to this retesting, the design issues encountered in the 2006 season were addressed (CEC 2007). One of the main goals of the 2007 testing was to increase the amount of visual observations in the hope of getting direct correlation between observed bird collisions and BSI-detected collisions.

4.1. BSI Refurbishment

Changes were made to the BSI sensors to address the design issues encountered during the 2006 field trial prior to redeployment. New batteries were also installed in each of the sensors. The most signification changes to the sensor design were in the antenna and the on/off switch. Almost all of the antennas of the sensors installed on the 115 kV lines had encountered failures at the tip because of high corona activity. In addition, there was some moisture ingress in a few of the sensors through the on/off switch at the bottom, and the switch was also a likely source of some corona activity. Figure 18 shows the redesigned 2007 BSI sensor with the new antenna and switch. The new antenna is all metallic, with a spherical tip that helps minimize corona. The switch is made of plastic, has a low profile, and is rounded.

Another major issue encountered with some of the BSI sensors in 2006 was accelerometers coming unglued because of glue failure. This was thought to be a result of improper application of the glue and limited cure time prior to installation. Extra precautions were taken in 2007 when installing the accelerometers, and sufficient time was allowed for the glue to cure.

It also was decided there was no need to monitor vibrations in the vertical direction as bird collisions with a transmission line will result in primarily horizontal vibrations. This was the case with all the bird collision recordings in 2006. Therefore, both the accelerometers were mounted such that they would be monitoring the horizontal, thus providing a backup for each other. This eliminated vibration monitoring in the vertical direction, which would likely eliminate some of the weather-related vibration recordings.

4.2. Field Installation

Thirty BSI sensors were installed on spans 2, 6, and 10 on April 13, 2007, with help of Western line crews. Just like the 2006 installation, the installation of the sensors in 2007 went very smoothly and all 30 sensors were installed quickly. Typical installation of ten sensors on one span took less than an hour. The base station was installed in the same shed as in 2006. An outage was taken on the line prior to installation. The base station became active on April 24, 2007.

Figure 19 shows a typical BSI sensor installed on the 115 kV conductors during the 2007 field trials. The sensors were installed on three spans, as shown in Figure 20. For the 2007 field trials, it was decided to install the BSI sensors near mid-span. This was done because the towers might act as visual markers for the birds and thus, the likelihood of collisions might be greater near the middle section of the span. The installation near the mid-span also would improve collision detection range of the BSI sensors.

Figure 18. Redesigned BSI with metallic antenna and switch

Figure 19. Typical BSI sensor installed on a 115 kV conductor during 2007 field tests

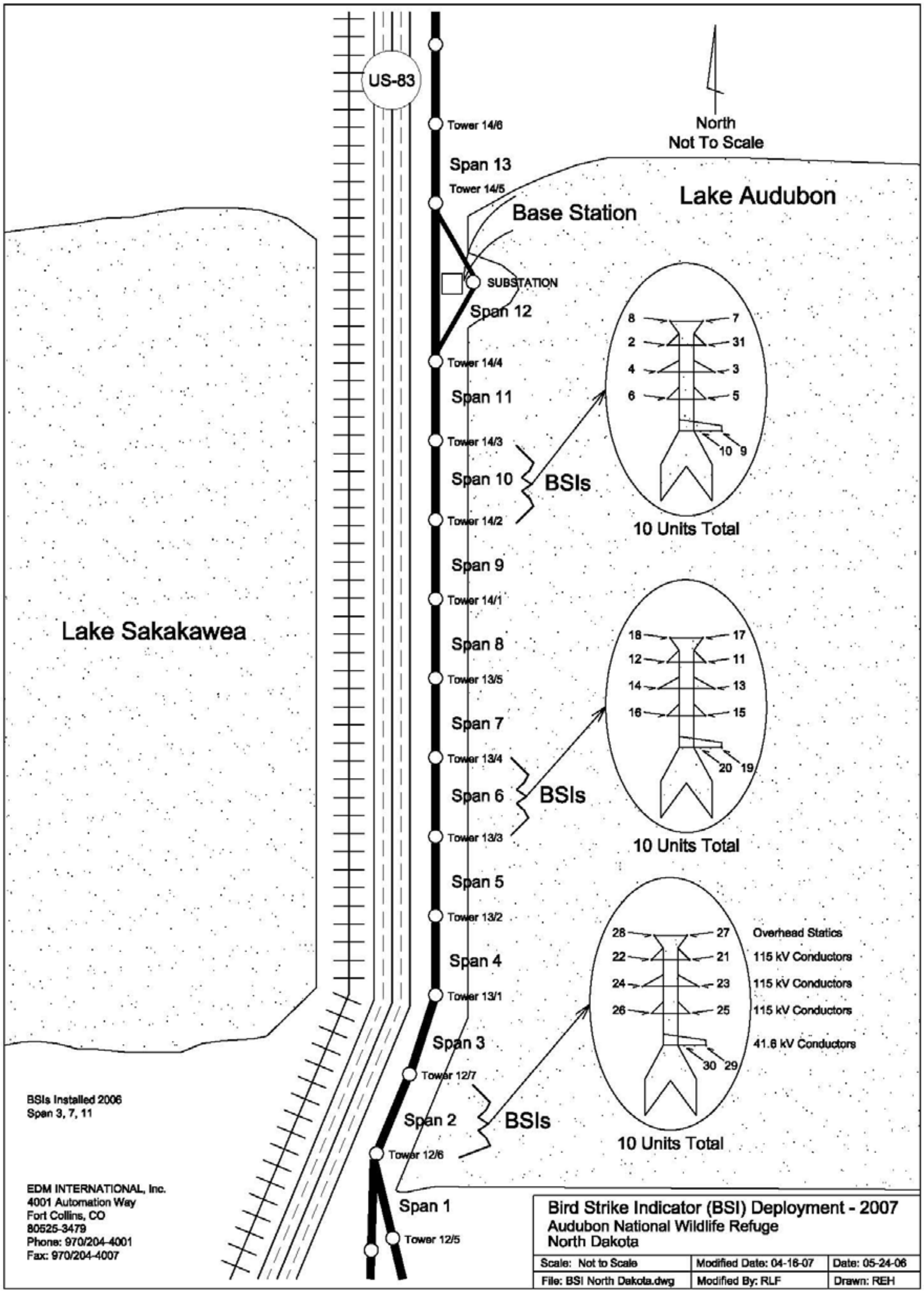


Figure 20. BSI sensor installation details for the 2007 field tests

4.3. BSI Performance

4.3.1. BSI Installation and Removal

The BSI sensor installation and removal process met the design requirements of ease of installation using a hot stick. After removal of the BSI sensors, a visual observation of the wire surface underneath the BSI clamps did not show any sign of damage.

4.3.2. Battery Life

The battery life for most of the BSI sensors exceeded the overall design requirements of six-month battery life. All the sensors' radio batteries exceeded the six-month design life and were still operational when the sensors were removed from the North Dakota site. The average battery life for the accelerometers was 6.6 months, with only 3 of the 30 sensors, highlighted in red in the table below, quitting just a few days before the six month period. Twenty-two of the sensors had battery capacity and continued working past the day of planned removal. Table 10 summarizes the battery performance for all the BSI sensors. Battery voltages highlighted in red in the table indicate a low voltage.

