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A MICROPROCESSOR-BASED DIGITAL FEEDER MONITOR WITH HIGH-IMPEDANCE FAULT DETECTION

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Introduction

The high impedance fault detection technology developed at Texas A&M University after more than a decade of research, funded in large part by the Electric Power Research Institute, has been incorporated into a comprehensive monitoring device f or overhead distribution feeders. This digital feeder monitor (DFM) uses a high waveform sampling rate for the ac current and voltage inputs in conjunction with a high-performance reduced instruction set (RISC) microprocessor to obtain the frequency response required for arcing fault detection and power quality measurements. Expert system techniques are employed to assure security while maintaining dependability. The DFM is intended to be applied at a distribution substation to monitor one feeder. The DFM is packaged in a non-drawout case which fits the panel cutout for a GE IAC overcurrent relay to facilitate retrofits at the majority of sites where electromechanical overcurrent relays already exist.

High impedance Faults

To understand the performance of the DFM, it is necessary to ,define the high impedance faults targeted by this device. A high impedance fault is characterized by having an impedance sufficiently high such that it is not detected by conventional phase or ground overcurrent protection. A downed conductor fault occurs when the conductor is no longer intact on pole top insulators, but instead is broken and in contact with earth or a grounded object. An arcing fault is any high impedance fault which exhibits arcing.

Combinations of these types are possible. An example is an arcing, high impedance, downed conductor fault. The intent of the DFM is to detect high impedance faults which arc, and to differentiate those which are downed conductors from those which are not. Electrical signatures are used to identify the presence of arcing. If the arcing begins with a loss of load or with an overcurrent disturbance (as might occur when a conductor falls across another phase or neutral wire and then falls to ground) , the DFM assumes that a conductor is down. If neither of these conditions initiates the arcing, the DFM assumes that the conductor is still intact. In the interest of system security, the DFM considers loss of load or an overcurrent disturbance to indicate a downed conductor if and only if one of these starts the arcing, and not if one these occurs after the initiation of arcing. The reason for this is that, following a recloser operation, power system load levels will often change sufficiently such that the DFM cannot distinguish between a recloser operation and a loss of load due to a broken conductor.

Algorithms Associated with High Impedance Fault Detection

An algorithm is simply a set of rules for solving a problem. For a microprocessor-based device, an algorithm is implemented by the software code run by the microprocessor. In the DFM, the detection of a downed conductor or arcing condition is accomplished through the execution of the following algorithms:

Energy Algorithm
Randomness Algorithm
Expert Arc Detector Algorithm
Load Event Detector Algorithm
Load Analysis Algorithm
Load Extraction Algorithm
Are Burst Pattern Analysis Algorithm
Spectral Analysis Algorithm
Arcing Suspected Identifier Algorithm

Energy Algorithm

Arcing causes bursts of energy to register throughout the frequency spectrum, and they are readily detected at non-fundamental and non-harmonic frequencies. This characteristic of arcing faults is represented in Figure 1. The Energy Algorithm monitors a specific set of non-fundamental frequency component energies of phase and neutral current. After establishing an average value for a given component energy, the algorithm indicates arcing if it detects a sudden, sustained increase in the value of that component. The DFM runs the Energy Algorithm on each of the following parameters for each phase current and for the neutral: (1) even harmonics, (2) odd harmonics, and (3) non-harmonics. on a 60-Hz system, the non-harmonic component consists of a sum of the 30, 90, 150, ... , 750-Hz components, while on a 50-Hz system, it consists of a sum of the 25, 75, 125,
625-Hz components. If the Energy Algorithm detects a sudden, sustained increase in one of these component energies, it reports this to the Expert Arc Detector Algorithm, resets itself, and continues to monitor for another sudden increase.

Randomness Algorithm

The Randomness Algorithm identifies another characteristic of these faults, that of having energy magnitudes which vary considerably from one half-cycle to the next, as shown in Figure 2. The Randomness Algorithm monitors the same set of component energies as the Energy Algorithm. However,, rather than checking for a sudden, sustained increase in the value of the monitored component energy, it looks for a sudden increase in a component

