CABLE AUTOMATION FOR URBAN DISTRIBUTION SYSTEMS

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INTRODUCTION

Located underground, cable distribution systems have a long track record of being very reliable.

However, when faults do occur, the Customer Minutes Lost (CML) is often much greater than for faults on the rural system. With more traffic congestion predicted for major cities, getting people to substations quickly will be a bigger problem; therefore, longer delays in restoring supplies are to be expected.

Today's requirement is to automatically locate cable faults and to communicate the response to Central Control. Supplies can then be restored quickly, and crews directed to make the repair.

The paper describes the novel 'Cable @utomat' approach. Using a series of earth fault sensing transmitters located at convenient points along the cable feeder, and a receiver at the primary substation, the transmitters communicate with the receiver using the primary cable as the medium.

To improve overall system reliability, transmitters are uniquely coded so that the receiver can identify each one. This offers a major safeguard against incorrect fault location.

Maintenance of fault location equipment represents a large cost to users. By adding regular 'healthy' reporting, the maintenance strategy can be made 'pro-active'; demanding no action until a failure is reported.

Finally, the paper describes short-lived 'pecking' faults, often found on cables, that can easily confuse fault location methods. The new product has added design features to ensure reliable operation under such difficult conditions.

CABLE DISTRIBUTION CIRCUITS

The normal UK underground distribution system comprises running a cable from a primary 11kV substation to a set of Ring Main Units (RMU's), and then back to a primary substation. At a convenient location, there will be a normally open point. Distribution transformers are connected via the RMU's and transform the voltage to 415V for customer's supplies, see example in fig 1. Each RMU can be switched so that supplies are fed from either side, allowing a faulty cable section to be removed from the supply path while repairs are carried out. The vast majority of RMU's in the UK are manually operated at the present time.

TRADITIONAL FAULT LOCATION DESIGNS

Most fault location designs employ visual earth fault indicators, located at points along the cable. Originally these were electro-mechanical, but more modern versions use electronic circuitry. In the UK, many thousands of these devices are installed and in operation today.

The key issue is that with these designs, fault location relies very much upon people. Engineers must visit each substation in turn to identify the likely faulty section, before returning to the correct substation(s) to carry out the switching sequence. This is both time consuming, and demands a high level of skill / experience in the engineer.

Because long term reliability of these devices has not been 100%, it has been known to locate faults wrongly. In the worst case, the supply can be closed onto the fault again. Although infrequent, this has been a major problem with some industrial customers where production processes have been badly affected.

In order to improve the quality of supply, the existing method of manual cable fault location will be replaced with the following system.

'Cable @utomat' – OPERATING PRINCIPLE

The new 'Cable @utomat' design employs earth fault sensing transmitters which are located at key points along the cable feeder. Each transmitter has a unique address and communicates with the receiver by sending this address as a digitally coded message. See fig 2.

The transmitters operate in 2 different modes, post fault dead-line and healthy live-line signalling.

In either mode, the coded signal is transmitted along the cable using a Frequency Shift Keying (FSK) technique. '0' is represented by one high frequency, and '1' is represented by another.

The receiver is located on, or near, the circuit breaker in the primary substation. It is a digital device that processes the incoming signals.

It can also communicate with SCADA to pass messages to Central Control. See figs 3 & 4. The link to SCADA offers a major advantage: all operations can be accessed remotely, and, therefore, engineers can be immediately directed to the correct substations. This saves significant time in restoring supplies.

High frequency signal coupling

Transmitter - To inject the coded signal, the transmitter uses magnetic coupling, see fig 2.

Receiver - To sense the coded signal at the cable feeder circuit breaker in the primary substation, the receiver has two inputs: -

1. Live-Line - zero sequence current input
2. Dead-Line - zero sequence voltage input

Signals 1 and 2 tend to be exclusive, hence the receiver can measure that signal with the greatest magnitude automatically.

Fault location using dead-line signalling

The most common type of fault is an earth fault. On cable circuits, it is also recognised that in the development of many multi-phase faults, there are periods in which there is a connection to earth.

