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A Fault Detection Neural Network for dc Trolley System Protection

Objective

To prevent mine fires caused by undetected arcing faults on coal mine dc trolley systems by using computerized signature analysis techniques that distinguish legitimate loads from arcing faults.

Background

Dc trolley haulage systems move personnel, supplies, and coal in approximately 50 U.S. mines. A suspended trolley line energized at 300 or 600 V dc provides electrical power, and a system of steel track serves as the return path. When roof falls and other events force the trolley line down near the ground return rail, inductance inherent in the trolley system facilitates continued current flow along an ionized path between the line and rail. This releases a significant amount of energy in the arc and may damage and/or ignite surrounding material. Conventional circuit breaker systems cannot prevent this continued arcing because the magnitudes of the currents involved may be significantly less than typical breaker trip settings.

In 1980, the former U.S. Bureau of Mines demonstrated research to detect arcing and other types of trolley faults. The system required an oscillator to superimpose a 3-kHz signal in the trolley line, a signal wire suspended parallel to the trolley line for circuit breaker coordination, and a filtering system on locomotives larger than 25 tons. Although the system functioned satisfactorily, the coal industry did not adopt it because of the complexity and cost of the hardware.

Today, the threat of trolley fault-induced fires still exists. The National Institute for Occupational Safety and Health (NIOSH) has sought solutions that would require minimal hardware maintenance and be cost-effective. Using an artificial neural network (ANN) based system to detect trolley faults would require no modification of the trolley rectifier, line, feeder, or its vehicles, lessening maintenance concerns and costs. Further, all hardware used in the development of this system is commercially available.

Approach

Developing a method to safely induce arcing faults on mine trolley systems and to record and analyze the electrical signature, or output, of a trolley rectifier was the key to a neural network detection algorithm for the project. Early field tests led to the development of an induced fault test circuit (figure 1) that was simply clamped onto the trolley system. After closing of the contactor, the fuse wire melted away and electrical current arced between the metallic electrodes, creating the induced fault. A custom data acquisition/analysis system digitally recorded field data and performed the necessary analysis to distinguish between normal operation and an arcing fault. The system included a ruggedized PC, an eight-channel analog-to-digital converter for data collection, instrumentation for electrical signal gain or attenuation and electrical isolation, and low-pass filters.

NIOSH personnel visited several coal mines in Pennsylvania and West Virginia to conduct tests of dc trolley systems under various operating conditions. These conditions consisted of traffic present on the system at any given time, e.g., assorted vehicle traffic; pump activity; and heavy, intermediate, and minimal loading. Each test recorded the line current and line-to-ground voltage signature at a trolley rectifier and varied in length from several seconds to as much as 45 s, depending on the existing conditions of the trolley system. These tests represented the normal operation, or no-fault, portion of the data collected. Similar tests with the inclusion of an induced arcing fault comprised the faulted data tests. To ensure observation of a variety of possible test conditions, carefully selected sites both on the surface and underground and at various distances from the trolley rectifier served as fault locations.

Data collected during early field visits were used to train the ANN, the basis of the arcing fault detection scheme. After the ANN was sufficiently trained and tested in the laboratory, field tests were conducted using the ANN to monitor the dc current signal of a trolley rectifier. Early field tests showed that the current signal alone provided sufficient data for the fault detection algorithm.

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How It Works

To explain the operation of the fault detection algorithm, it is important to first describe the training process of the ANN. The ANN learned by randomly selecting patterns from a training data set, calculated an output based on these patterns (+1 for normal operation or −1 for a fault), and compared the result with the desired output. Error values calculated during this stage were used to modify the network architecture to achieve a result closer to the desired output. These iterations continued until the network performance became acceptable. The input was then switched to the test set where the network conducted a single pass to generate independent error values. This tested the network on control data not used in training and determined if the training set was memorized. A network that memorizes training data becomes too specific and will not perform well on new patterns. Further, examining the network output and its variances between the set values of ±1 (normal or fault) helped identify weak areas in the training set. Additional training patterns were later added to help improve network accuracy.