4.3.3. Physical Performance

As the BSIs were taken off the wires, a review of the outside indicated no physical damage. The design changes incorporated in the sensors had completely eliminated the problems identified in the 2006 season due to corona activity at the antenna tips. Further, after opening the lid to evaluate the inside of the BSI sensors, there was no sign of any moisture ingress into any of the 30 BSI sensors. In addition, none of the accelerometers were unglued. Therefore, all the 30 sensors were functional throughout the entire 2007 field trials. Only 3 of the sensors' battery died just before the six month period.

4.4. BSI Sensor Collision Recording

The BSI sensors recorded wire vibration data that were either from bird collisions or weather-related events as a result of factors such as high wind or hail. These recordings included 154 bird collisions on the three spans being monitored. Bird collisions were determined by analyzing the vibration signal or signature recorded for each event.

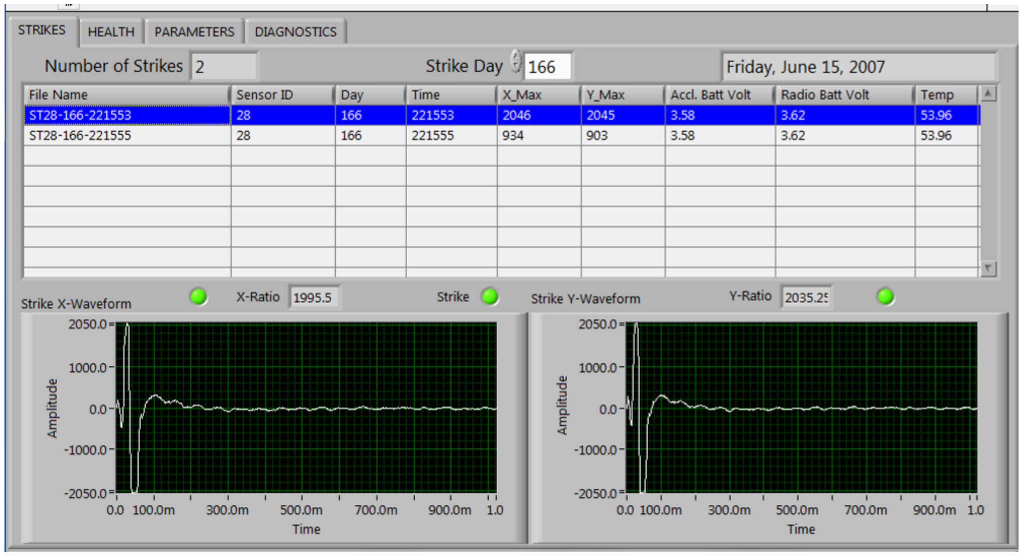
4.4.1. Bird Collision Signals

Review of the vibration signal recordings identified bird collision signals which are unique and different from the weather-induced vibrations. As a bird collides with a power line it pushes the wire, generating a slow back-and-forth motion, which quickly dissipates, into the wire. This form is depicted by the transient nature of the vibration signal shown in Figure 21. After the initial strike, the wire recovers from the displaced position and slowly goes back to rest. The vibration signal then travels down the wire and disperses and spreads out depending on the distance it has to travel to the sensor. The signal might be strong enough to reflect back from the clamps at the span ends and get picked up again by the BSI sensor as shown in Figure 21 (b). Bird collision vibration recordings are slightly different than those from 2006, because the sensor is installed near mid-span. The 2007 BSIs also have both accelerometers mounted to monitor the horizontal plane, as opposed to the 2006 BSIs, where horizontal and vertical signals were recorded.

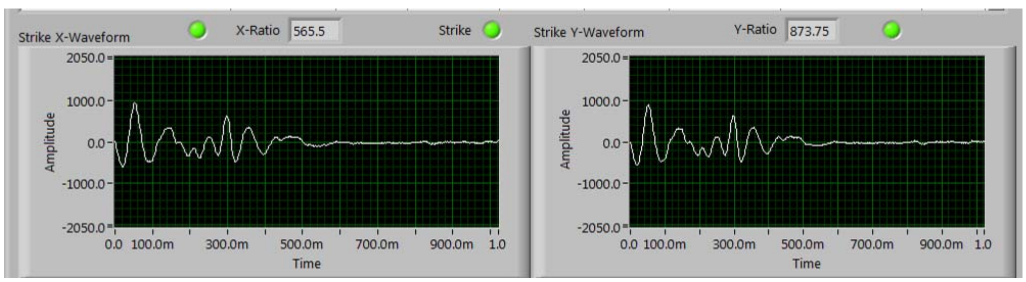
Table 10. Battery performance of the BSI sensors during 2007 tests

BSI Sensor No.	Last Day of Health Reporting		Days since installation	Reported Battery Voltage	
	Day	Date		Accelerometer	Radio
2	309	11/5/2007	206	3.51	3.54
3	297	10/24/2007	194	3.21	3.46
4	309	11/5/2007	206	3.48	3.53
5	266	9/23/2007	163	3.01	3.58
6	309	11/5/2007	206	3.43	3.41
7	309	11/5/2007	206	3.47	3.55
8	279	10/6/2007	176	2.86	3.53
9	309	11/5/2007	206	3.52	3.57
10	309	11/5/2007	206	3.52	3.53
11	309	11/5/2007	206	3.49	3.55
12	297	10/24/2007	194	3.17	3.47
13	288	10/15/2007	185	2.85	3.52
14	309	11/5/2007	206	3.48	3.5
15	284	10/11/2007	181	2.85	3.5
16	275	10/2/2007	172	3.09	3.62
17	309	11/5/2007	206	3.51	3.55
18	309	11/5/2007	206	3.48	3.52
19	309	11/5/2007	206	3.48	3.51
20	309	11/5/2007	206	3.5	3.54
21	309	11/5/2007	206	3.5	3.55
22	309	11/5/2007	206	3.52	3.54
23	302	10/29/2007	199	2.82	3.41
24	309	11/5/2007	206	3.51	3.56
25	309	11/5/2007	206	3.47	3.51
26	309	11/5/2007	206	3.48	3.54
27	309	11/5/2007	206	3.45	3.49
28	309	11/5/2007	206	3.49	3.54
29	309	11/5/2007	206	3.51	3.53
30	309	11/5/2007	206	3.51	3.55
31	309	11/5/2007	206	3.5	3.52

Note: Red indicates a low battery level.



(a) Bird collision vibration signal



(b) Signal reflected from the end of the span

Figure 21. Typical BSI sensor recordings for a bird collision with the power line with sensor installed near the center of the span

Figure 22 shows a vibration recording consisting of two possible bird collisions. This could be two birds in a flock colliding with the same wire within a second.