During a fault, the transmitters in the fault path that 'see' earth fault current above threshold are triggered. After the fault has been removed by the circuit breaker at the primary substation, these transmitters send the digitally coded signal to the receiver at the primary substation. With the circuit breaker open, signalling is over a dead-line.

To avoid the risk of 'dead-line' messages from 2 or more transmitters colliding, the transmission of each code is spaced apart in time, with the instant of fault removal acting as a synchronising signal.

The local transmitter in the primary substation detects the fault in an identical way to all other transmitters, and operates a 'start' contact to tell the receiver to begin a fault location sequence. The receiver decodes the incoming series of transmitter codes, and can deduce the fault location from the stored internal list of device locations. This fault location is then transmitted to Central Control via the SCADA interface.

During cable faults, the supply of ac auxiliary power at the RMU's along the feeder is normally cut-off as the fault is removed by the circuit breaker. To ensure that transmitters can function, enough energy is stored inside the transmitter to send a full coded sequence. No secure supply, such as a dc battery, is required at the RMU locations.

Marginal fault operation. Although most cable faults produce relatively large fault currents, the design has specifically addressed low-level marginal faults, and ensured that co-ordination is maintained down to the threshold of operation.

To ensure reliable operation, the new transmitter has a well-defined fault current trigger level, both in magnitude and ampere seconds. This current level was chosen to be greater than the maximum practical zero sequence charging current that flows in the healthy part of the cable network during an earth fault. This is essential to prevent the healthy transmitters sending a false signal.

The fault sensitivity of the receiver is designed such that when it operates, all relevant transmitters will be capable of sending a correct message. This includes a safety margin that covers the cumulative sources of error, including calibration variations in multiple transmitters, different temperature at different locations, etc.

Supervision via healthy live-line signalling

As cable faults are rare, the most common type of transmission is healthy live-line signalling. Each transmitter has a time delay (typically set at 4 hours) that automatically recycles. At the end of each time period, the transmitter enters a test mode that sends its unique coded address message. To ensure that the test is most effective, over 95% of the same circuitry is used in both dead-line and live-line operation.

The receiver decodes the messages, and keeps an ongoing record of which transmitters it has identified during the reporting period (normally 72 hours).

In a live power system, there is a certain risk that a major transient is coincident with a healthy send that causes message corruption, e.g. circuit breaker switching. However, for effective supervision, 100% correct messages are not essential. Only transmitters that fail to report successfully once every reporting period (72 hours) to the receiver would give a faulty warning message. This will draw attention to the specific device that is in need of maintenance via the SCADA interface.

This facility has a major advantage. It allows a pro-active strategy that directs all maintenance effort to those devices identified as faulty. Routine maintenance is not required.

Practical transients on cables

At the most basic level, the cable is described as either 'healthy' or 'faulty'. However, in practice, there will always be a risk of spurious induced earth currents, especially into cable sheaths. Sources of such transients include lightning strikes, faults on parallel circuits, circuit switching transients, decay of healthy phase stored energy on fault removal, capacitive charging currents etc.

Most effects will be short duration, high frequency transients, although cables discharging through the magnetic circuit of transformers can be low frequency (< 50Hz). In either case, it is essential that such 'noise' does not trigger the transmitter or receiver in error. Special measures have been added to the new design to ensure this.

Pecking faults on cables

Owing to the close proximity of the live conductors and earth, engineers once considered all cable faults to be solid and of low impedance. However, recent deployment of much better disturbance recorders has proven this to be false.

Short duration 'pecking' faults on cable circuits have not only been identified in the UK, but recognised as being rather common.

Basically, a fault occurs, but then disappears after a short period. With a Neutral Earthing Resistor, as used in UK, the initial 'peck' of fault current can be as short as 10 or 20ms. The unexpected 'self-healing' action occurs at the next current zero.

The exact self-healing process is still uncertain. On new XLPE cables, the hypothesis is that the arc rapidly generates insulating gases that 'blow' out the fault. Alternatively, in the case of oil filled equipment, violent eruption of the oil may cool the arc enough to extinguish the fault.

