A GROUND-BASED SENSOR FOR THE DETECTION OF
TRANSMISSION LINE CONDUCTOR MOTION

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Abstract - This paper describes a new method of
detecting transmission line conductor motion. Two
people can install the detector beneath a transmission
line without the necessity of a line outage or physi-
cal connection of the detector to the transmission
line structure. The theory of operation is discussed,
and the results of field testing are presented.

INTRODUCTION

Iced conductor galloping, a natural phenomenon
caused by freezing precipitation and wind, has been
recognized since the 1930's as a cause of service
interruptions, conductor damage, and hardware
failure [1]. Because of the random nature of
galloping, and the remote location of many
transmission lines which experience galloping, data
acquisition and documentation are quite difficult.
For the same reasons, it is difficult to evaluate the
effectiveness of proposed solutions to the problem.
For instance, Western Area Power Administration
(WAPA) participated in an Electric Power Research Institute
(EPRI) study of ways to control galloping [2]. No
galloping data were collected by WAPA during the
study. WAPA also installed aerodynamic antigalloping
devices [3] on a transmission line test section to
determine their effectiveness in controlling galloping.
Again, no data were collected due to the random nature
of galloping and the line's remote location. In both
cases, random line patrols were used for data gather-
ing. In view of this lack of success, other means of
collecting data were investigated.

The installation of load cells [4] in the
transmission line insulator string was considered, but
was not pursued because of the cost of equipment and
installation. Consequently, WAPA requested that the
Electric Power Branch of the Bureau of Reclamation's
Research and Laboratory Services Division develop a
method of monitoring transmission line conductor
movement which did not require a physical connection to
the transmission line structure, and which operated at
or near ground potential. In addition to lowering
installation costs, this detector would enhance per-
sonnel safety by eliminating bucket truck operations
or hot line work. This paper describes the sensor
that was developed to meet these needs and the field
experience resulting from the use of the sensors to
detect transmission line galloping during the 1987-88
winter season.

FIELD STRENGTH

Fig. 1 E-field at detector sensing location
with no conductor motion

CONDUCTOR MOTION SENSING OVERVIEW

From a measuring point several feet off the
ground under an energized transmission line, the
electric field (E-field) due to a motionless line is a
60-Hz ac field of constant amplitude (Fig. 1). If
the line moves, it will alternately move closer to and
farther from the measuring point (Fig. 2). As the
line moves closer, the field strength at the measuring
point increases, while as the line moves farther away,
the field strength decreases. As long as the fre-
quency of motion is substantially less than 60 Hz, the
E-field at the measuring point will resemble an
amplitude-modulated (AM) signal, with a 60-Hz carrier
frequency and a modulation frequency equal to the
motion frequency (Fig. 3). The larger the motion
amplitude, the higher the modulation percentage.

Conductor motion is sensed by allowing the
E-field to induce a voltage on a conducting sensor
plate. This induced voltage is then demodulated.
The demodulated signal can then be filtered to make
the probe respond only to motion at frequencies of
interest. The output signal from this filter reflects
the conductor motion. The motion signal from the
demodulator is converted to a dc voltage proportional
to the motion magnitude. When this voltage exceeds a
predetermined level continuously for about 90 seconds,
sustained conductor motion is considered to be occur-
rning and a tone-modulated radio signal is transmitted.
The 90-second requirement ensures that no transmission
is sent due to random wind motion, transformer tap
changes, faults, or other nonperiodic events which may
alter the E-field.

The transmission is received by an observer
package which consists of a radio, tone decoder, and
an audible alarm. Upon reception of a transmission,
the alarm is activated. This alarm will sound con-
 tinuously until it is manually reset. Upon noting
the alarm, the observer can take appropriate action.
E-FIELD MEASUREMENTS AND DETECTOR SENSITIVITY

In the spring of 1986, the steady-state 60-Hz voltage (no conductor motion) induced on a sensor plate 2.4 m (8 ft) off the ground was measured under transmission lines near Ault Substation in Colorado, USA. The induced voltages ranged from 27 V under a 115-kV line to 154 V under a 345-kV line. It was also found that the induced voltage was sensitive to the presence of objects within a few feet of the sensor plate locations.

DETECTOR SENSITIVITY AND LOCATION

From these measurements and a computer simulation of the voltages induced by different line configurations, it was decided to make the detector sensitive enough to detect motion amplitudes of about 0.3 m (1 ft) peak-to-peak (p-p) amplitude. Also, placing the detector 3/8 of the distance between towers optimizes motion detection for up to seven loops. If the number of loops between towers is known, the detector should be placed under a loop. This will maximize the E-field change at the sensor plate.

DETECTOR PACKAGE

The detector package consists of a NEMA 4 enclosure with a PVC pipe extending from the top. This pipe contains the sensor plate and motion detector-demodulator electronics package (Fig. 4). The enclosure contains the motion detector processing logic, power supply, radio, and tone encoder (Fig. 5). The enclosure is mounted on a 0.1-m-diameter (4-in) pipe which is installed in a post hole at the monitoring location. The sensor plate sits about 2.4 m (8 ft) off of the ground. The exact height of the plate is not critical.