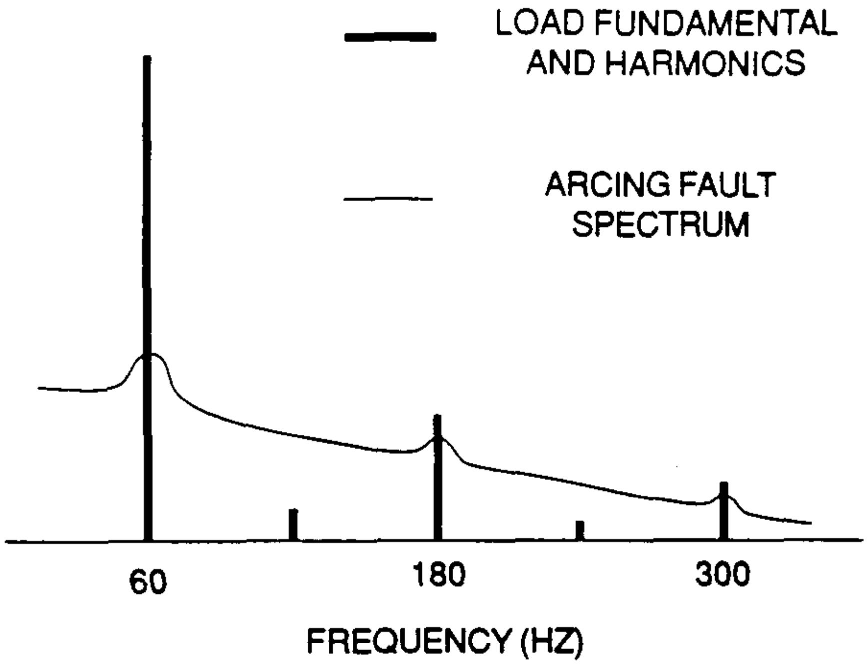


Figure 1

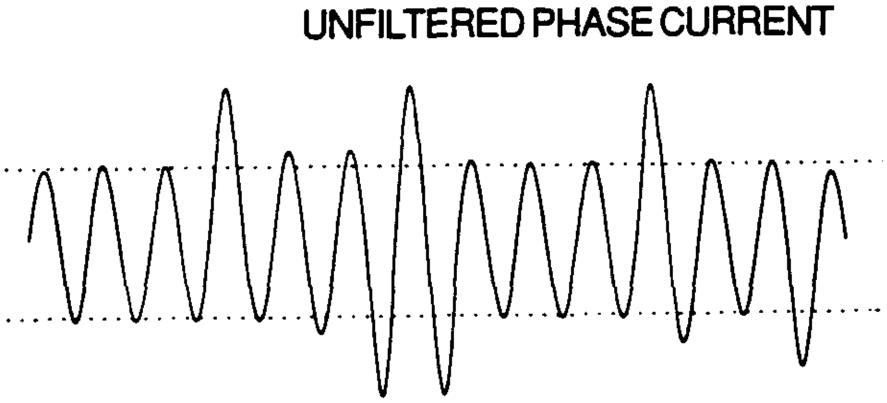


Figure 2

followed by highly erratic behavior. This type of highly random behavior is indicative of many arcing faults. Just as with the Energy Algorithm, if the Randomness Algorithm detects a suspicious event in one of its monitored components, it reports this to the Expert Arc Detector Algorithm, resets itself, and continues to monitor for another suspicious event.

Expert Arc Detector Algorithm

The purpose of the Expert Arc Detector Algorithm is to assimilate the outputs of the basic arc detection algorithms into one belief-in-arching confidence level per phase. Note that there are actually 24 independent basic arc detection algorithms, since both the Energy Algorithm and the Randomness Algorithm are run for the even harmonics, odd harmonics, and non-harmonics for each phase current and for the neutral. The assimilation performed by the Expert Arc Detector Algorithm, then, is accomplished by counting the number of belief-in-arcing indications determined by any one of the twenty-four algorithms over a short period of time. Also taken into account is the number of different basic algorithms that indicate a belief in arcing. Various weights are assigned to each of the parameters to reflect the significance of the information in each parameter. These weights were derived from the analysis of hours of data from over 300 staged faults and other events.

The Expert Arc Detector Algorithm's belief-in-arcing confidence level for each phase increases as the number of basic algorithms that indicate a belief in arcing increases. It also increases with increasing numbers of indications from any one basic algorithm. These confidence level increases occur because multiple, consecutive indications and multiple, independent indications are more characteristic of the presence of arcing than a single algorithm giving a single indication.