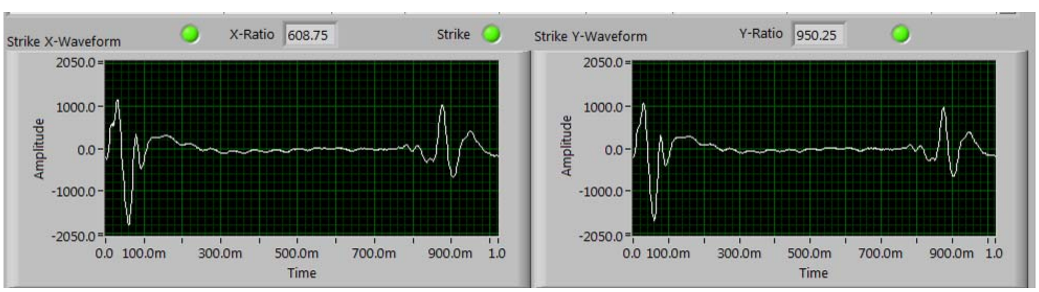


Figure 22. Vibration recording from a likely two-bird collision within a second

Table 11 provides a summary of bird collisions recorded by the BSI sensors broken down by sensor, span, and location. Overall 154 bird collisions were recorded during the 2007 season. The most collisions were recorded on Span 6 (n=68). Span 10 (n=44) and Span 2 (n=42) recorded approximately the same number of collisions. For each of the three spans, most of the collisions were recorded by the top-most sensors, followed by the next two sensors.

Table 11. Summary of bird collision recordings in 2007 by span and sensors

Span	West Sensor No.	West Sensor Strikes	Total	East Sensor Strikes	East Sensor No.
Span 10	8	3	25	22	7
	2	10	16	6	31
	4	3	3	0	3
	6	0	0	0	5
	10	0	0	0	9
		16	**44**	**28**	
Span 6	18	26	52	26	17
	12	3	9	6	11
	14	3	3	0	13
	16	1	1	0	15
	20	2	3	1	19
		35	**68**	**33**	
Span 2	28	22	28	6	27
	22	2	6	4	21
	24	2	4	2	23
	26	1	3	2	25
	30	0	1	1	29
		27	**42**	**15**	
Total		**78**	**154**	**76**	

A breakdown of the bird collisions by wire location are shown in Table 12 and Figure 23. These recordings show that 68% of the collisions were detected on the top most (shield wire) wires, followed by another 20% on the top two 115 kV conductors. The bottom wires recorded very few bird collisions (2.6%).

Table 12. Bird collision recordings in 2007 by wire location

Sensor Location	Wire	Collisions	
		No.	**%**
Top 2	Shield Wire	105	68.18
Next 2	115 kV	31	20.13
Next 2	115 kV	10	6.49
Next 2	115 kV	4	2.60
Bottom 2	69 kV	4	2.60
		154	100

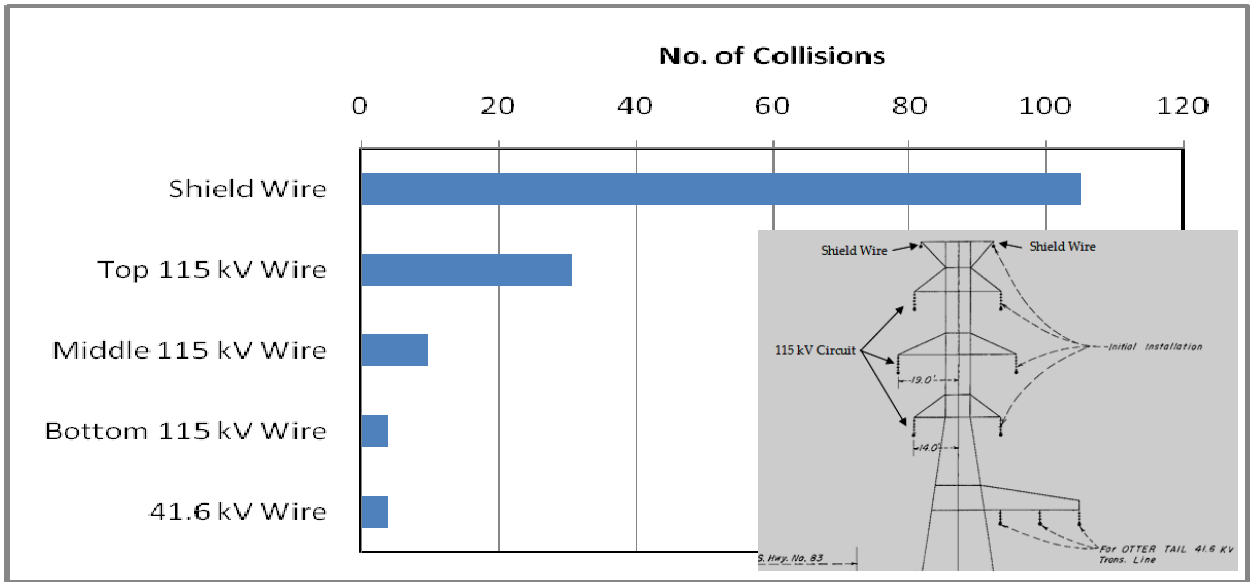


Figure 23. Summary of bird collision recordings in 2007 by wire location

Most of the bird collisions occurred during early morning, evening, and night time as shown in Figure 24. The maximum number of collisions occurred just around dusk, between 21:00 to 22:00. Very few collisions occurred during daylight hours.