After training and testing the network in the laboratory, it was converted into a C language module. This module was then incorporated into a fault detection program written to run on a PC platform and was taken into the field for further testing. Field testing included repeating the same type of tests run during the recording sessions, but with the ANN detection algorithm "monitoring" the trolley rectifier current signal. After several postprocessing steps, the network classification (fault or no-fault) was outputted to the user via the PC display (figure 2).

Results

NIOSH personnel conducted a series of field tests using the final detection algorithm in its "monitoring mode." The results were very promising. Sixty-two monitoring passes, each of which comprised multiple classifications of either fault or no-fault, were conducted. The network correctly classified the status of the trolley system 97.9% of the time. Of the 2.1% incorrect classifications, 1.9% were situations where the algorithm failed to detect a fault and 0.2% were false alarms.

The network discussed here is rectifier-specific, i.e., it was trained solely on patterns obtained from a single mine rectifier. This would mean that in deploying this network to mines, it would require training for each individual mine system. However, the research shows that this technology is a viable solution to the problem of detecting dc trolley faults. A detection system could be implemented using a self-contained microprocessor mounted on each rectifier where it would monitor the dc current, providing an additional margin of safety for U.S. mine workers.

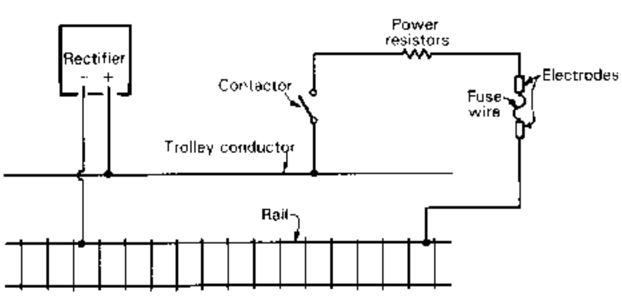

Figure 1.—Trolley system induced arcing fault test circuit.

For More Information

Mine operators or others interested in this new technology should contact:

Jeffrey Shawn Peterson, National Institute for Occupational Safety and Health (NIOSH), Pittsburgh Research Laboratory, Cochrans Mill Rd., P.O. Box 18070, Pittsburgh, PA 15236-0070, Phone: (412) 892-4299, Fax: (412) 892-4384, e-mail: jnp3@cdc.gov. Mention of any company name or product does not constitute endorsement by the National Institute for Occupational Safety and Health.

To receive additional information about mining issues or other occupational safety and health problems, call **1-800-35-NIOSH (1-800-356-4674)**, or visit the NIOSH Home Page on the World Wide Web at http://www.cdc.gov/niosh/homepage.html.

As of October 1996 the safety and health research functions of the former U.S. Bureau of Mines are now located in the National Institute for Occupational Safety and Health (NIOSH).

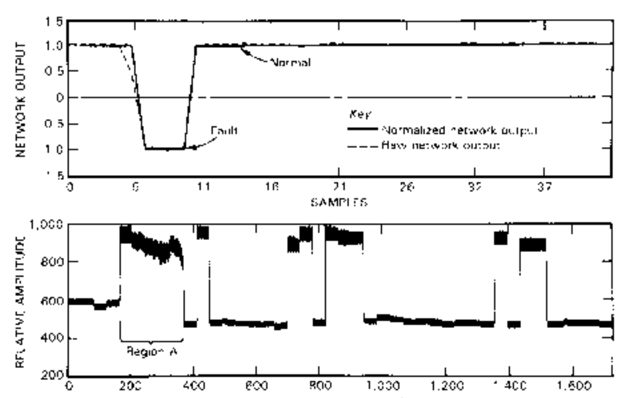

Figure 2.—Detection network output before, during, and after an induced fault. Fault occurs during Region A of lower graph.