Load Event Detector Algorithm

The Load Event Detector Algorithm examines, on a per-phase basis, one reading of RMS values per two-cycle interval for each phase current and the neutral. It then sets flags for each phase current and for the neutral based on the following events: (1) an overcurrent condition, (2) a precipitous loss of load, (3) a high rate-of-change, (4) a significant three-phase event, and (5) a breaker open condition. These flags are examined by the Load Analysis Algorithm. Their states contribute to that algorithm's differentiation between arcing downed conductors and arcing intact conductors, and inhibit the Expert Arc Detector Algorithm from indicating the need for an arcing alarm for a limited time following an overcurrent or breaker open condition.

Load Analysis Algorithm

The purpose of the Load Analysis Algorithm is to differentiate between arcing downed conductors and arcing intact conductors by looking for a precipitous loss of load and/or an overcurrent disturbance at the beginning of an arcing episode. A typical downed conductor pattern recognized by the algorithm is shown in Figure 3. The presence of arcing on the system is determined

Load/Event Analysis

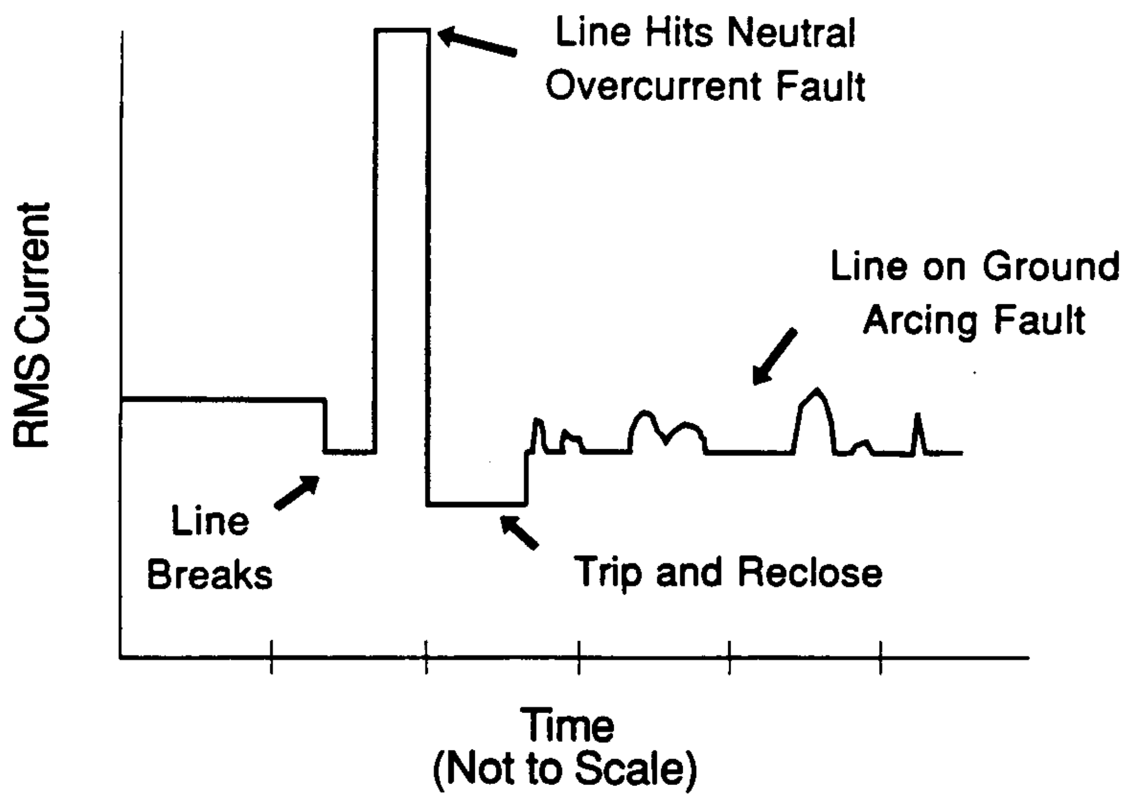


Figure 3

based on the output of the Expert Arc Detector Algorithm. If the DFM finds persistent arcing on the power system, the Load Analysis Algorithm then considers the type of incident that initiated the arcing and classifies the arcing conductor as either downed or intact. Another function of the algorithm is to provide coordination between the DFM and the power system's conventional overcurrent protection by observing a timeout from the beginning of the arcing before giving an indication of arcing.