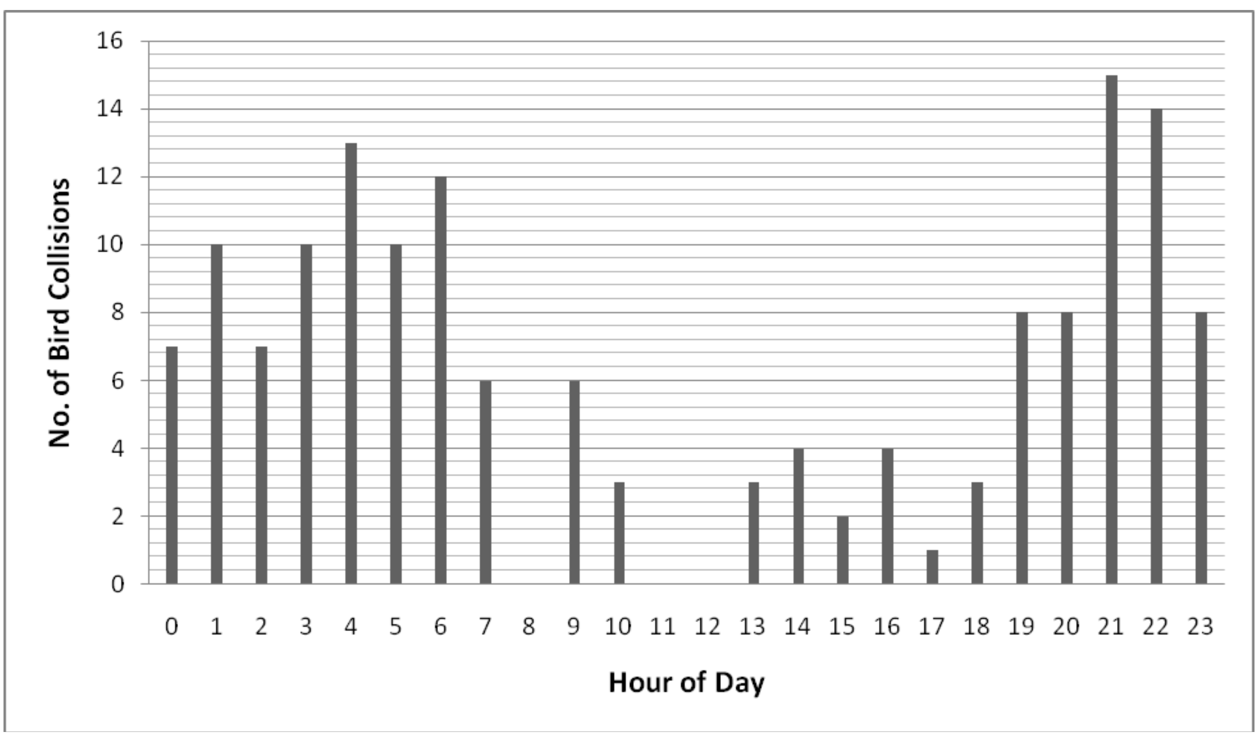


Figure 24. Bird collisions recorded in 2007, by hour of day

In the beginning of the monitoring season, bird collisions were being detected more often on Span 2, but later the intensity of bird collisions picked up on Span 6 and continued at the same pace until the end of the season. Figure 25 provides a representation of the bird collision recordings over the entire monitoring season, by span.

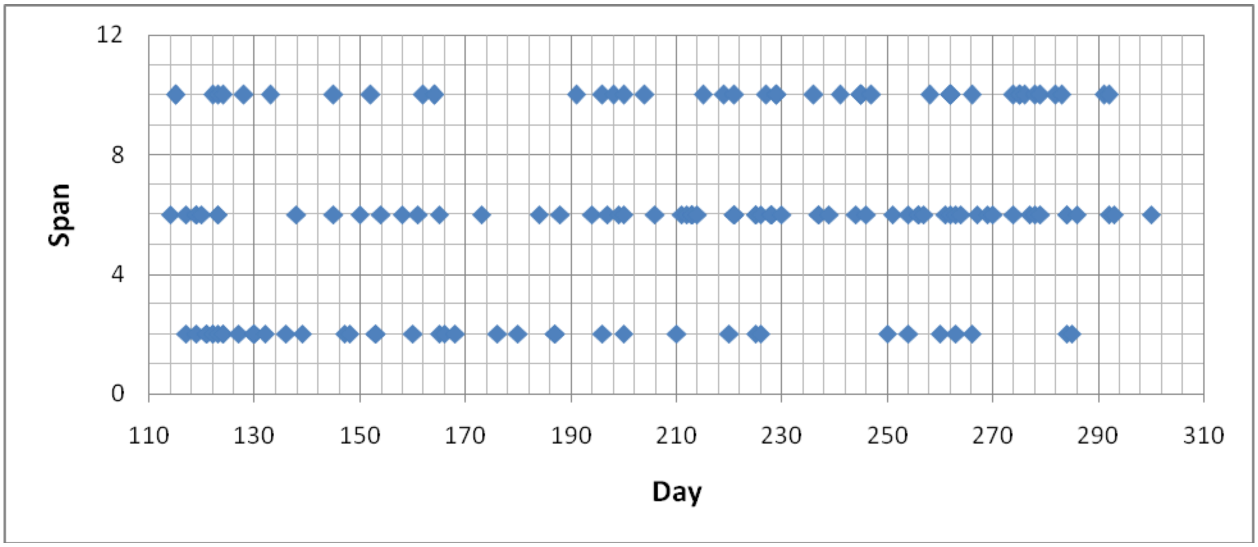
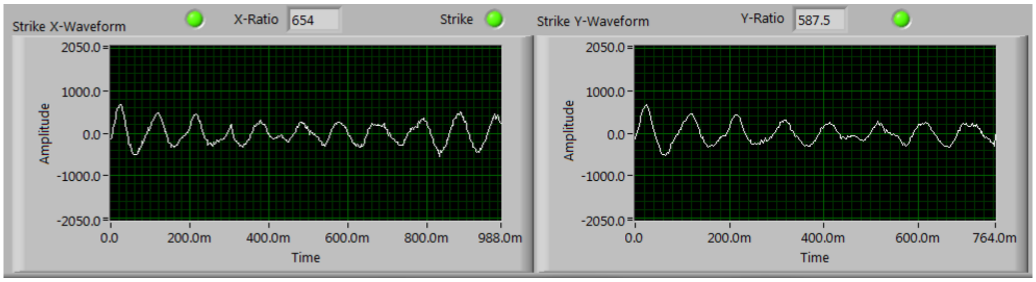


Figure 25. Bird collision recording distribution by day on the three spans

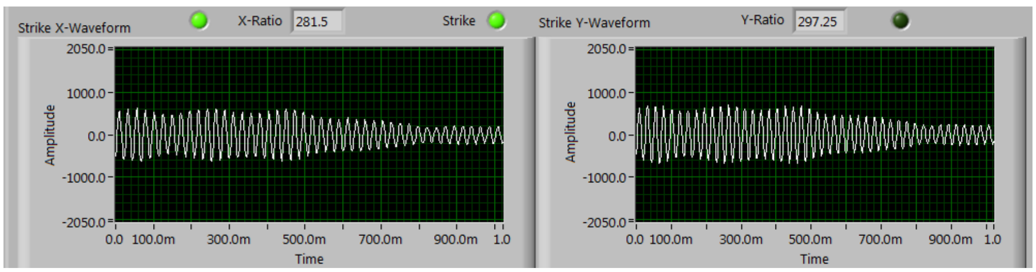
4.4.2. Weather Related Strikes

Severe weather events, such as hail and extreme high winds, produced "strikes" detected by the sensors in 2006. Orienting both accelerometers to monitor the horizontal axis eliminated all of the hail- and rain-related vibration recordings, as these events primarily produce vibration in the vertical direction.

However, in 2007 wind-induced vibration was recorded when the wind exceeded moderate levels. Moderate winds are 3 to 4 on the Beaufort Wind Scale (8–18 mph). Higher winds produced vibration recordings that were very different from the bird collision recordings. The wind-induced vibrations also were different compared to the 2006 season because the sensors were installed near the mid-span in 2007 as opposed to near the end of the span in 2006. Figure 26 shows two typical vibration signals recorded by the BSI sensors that were result of wind-induced vibration. During the visual field observations, the observer made recordings of wind speed based on the Beaufort Wind Scale. The recorded wind induced vibrations correlated well with high winds, 6 or greater on the Beaufort Wind Scale.