Disturbance records from UK Utilities have shown that after each burst of fault current it can take several tens of seconds, or even minutes, before the next short fault occurs. Normally, the second fault has a longer duration, say 20 to 40ms. This process tends to continue until the fault duration becomes permanent.

Records show that the number of bursts of fault current can be as high as 7 or 8 before a solid fault develops. On some feeders, more than 50% of cable faults were found to start off in this way.

Triggering falsely on an early burst of fault current, and storing that result, can cause major fault location errors. These confuse operators. Once user confidence has been eroded, then the device is often ignored.

To conclude: any new fault location system has to be reliable and, therefore, deal with pecking faults.

MAINTENANCE STRATEGIES

Given that the original visual earth fault indicators remain inoperative for several years, then are suddenly called upon to operate, it is clear why the long term reliability / availability is not 100%.

Yet operationally, failure of even one fault indicator can directly lead to a mistake in fault location. That error can result in wrong switching, and thus cause more customer minutes to be lost.

If multiple indicators fail, then the performance deteriorates very fast, and the indicators may as well be withdrawn from service. Traditionally, to reduce these risks, conventional equipment has demanded a programme of regular maintenance.

However, with a large number of indicators, spread over a geographical area, the demands of routine maintenance represent a major cost and manpower problem to the user. Somehow, a new solution to this dilemma is required.

Modern maintenance regimes – are best when pro-active, i.e. directed to 'known faulty' device(s). If healthy reports are received from all devices, then no maintenance is required. When faults do occur, self-diagnostics speed up the repair.

By adding live-line signalling into the new design, and regular 'healthy' reports via the auto-test routine, this pro-active type of maintenance regime is readily available for immediate use, and recommended as the best strategy for all Utilities.

'Cable @utomat' - Self-diagnostics

In-built self-diagnostics are a valuable aid to initial commissioning and later, to fault finding.

The microprocessor-based design allows failures to be trapped, displayed locally in the primary substation, then repeated remotely, by sending messages to Central Control. These include:-

- *Transmitter fails to send any healthy codes:* The receiver identifies the failing transmitter.
- *Transmitter sends an incomplete code:* During live-line transmission of the healthy code, the receiver will recognise the incomplete code. If repeated errors continue for a longer set period, it will be reported as a fault. If an incomplete code is received in a fault sequence, a 'bad code' will be recorded.
- *Dead-line code out of sequence:* An out of sequence reception for a fault will not inherently result in a wrong location. However, an error of this nature is normally associated with wrong transmitter setting(s). If two transmitters are set the same, the two codes will be sent at virtually the same instant of time and risk collision / corruption. Any such corruption is recorded and the receiver will send the fault location information plus an error code.
- *Communication to SCADA failure*: Each time a healthy code is received, the receiver sends a message to the SCADA interface. If the SCADA interface does not receive anything from a receiver for a period of time it will send an error message to Central Control.

'Cable @utomat' - SERVICE EXPERIENCE

The equipment has been installed in Northern Electric's distribution network and specially monitored to confirm its on-site performance.

Using the 'healthy' auto-test feature, extensive live-line tests have already been completed, and signalling shown to be very reliable. Dead-line signalling has also been successfully carried out.

Primary faults are rare on cables, therefore, the installation is in the process of being extended onto a mixed cable / overhead circuit, where more faults are expected.

CONCLUSION

Automation of cable circuits is a requirement for Utilities that need either, to speed up the restoration of supplies, or, to use fewer staff to run their power system.

The novel design described communicates the fault location automatically to Central Control, so that the engineer can be sent directly to those substations that require switching to reconnect customers. Experience indicates that this will reduce the present restoration time by over half that presently achieved.

UK Utilities now prefer maintenance regimes to be biased away from routine effort, and towards pro-active intervention. To meet this challenge, the new fault location system includes an automatic supervision feature that directs maintenance efforts to only those devices identified as 'not healthy'. This offers the user a major cost saving.