If the Load Analysis Algorithm determines that a downed conductor or arcing exists, it attempts to determine the phase on which the high impedance fault condition exists. It does this in a hierarchical manner. First, if a significant loss of load triggered the Load Analysis Algorithm, and if there was a significant loss on only one phase, that phase is identified. If there was not a single phase loss of load, and if an overcurrent condition on only one phase triggered the algorithm, that phase is identified. If both of these tests fail to identify the phase, the phase with a significantly higher confidence level (e.g. higher than the other two phases by at least 25%) is identified. Finally, if none of these tests provides phase identification, the result of the Arc Burst Pattern Analysis Algorithm is checked. If that test fails, the phase is not identified.

Load Extraction Algorithm

The' Load Extraction Algorithm attempts to find a quiescent period during an arcing fault so that it can determine the background load level of the neutral current. If it is successful in doing so, it then removes the load component from the total measured neutral current, resulting in a signal which consists only of the fault component of the neutral current. This information is then provided as input to the Arc Burst Pattern Analysis Algorithm.

Arc Burst Pattern Analysis Algorithm

The Arc Burst Pattern Analysis Algorithm attempts to provide faulted phase identification information based on a correlation between the fault component of the measured neutral current and the phase voltages. The fault component is received from the Load Extraction Algorithm. The result of the analysis is checked by the Load Analysis Algorithm if its other phase identification methods prove unsuccessful.

Spectral Analysis Algorithm

The Spectral Analysis Algorithm analyzes the non-harmonic components of the neutral current on the power system and correlates the shape of the non-harmonic components of the spectrum to an ideal 1/f arcing spectrum. A high correlation provides confirmation of the DFM's belief in arcing on the power system.

Arcing Suspected Identifier Algorithm

The purpose of the Arcing Event Trend Identifier Algorithm is to detect multiple, sporadic arcing events. If taken individually, such events are not sufficient to warrant an arcing alarm. When taken cumulatively, however, these events do warrant an alarm to system operators so that the cause of the arcing can be investigated.

Figure 4 illustrates the interaction of these various algorithms to produce three separate outputs associated with high impedance fault detection. The "arcing" output occurs relatively fast when persistent arcing is present or relatively slow (fraction of an hour to one or two hours) when arcing is intermittent. The "downed conductor" output occurs only when a precipitous loss of load or an overcurrent condition indicating a fault occurs prior to the detection of arcing. "Phase identification" (phase A, phase B, or phase C) is determined when either the arcing or downed conductor output occurs.