(a) Low frequency, wind-induced vibration



(b) High-frequency, wind-induced vibration

Figure 26. Wind-induced vibration signal recorded by the BSI sensors in 2007

4.5. Visual Observations and Correlation

One of the main goals for the 2007 redeployment was to increase the amount of visual observations. The goal was to try to obtain a direct correlation of observed bird collisions with BSI detected collisions.

A technician was deployed to visually monitor line segments instrumented with the BSIs. Visual monitoring was started on May 26, 2007, and continued until September 13, 2007. One of the three spans with BSI sensors was visually monitored in the early morning and late evening five days a week. The morning observations started before sunrise and continued for about four hours. The evening observations were also typically four hours in duration and lasted until it became too dark to see. During the 79-day visual observation period the lines were visually monitored for a total of 446 hours.

The protocol for visual observation was to sit at the south end of the span and watch for bird activity in the vicinity of the span. Bird activity was noted along with weather observations with respect to sky condition and wind speed.

In the beginning, it was difficult to observe any bird collisions, as most of the collisions detected by the BSIs were either occurring outside the observation period and/or on spans that were not being visually observed. Accordingly, visual observation efforts were shifted to the span with most of the collisions being detected by the BSI sensors (Span 2). Near the end of the monitoring season, the activities shifted to Span 6. In the last two weeks of the visual observations, finally several bird collisions were observed. These observations resulted in several successful correlations with BSI-detected collisions.

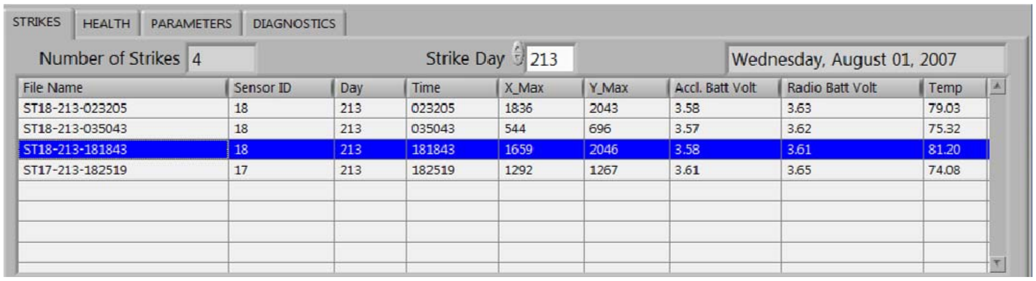
During the 79-day long visual observation cycle, three collisions and one glancing collision were observed on the test spans, all on the middle Span 6. The observed collisions as recorded by the observer and their correlation with BSI-recorded collisions are described below. It is important to note that during the visual observation period (consisting of a total of 446 hours of visual observations) there were no collisions recorded by the BSI sensors on the spans being visually observed aside from the collisions described below. The fact that no false strikes were recorded during the visual observations in itself provides further confidence that the BSI sensors worked properly.

Collision Observed on August 1, 2007

The first collision was observed on August 1, 2007, at 18:20 on Span 6, approximately 75 feet from the BSI sensor. A juvenile Franklin's gull directly struck the uppermost 115 kV wire on the west side installed with BSI sensor 12. After hitting the wire, the bird landed in the water on its back and floated back to the rocks where it died within five minutes.

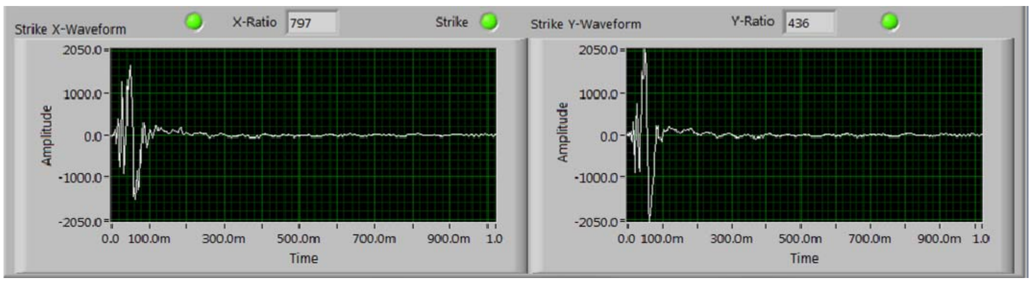
A review of that day's BSI collision summary data, shown in Figure 27, indicated that there were four collisions detected by the BSI sensors and reported to the base station. All of the collisions were on Span 6 and two of the collisions were recorded during the visual observation period. The first collision during the visual observation period occurred at 18:18:43 on sensor 18 (the uppermost west wire). A comparison of the base station clock with the visual observer's watch indicated that the base station computer's clock is approximately two minutes slower. Thus the recorded collision matched very well in time with the observed collision. However, the observer recorded that the collision likely occurred on the wire with sensor 12 instead of sensor 18, which is one wire higher up from sensor 12. The view of the wires from the observer's vantage point is shown in Figure 28. As can be seen from Figure 28, it is fairly difficult to tell the wires apart, especially when the collisions occur further away from the observer, which was the case with this collision.

Approximately six minutes after the collision observed by observer, another collision was recorded by sensor 17 (the uppermost east wire) on the same span. This collision was not recorded by the observer, and no carcass was found. The observer had gone down to the rocks and was watching the bird after the initial collision and thus missed observing the second event which occurred within that short time frame.

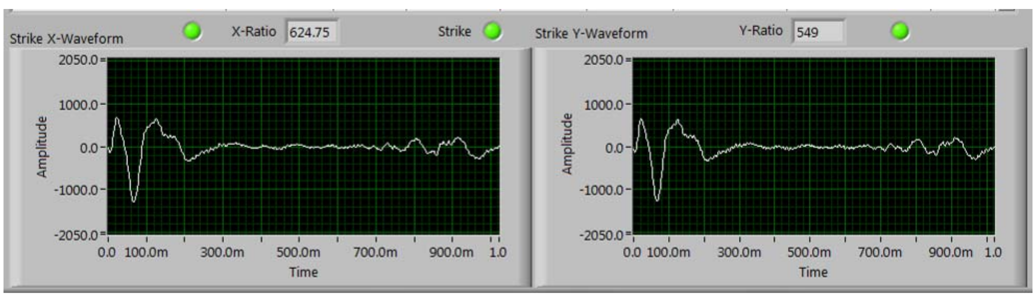


File Name	Sensor ID	Day	Time	X_Max	Y_Max	Accl. Batt Volt	Radio Batt Volt	Temp
ST18-213-023205	18	213	023205	1836	2043	3.58	3.63	79.03
ST18-213-035043	18	213	035043	544	696	3.57	3.62	75.32
ST18-213-181843	18	213	181843	1659	2046	3.58	3.61	81.20
ST17-213-182519	17	213	182519	1292	1267	3.61	3.65	74.08