'Noise' sources on cables have been identified, and include a little known phenomenon, the 'pecking' fault. To be effective, modern designs of fault location equipment must match the practical realities of all known transient effects on cables.

Once reliable fault location is available at Central Control, then there is a plan to begin automating the RMU switching process via SCADA. This demands signalling from the primary substation to the RMU's. This will be reported in a future paper.

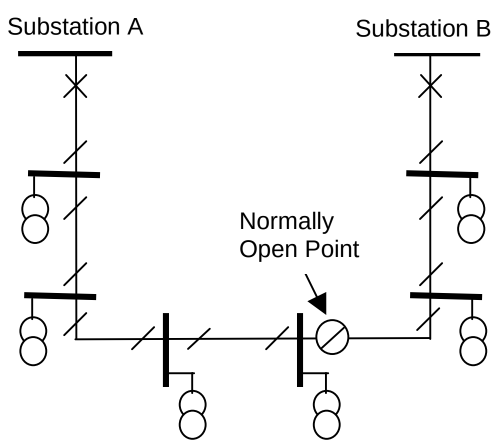

Fig 1 - Typical UK cable feeder

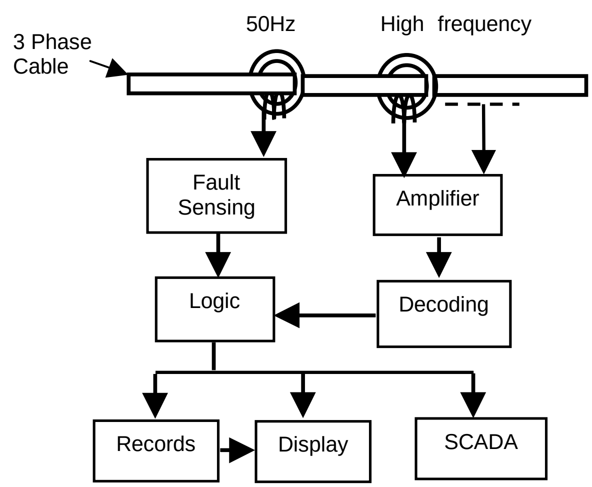

Fig 3 – 'Cable @utomat' receiver

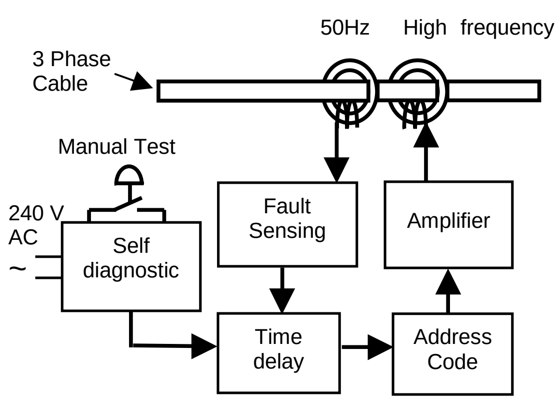

Fig 2 – 'Cable @utomat' transmitter

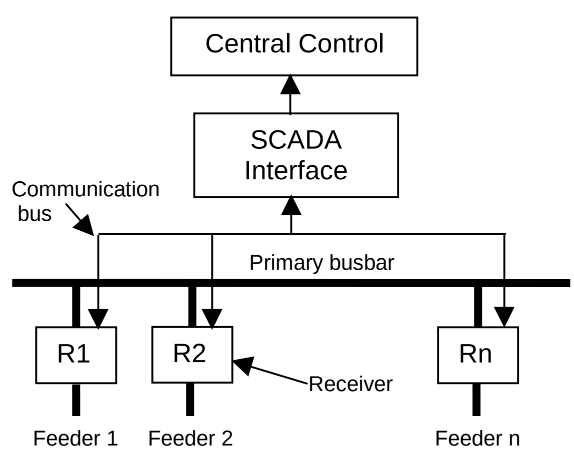

Fig 4 – Substation communication network