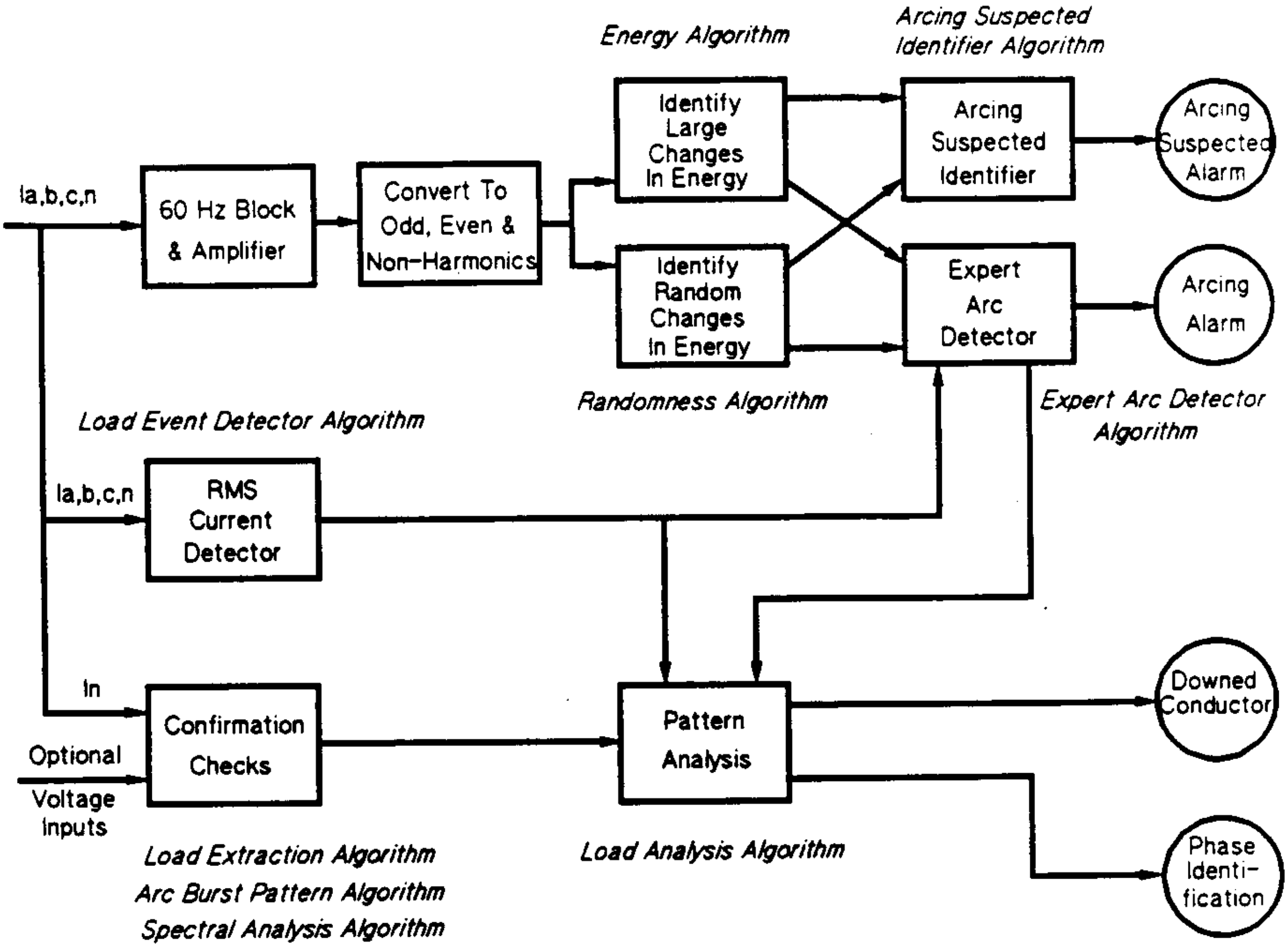
Control Strategies for High Impedance Fault Detection

Users of the DFM expect its high impedance fault detection to be secure and dependable. Most users will consider service continuity important, and will use the DFM to improve the ability to de-energize a feeder where a downed conductor poses a threat to life and property.

The DFM is designated a "monitor" rather than a protective relay to emphasize the fact that not all downed conductors can be detected by the DFM. For instance, a downed conductor on dry asphalt that does not produce arcing will not be detected by the DFM. It is difficult to derive a definitive, statistical performance of merit for DFM high impedance fault detection because of the wide variety of ground and circuit conditions which may be encountered. However, based upon documented field experience and assumptions of circuit environmental conditions, it can be expected that approximately 80% of all arcing, high impedance faults will be detected by the DFM, assuming the default sensitivities set at the factory.

once detection occurs, the user must decide upon a course of action. A DFM contact closure associated with the downed conductor output of Figure 4 can be used to alarm or initiate a control action, the most apparent of which is tripping the feeder breaker. However, the user may consider whether tripping the feeder breaker and the resultant interruption of service is necessary where there is virtually no risk to person or property.

Downed conductor accidents have been and will be the subject of litigation. Given devices such as the DFM which can detect a high percentage of downed conductors, utilities, acting alone and influenced by regulating bodies, may feel compelled to install such devices to improve safety by selective clearing of suspected downed conductor faults. This approach will reduce the overall risk to person or property although the risk will not be entirely eliminated because not all downed conductors can be detected. On the other hand, a utility that chooses not to install such a device or not to trip if one is installed may be at a disadvantage in a court room situation. This is all very speculative, but it points out the advantage in using a new product which offers substantial improvements but is not perfect.



High Impedance Fault Detection Block Diagram

Figure 4

There are other service continuity and safety considerations that will influence how the DFM is used. In partially arid regions where a downed conductor can easily start a wild fire, the user may elect to always trip the feeder breaker. In a dense suburban area, the safety risk of a downed conductor may be substantially less than if one or more traffic lights at busy intersections are disabled as a result of the DFM tripping the feeder breaker. In a sparsely populated rural area with few feeders and laterals, where threat of wild fire from a downed conductor is low, service continuity may dictate that the DFM alarm only.

The ability or inability to communicate with a given distribution substation will also affect how the DFM is used. If information that an alarm contact has closed cannot be detected at a remote location, where appropriate action can be taken, then the remaining option is to allow the DFM to trip when a downed conductor is detected. For those distribution substations which are part of a SCADA system, a DFM alarm contact may be wired directly to the RTU at the substation.