(a) Collision summary for August 1, 2007



(b) BSI recorded collision at 18:18:43 on sensor 18



(c) BSI recorded collision at 18:25:19 on sensor 17

Figure 27. BSI recorded collisions on August 1, 2007

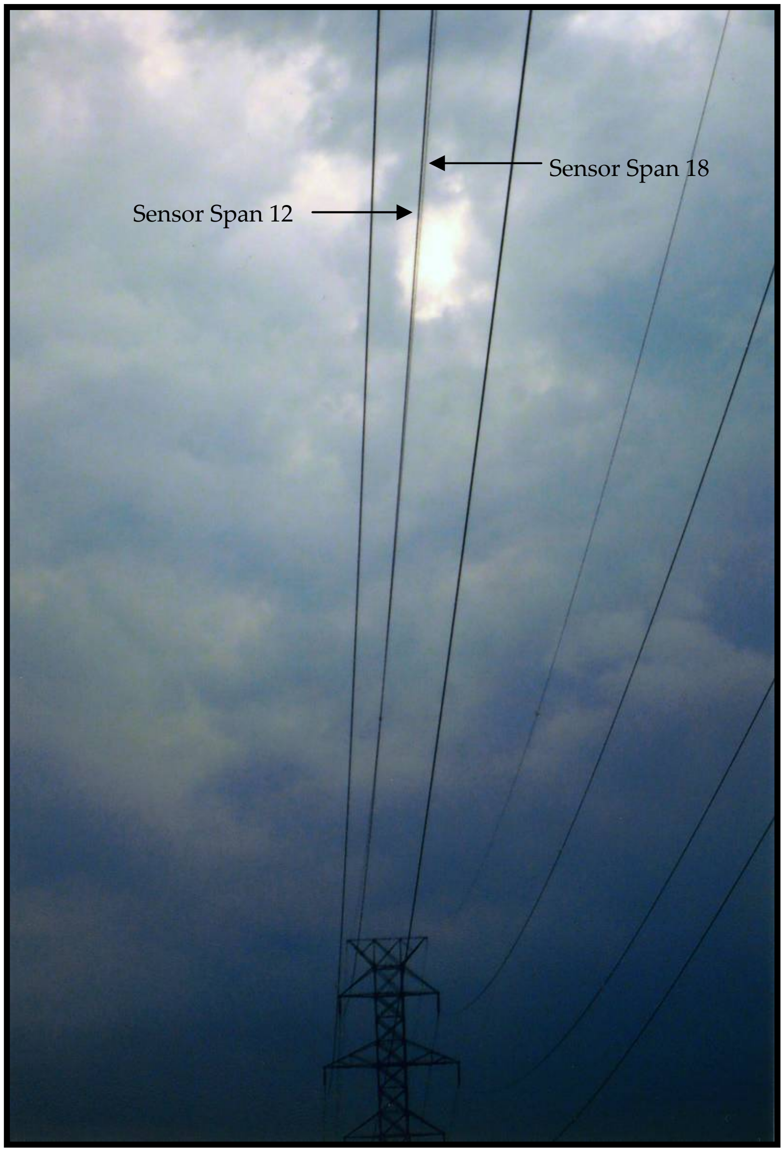


Figure 28. Observer's field of view from his sitting location at the south end of the span

Collision Observed on August 5, 2007

On August 5, 2007, at 18:04, another Franklin's gull had a glancing collision with the west shield wire (BSI sensor 18). The collision occurred on Span 6, approximately 180 feet from the sensor unit. The gull fluttered and then continued flying east, apparently unimpaired. There were no collisions recorded by the BSI sensors on this day. The observed collision was only a glancing collision that occurred approximately 180 ft from the sensor, so it is not surprising that it was not picked up by the sensors. This suggests that a crippling bias may still be a factor.

Collisions Observed on August 9, 2007

Two collisions were observed on Span 6 on August 9, 2007. The first strike was observed at 19:06, approximately 75 ft north of the BSI sensor. A double-crested cormorant struck the lowermost 115 kV wire on the west (BSI sensor 16). The bird was the last bird in a flock of 13. It struck the wire and fluttered down approximately 10 feet and then continued flying east.

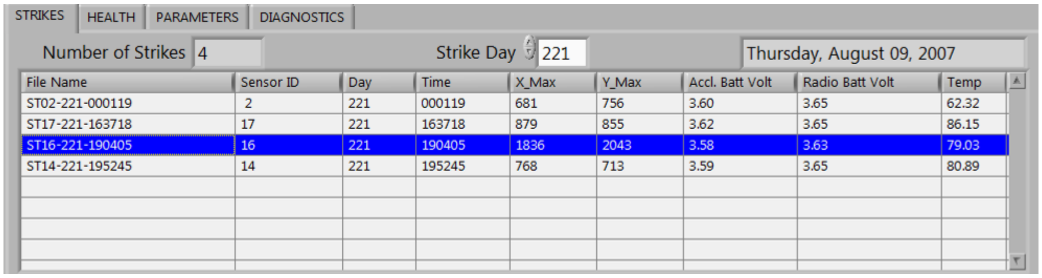
The second collision was observed again on Span 6 at 19:55. A double-crested cormorant in the middle of the flock struck the top most 115 kV wire on the west side of the span (BSI sensor 12). This was a glancing collision that took place approximately 90 ft north of the BSI sensor. The cormorant continued flying east with the flock.

Both these observed collisions were also recorded by the BSI sensors. Figure 29 provides a summary of collisions recorded by the sensors on August 9, 2007. Time records on the two of the collisions recorded by the BSI sensors (19:04:05 and 19:04:05) are within two minutes of the observed time. However, the observer recorded the second collision taking place on sensor 12, whereas the BSI sensor 14 was the one that recorded a strike at that time. Again, sensor 14 is only one wire below sensor 12, and it is felt that observer likely mistakenly noted the wrong wire.

In addition to the two visually correlated collisions, there was another collision recorded by the BSI sensor 17 at 16:37:18 on Span 6 which occurred within five minutes of the observer logging in for visual observations. The first note in the observer’s log that evening is at 16:53. It is likely the observer was walking to his observing station when this collision took place.

4.5.1. Visual Observation Correlation Summary

In the four-month visual observation period consisting of approximately 446 hours of observations, only four collisions were observed. Three of these observed collisions correlated with BSI recorded collisions. The only collision that was not detected by the BSI sensors was a glancing collision approximately 180 ft from the sensor. In addition, there were no false collisions recorded by the sensors during the entire visual observation cycle. These successful correlations provide a greater confidence level in the ability of the BSI sensors to detect collisions.