Figure 6 shows the detector package block diagram.
Sensor Plate and Demodulator

Figure 7 shows the block diagram of the sensor plate and demodulator. The sensor plate is a 0.1-m (4-in) circular plate of metal connected at its center to a brass rod. This rod connects to the input of the demodulator electronics package, which is completely shielded by grounded copper foil. The demodulator input consists of a low-pass (LP) filter. The combination of filter and shielding prevents component damage and electronics malfunction from the high level of RF energy present during radio transmission. The output waveform of this LP filter is the same AM motion waveform that is induced on the sensor plate. This output is buffered with an operational amplifier to convert the high-impedance E-field induced voltage to a low-impedance signal for further processing.

The buffer output is processed by a bandpass filter with a pass band of 50-70 Hz. This allows the AM sideband frequencies generated by modulating (motion) frequencies of up to 10 Hz to pass through the filter. The signal level is then adjusted by an automatic gain control (AGC) circuit. This AGC has a time constant of approximately 100 seconds, which guarantees that the gain will respond only to the average 60-Hz component of the signal, and not low-frequency conductor motion. The AGC also permits the detector to automatically adjust itself to the ambient E-field strength under the transmission line, which means that the detector needs no user adjustments to operate correctly under transmission lines of voltages from less than 115 kV to greater than 345 kV.

The motion processor consists of a temperature sensing circuit which permits the user to disable the system unless the temperature is within a specified range. For iced conductor galloping, this range was chosen to be 0 ± 10 °C.

Motion Processor

The motion processor consists of several subsections (Fig. 8). A temperature sensing circuit permits the user to disable the system unless the temperature is within a specified range. For iced conductor galloping, this range was chosen to be 0 ± 10 °C.
When the radio receives a transmission from the detector package, the tone decoder turns on the alarm. The decoder and alarm must be manually reset. There is provision for two tone decoders operating at different tone frequencies, so one observer station can monitor the transmissions from two detector packages.

Radios, Tone Encoders, and Decoders

The radios, tone encoders, and decoders are all standard wide-band 136- to 174-MHz two-way mobile communications packages of the type familiar to line crews. This facilitates their operation and maintenance.

SYSTEM COSTS

In 1987 dollars, the materials cost for one detector and one observer package was approximately $2,400. The total labor cost for nine systems was about $78,000. Because this was a research project, and design modifications were made as the packages were being built, it is not possible to obtain actual assembly labor costs separated out from development costs. However, it is estimated that about 50 percent of the labor expenditure was development, giving a per system assembly labor cost of approximately $4,300 making the total assembled system cost about $6,700. Shipping and installation costs were about $1,000 per system, and approximately $2,000 per observer station was spent for video equipment to provide records of conductor motion.

FIELD EXPERIENCE

Nine detector and five observer packages were installed in the fall of 1987. Four detectors were installed under the Watertown-Granite Falls double-circuit 230-kV transmission line to monitor four spans of the test section. Two detectors are under spans equipped with detuning pendulums, and two are under spans equipped with aerodynamic antigalloping devices. This is the same transmission line used in the EPRI study [2]. One of these installations is shown in Figure 11. Note the aerodynamic antigalloping device near the upper left-hand corner of the figure. Four detectors were also installed under the Brookings-White 115-kV transmission line, which does not have antigalloping devices installed, but will have another experimental type of antigalloping device installed soon. One detector was installed under a span of the Watertown-Sioux City double-circuit 115/345-kV transmission line to monitor an untreated line that has experienced a high incidence of transmission line hardware damage. These lines are all located in South Dakota, USA.

Contracts were signed with local residents to collect galloping conductor data. These observers were trained to collect galloping data using data gathering techniques modeled after EPRI's RP-1095 program, and were supplied with video cassette recorders, tripods, wind speed indicators, and printed data forms.

On December 5, 1987, transmission line galloping was detected on the Brookings-White 115-kV line. The observer was able to collect both written and videotaped data. The moving section of line did not have antigalloping devices installed. All three phases were in motion, with one phase displaying 0.9- to 1.5-m (3- to 5-ft) amplitude single-loop galloping at 20 cycles per minute (0.33 Hz), and the other two phases displaying 0.3- to 0.6-m (1- to 2-ft) amplitude two-loop galloping at 40 cycles per minute (0.67 Hz). The movement did not cause a service interruption, but did provide field evidence of the detectors' effectiveness in monitoring transmission lines for galloping. The recorded wind
velocity was approximately 0.9 to 2.2 m/s (2 to 5 mi/h) [5], which is considerably lower than the 6.7 to 18 m/s (15 to 40 mi/h) wind velocity usually associated with galloping [6].

On January 14, 1988, a periodic conductor blowout condition was detected by a detector package on the Watertown-Granite Falls 230-kV transmission line. Though the conductor blowout was not a galloping event, the observer did collect data on the incident. The bottom phase directly above the detector on this double-circuit transmission line was swinging back and forth 4 to 6 feet at a rate of approximately 23 cycles per minute (0.38 Hz). This event again showed the detector's ability to detect transmission line conductor motion.

WAPA's galloping conductor monitoring project is scheduled to continue for another 4 years.

CONCLUSION

A new lower-cost method of detecting transmission line conductor motion has been developed. The detector is ground based and can be installed by two people with no line outage or physical connection to the transmission line structure. Detection sensitivity is approximately 0.3 m (1 ft) p-p. Field testing has shown that the detector can detect several modes of conductor motion, including both single- and double-loop motion, as well as conductor blowout conditions. This detector can greatly aid in conductor motion data gathering with reduced cost and enhanced personnel safety over alternate approaches.

REFERENCES