If a SCADA RTU is not present, then the DFM's RS232 serial ports can provide remote communications. A DB-25 connector (PL-1) located on the rear of ' the case permits the user to communicate with the DFM from a local or remote computer or to connect the DFM to the host computer of a G-NET substation information and control system. A DB-9 connector located on the front panel of the DFM permits the user to communicate with the DFM from a local or remote computer, but it cannot be used to connect the DFM to the host computer of a G-NET system.

when communication via a serial port is desired, a local PC may be connected via the proper null-modem cable or a remote PC may be connected via interposing modems. Unique PC software, DFM-LINK, is required to communicate with the DFM, DFM-LINK allows the user to call in and inquire if an alarm condition exists. The G-NET system, which would typically be used at a substation to gather and sort information from multiple intelligent electronic devices (IEDs), will automatically call a remote PC to indicate that an alarm exists.

Other monitoring Functions

In addition to high impedance fault detection, the following functions are available in the DFM:

Breaker Health Monitoring
Overcurrent Disturbance Monitoring
Power Quality Monitoring
Present Value Monitoring

Breaker Health Monitoring

The DFM calculates and stores the cumulative It or I2t value (depending on a setting) of each of the three phase currents in order to monitor breaker health. These cumulative values, along with a count of breaker trips, are accessible either through the local man-machine interface (MMI) or via a serial port.

If the DFM is connected to a breaker that has had prior use, the DFM accepts initial cumulative values for each phase and an initial value for the total number of trips. This initialization is accomplished through a serial port. The breaker health values can also be reset through a serial port upon completion of breaker maintenance. If the DFM is configured to allow local MMI resets, a breaker health reset can also be accomplished through the local MMI.

Overcurrent Disturbance Monitoring

The DFM monitors for an overcurrent condition on the feeder by establishing overcurrent thresholds for the phases and for the neutral and then checking for a single two-cycle RMS current that exceeds those thresholds. oscillography and fault data are captured if it is determined that an overcurrent condition exists. In addition, the DFM's local MMI responds with a blinking overcurrent message on the top display line and appropriate LEDs being lit.

Power Quality Monitoring

The DFM's power quality monitoring function provides information for assessing the duration and severity of periods of poor power quality. The DFM checks the power quality by calculating the total harmonic distortion (THD) on each of the three phase currents and voltages over one-minute intervals. The THD is then used to define the effect of harmonics on the power system currents and voltages. It represents the ratio of the root-mean-square of the harmonic content to the root-mean-square value of the fundamental quantity, expressed as a percent of the fundamental. Calculation of THD values requires the accumulation of the real and imaginary components of the 2nd through 13th harmonic frequencies. This accumulation is performed on the phase currents f or each two-cycle sample interval. The three voltage inputs are sequentially analyzed, also using a two-cycle data window.

The THD values stored in the DFM are updated once per minute for each phase current and voltage. These values can be viewed on the local MMI or retrieved through a serial port. A command may also be used to retrieve all the real and imaginary components of the thirteen multiples of the fundamental frequency for the last two-cycle interval.

The power quality data maintained in the DFM includes minimum, maximum, and average values for THD, and the minimum 2-second RMS average for each phase voltage. This data is reported for a time interval configurable to 15, 30, or 60 minutes, with 2, 4, or 8 days of storage provided, respectively, depending on the time interval selected. An extended memory option is available that

provides 35, 70, or 140 days of entries, respectively, again depending on the time interval. (The selected interval and storage capability apply to all the demand data in the DFM.)
Present Value Monitoring

The DFM provides typical panel meter functions by monitoring the present values of the three-phase distribution feeder and displays these on a 2-line by 20-character alphanumeric display located on the front panel. Present value data consists of the individual currents, voltages, watts, VARs, and power factors, as well as the individual total harmonic distortions (THDs) for each of the three phase currents and voltages in models that include power quality monitoring. Three-phase values are calculated for the watts, VARs, VA, and power factors. Each present value is updated once per second.

Additional Features
The following features are included in the DFM. The list of features is followed by detailed descriptions of each.