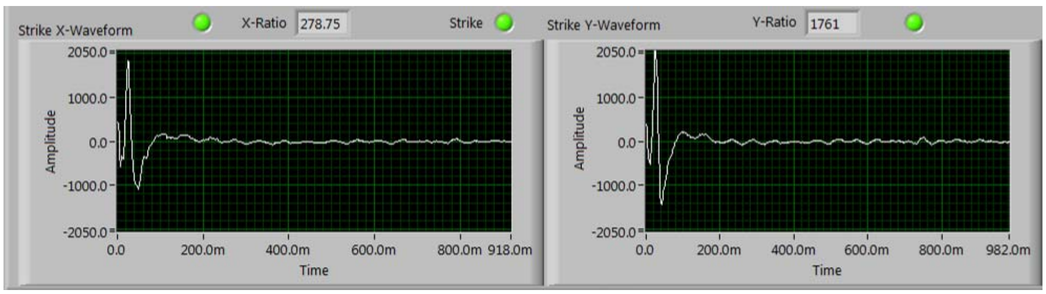


STRIKES | HEALTH | PARAMETERS | DIAGNOSTICS

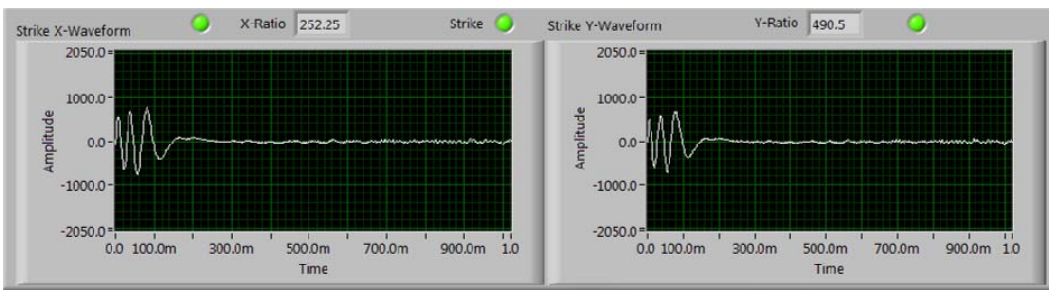
Number of Strikes 4 — Strike Day 221 — Thursday, August 09, 2007

File Name	Sensor ID	Day	Time	X_Max	Y_Max	Accl. Batt Volt	Radio Batt Volt	Temp
ST02-221-000119	2	221	000119	681	756	3.60	3.65	62.32
ST17-221-163718	17	221	163718	879	855	3.62	3.65	86.15
ST16-221-190405	16	221	190405	1836	2043	3.58	3.63	79.03
ST14-221-195245	14	221	195245	768	713	3.59	3.65	80.89

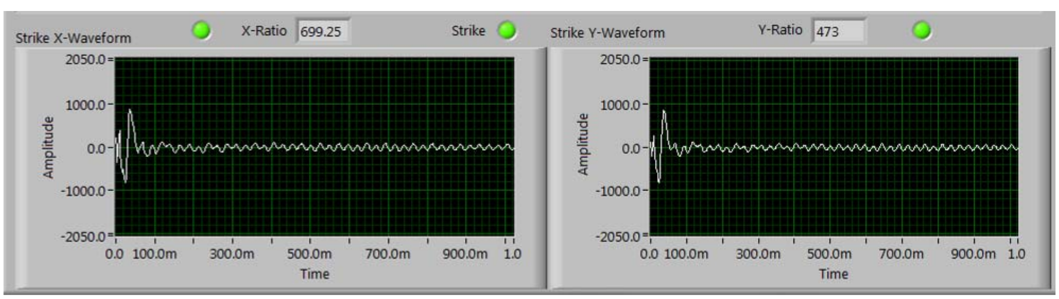
(a) Collision summary for August 9, 2007



(b) Collision recorded at 19:04:05 on sensor 16



(c) Collision recorded at 19:52:45 on sensor 14



(a) Collision recorded at 16:37:18 on sensor 17

Figure 29. BSI recorded collision from August 9, 2007

4.6. Summary of BSI Sensor Field Testing: 2007

The 2007 field season began on April 20, 2007, and ended with the last day of pedestrian survey data collected on October 19, 2007. The field season consisted of 182 days of pedestrian survey data. The protocols for the field surveys were similar to that used in the 2001 and 2002 study, as described in a previous report (CEC 2003).

A total of 344 bird carcasses were recovered along the causeway during the 2007 field season. Western and APLIC provided the preliminary results of their field efforts, which are discussed briefly below. These efforts are a part of a study being conducted by Western and APLIC. As such, the detailed results of the pedestrian surveys will be presented in their separate report.

The 344 bird fatalities recorded during the 2007 field season, encompassing approximately 65 species, was less than the number of fatalities recorded during the 2001 season (451 dead birds, 63 species), 2002 season (434 dead birds, 77 species), and even the 2006 season (429 dead birds, 67 species).

Table 13 presents necropsy results by span, along with numbers of bird collisions recorded by the BSI sensors for the 2007 season. The number of BSI-detected collisions (n=154) exceeds the total number of bird fatalities (n=101) on the monitored spans. If the birds whose cause of death was identified as “vehicle” are eliminated, the correlation becomes even worse, as there are 64 bird fatalities that have a cause of death of either “Power Line” or “Unknown.”

Table 13. Summary of necropsy results for the 2007 field survey season

Span ID	Spans with BSIs	No. of Strikes Detected by BSIs	Total Number of Bird Fatalities per Span	Cause of Death		
				Power Line	Vehicle	Unknown
2	**BSIs**	**42**	**38**	**9**	**15**	**14**
3			40	13	11	16
4			41	13	16	12
5			30	8	10	12
6	**BSIs**	**68**	**31**	**11**	**12**	**8**
7			19	5	6	8
8			32	8	11	13
9			28	5	12	11
10	**BSIs**	**44**	**32**	**9**	**10**	**13**
11			28	4	12	12
12			25	4	6	15
Totals			**344**	**89**	**121**	**134**
Total for BSI Spans	**BSIs**	**154**	**101**	**29**	**37**	**35**

The nature of the causeway makes it difficult to discern the cause of death for many of the retrieved birds. As mentioned previously, secondary injuries sustained from vehicles may mask power line collision injuries. In addition, it is possible for birds to collide with the power line and continue flying and fall outside the search area, or even to fall into the lake and thus avoid detection. Also, some collisions might not result in bird fatalities as the collision might not be severe enough. In this case, birds might continue flying either unimpaired or somewhat impaired. Both these scenarios have been visually observed on site and might explain the higher number of bird collisions recorded by the sensors. These uncertainties increase the complexity of correlating collision signatures recorded by the BSI sensors to carcasses on the ground.

There is no definite way of relating a dead bird found on the ground to a particular collision recorded by the BSI sensor. Although strong correlations can be developed, as was done in the 2006 study, causation cannot be determined. Accordingly, the exercise of trying to correlate dead birds to actual collision recordings was dropped for the 2007 season field trials. It was felt that visual observations of the spans and correlating the visual observations to the sensor recordings to identify any false positives or false negatives from the BSI sensors were the best use of the available resources. That effort included watching instrumented spans for 446 hours over 79 days and yielded no false positives. Additionally, three of the four observed collisions positively correlated with BSI records. One glancing collision 180 feet from a sensor was not recorded by the sensor, and the bird flew away.

5.0 Conclusions and Recommendations

5.1. 2006 Field Trials

The field testing of the BSI sensors at the North Dakota test site shows the BSI sensors are able to successfully detect and record bird collisions with power lines. During the monitoring season, 71 collisions were recorded and 35 were correlated with ground searches. These birds consisted primarily of larger birds such as coots (n=10), gulls (n=7), cormorants (n=2), grebe (n=2), ducks (n=2), terns (n=2), and loon (n=1). Additionally, smaller birds such as common grackles and a least flycatcher also were linked with strikes. The BSIs recorded some collisions that could not be correlated with carcasses found by the surveyors, indicating that some of the carcasses might have fallen outside the search area, as indicated by some of the observed collisions. Despite these successes, some bird collisions were also missed. On three occasions the BSIs failed to log collisions observed by field technicians. In addition, 9 out of 30 sensors failed at some point during the field trials and thus missed recording any collisions after their failure.

The field trial successfully demonstrated the ability to collect collision information remotely and transmit it across the Internet for review and analysis. The system was designed to have the ability to remotely change parameters in the sensors without removing them. During this project, this feature was tested and the sensors were successfully reprogrammed remotely to remove traffic-induced vibrations. Throughout the six-month trial, the battery life was within the expected tolerances, and wireless communication between the sensors and base station was functional. It also was demonstrated that both BSI installation and removal required minimal effort.

This project did encounter unique issues that might not be encountered at most other sites. Notably, the presence of the train and vehicle traffic parallel to the instrumented lines created some unique vibration signal challenges. However, these trials demonstrated that there are unique signal pattern differences between the vibration signatures produced by traffic, weather, and bird collisions. The unique signatures produced by bird collisions made it possible to distinguish bird collisions from other vibrations recorded by the sensors.

The presence of heavy vehicular traffic also presented problems in determining the cause of death for birds detected along the causeway. Despite performing necropsies, it was a challenge to correlate the bird collisions detected by the BSI sensors to the carcasses recovered by field surveys because it was difficult to determine the cause of death when there was a possibility of a secondary vehicle collision after a power line collision.

The field testing did identify some design/fabrication issues affecting the field performance of the sensors. Throughout this study, the BSIs on the upper static wires performed as expected and recorded the most strikes (n=59). The sensors on the 41.6 kV circuit also recorded six strikes. However some sensors on the 115 kV wires and one on the 41.6 kV line encountered some problems. The most significant design/fabrication issue was that some accelerometers became detached from the sensors as the result of glue failure, rendering them dysfunctional. The sensors installed on the 115 kV wires also had damaged antenna tips from corona activity.

However, this damage did not have any effect on the communication performance of these sensors.

The findings of the field testing were encouraging, especially considering that this was the first installation of the BSI sensors on energized power lines at such a complicated test environment.

After the 2006 testing, additional testing of the BSI sensors was recommended to further determine the effectiveness and sensitivity of the BSI sensors to detect bird collisions. Some of the specific recommendations were as follows:

1. Install the sensors closer to the middle of the span to improve the range and sensitivity of collision detection. This siting could reduce the sensors' sensitivity to traffic-induced vibrations by putting the sensors farther from the towers.
2. Install the accelerometers in a manner that ensures they are permanently attached, and investigate using accelerometers that can be mounted without glue.
3. Reinforce antenna tips or find an alternate metallic antenna with no sharp tips, to minimize corona effects.
4. Use greater precaution during fabrication to ensure that the area around each switch is properly sealed to prevent moisture intrusion.
5. Increase the duration of visual observations to increase the chances of direct verification of bird collisions with BSI-detected collisions.

These recommendations were addressed in the 2007 field trials, as described in the following section.

5.2. 2007 Field Trials

Design changes incorporating the recommendations from the 2006 season eliminated the problems encountered during the 2006 season. The 2007 physical performance of all 30 sensors had no failures and no moisture ingress. The average battery life of 6.6 months exceeded the design life of six months. Only three sensors' batteries quit before six months.

Increased visual observations during the 2007 field trials provided a preliminary study of the BSI sensors' ability to detect collisions. There were three visually verified bird collisions recorded during the 2007 season, and their unique signature provides confidence that the 154 events recorded throughout the field trials are consistent with bird collisions. During the visual observation period the sensors missed recording a glancing collision that appeared not to impair the bird. Additionally there was one event assigned to the wrong wire, suggesting that even when observing wires it may be difficult without a BSI to determine exactly which wire was struck. It is also important to note there were no false collision recordings (false positives) by the BSI sensors during the visual observation period of 446 hours over 79 days.

Collisions are relatively rare events, and the small number of visually observed collisions highlights the need for a tool like BSI, as it is very difficult and expensive to monitor all the spans at all times. Additionally, the BSI data suggest that many collisions occur during low visibility, making it impossible to visually observe them with the unaided eye. The maximum number of events occurred just around dusk, between 21:00 to 22:00 and again around 4:00 . Very few collisions occurred during daylight hours. The large discrepancy in the BSI-recorded events (n=154) versus the dead birds found during the 2007 field surveys (n=101) also identifies the need for a tool like BSI. Field surveys will obviously miss carcasses falling outside a search area. In addition, collisions that do not result in fatalities will not be detected by field surveys.

The BSI results also demonstrate how events may change throughout a season. In the beginning of the monitoring season, bird collisions were being detected more often on Span 2, but later the intensity of bird collisions picked up on Span 6 and continued at the same pace until the end of the season. The collision recordings also show that 68% of all events occurred on the upper two shield wires.

The sensors did record several other vibration signals resulting from high wind events. Winds exceeding approximately 30 mph produced enough vibration to be picked up by the sensors. Even though wind-induced vibration signatures are very different, they unnecessarily waste battery life. Because of the difference in their signatures, a digital filter could be implemented in the firmware of the BSI sensors to automatically eliminate most of these vibrations from being recorded. This would significantly enhance the overall usefulness of the BSI sensors.

Although correlations were found between strikes and carcasses as small as sparrows, more still needs to be learned about the sensitivity of detecting bird collisions for various birds. Detecting a collision includes several variables, such as the bird size and flight speed. These factors will determine the amount of energy transferred into a wire. The wire span length, size of the wire, the BSI mounting position (for example, midspan), and the BSI accelerometer sensitivity settings are important variables for detecting the collisions. Controlled bird strike trials using simulated birds or bird carcasses projected at instrumented spans would provide useful information on the overall ability of the BSI to detect strikes for a variety of birds. Finding another study site with less confounding factors but with high-documented bird collisions would also be beneficial.

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7.0 Glossary

APLIC	Avian Power Line Interaction Committee
BPA	Bonneville Power Administration
BSI	Bird Strike Indicator
EPRI	Electric Power Research Institute
g	g-force; a measure of acceleration
GUI	graphical user interface
GPS	Global Positioning System
Hz	hertz
kV	kilovolt
mph	miles per hour
PG&E	Pacific Gas & Electric
PIER	Public Interest Energy Research
ROW	right-of-way
SCE	Southern California Edison
SRP	Salt River Project
SwRI	Southwest Research Institute, Inc.
Tri-State G&T	Tri-State Generation & Transmission Association
UPS	uninterruptible power supply
USCG	United States Coast Guard
USFWS	United States Fish and Wildlife Service
Western	Western Area Power Administration