Breaker Control
Configurable Contact Converters
Configurable Outputs
Configurable Time Interval Demand Reporting
Daily Maximum Demand Reporting
Peak Value Reporting
Event Reporting
Fault Reporting
Harmonic Spectral Analysis
Instantaneous and RMS Oscillography
Local Man-Machine Interface (MMI)
Multiple Groups of High Impedance Settings
Password Protection
Power-On Self-Tests
Run-Time Self-Tests
Serial Communications
Time synchronization

Breaker Control
Two of the DFM's output contacts are designated as control contacts and are configurable for tripping a breaker. If one or both of these are configured as such, the breaker can be tripped by closing one or both of those contacts. A 'close breaker' command will close a dedicated output contact. It is also possible to trip and close the breaker via external contacts wired to the DFM's contact converters by configuring one to 'open breaker' and another to 'close breaker'.

Configurable Contact Converters
All three of the DFM's contact converters are configurable. The user can select from eight possible assignments, but each

contact converter (CC) may be given one and only one assignment, and no two CCs can be given the same assignment.

Configurable Outputs.

To provide greater flexibility in utilization of the output contacts, four of the output contacts are designated as configurable. Two of these are designated as control contacts; the other two, as alarm contacts.

Configurable Time Interval Demand Reporting

Demand profiles are maintained in the DFM for the currents, watts, VARs, 3-phase VA, and power factors, as well as for the minimum, maximum, and average total harmonic distortions (THDs) and minimum 2-second average RMS voltages in models that include power quality monitoring. The demand profiles are averages that are calculate- based on an interval of time known as the demand period, which is configurable to either 15, 30, or 60 minutes.

Daily Maximum Demand Reporting

In addition to the demand profiles, a 35-day history of daily maximums (or minimums, depending on the data) is also maintained. Included in this history are the maximum current per phase and neutral, the maximum three-phase watts, VARs, and VA, and the minimum three-phase power factor. For DFM models that provide power quality monitoring, the maximum THD per current and voltage phase and the minimum 2-second RMS voltage per phase are also included. Each of the entries in the 35-day log is based on a daily demand period average which represents the maximum (or minimum, if applicable) for each day. Each entry is time stamped independently to the nearest second. The 35-day log of daily maximums can be accessed through a serial port.

Peak Value Reporting

Peak values are maintained in the DFM which represent maximum values (or minimum, depending on the data) since the data storage memory was last cleared. Peak entries include the maximum phase and neutral currents, the maximum three-phase watts, VARs, and VA, and the minimum three-phase power factor. Peak THDs for each phase current and voltage, as well as the minimum 2-second average RMS voltages per phase are also included in models that provide power quality monitoring.

Event Reporting

A log of events is maintained in the DFM that contains the last 150 events. Events are time stamped to the nearest half-millisecond. Examples of events logged include alarms, contact operations, logins and logouts, oscillography captures, remote operations, and resets. Event data can be accessed through a serial port.

Fault Reporting
when either a high impedance fault or an overcurrent disturbance is detected, pertinent information (unit ID, date and time, operating time, pre-fault currents, fault currents and voltages, fault type, operation type, selected events) is stored in the DFM. Complete data for the most recent faults is maintained, up to a maximum number of faults. This maximum is configurable to either 1, 2, 4, or 8. The fault data can be accessed through a serial port, or an abbreviated summary containing only the fault types, operation types, and dates and times can be viewed on the DFM's local MMI.

Harmonic Spectral Analysis
Harmonic spectral analysis is performed in DFM models that provide power quality monitoring. Harmonic data is maintained by accumulating the real and imaginary components of the 2nd through 13th harmonic frequencies for phase currents and voltages. The last two-cycle interval of these components can be retrieved through a serial port for analysis.

Local Man-Machine Interface (MMI)
A local MMI, consisting of four pushbuttons, six LEDs, and a 2-line by 20-character alphanumeric display, provides the user easy access for monitoring present values, peak demand data, contact converter and output contact assignments, contact converter states, and disturbance data, as well as DFM status and alarm information. In addition, via the local MMI, the user may view the current date and time, view the DFM model and EPROM version numbers, zero the peak demands and breaker health values, initiate a self-test of the MMI, or initiate the automatic scrolling of present values on the bottom line of the display.

Multiple Groups of High Impedance Settings
Two separate groups of high impedance settings may be stored in the DFM's nonvolatile memory, with only one group active at a given time. The currently active group is determined by a setting. This setting can dictate that the normal settings are active, that the alternate settings are active, or that the active group is determined by the state of a contact converter. If tied to the state of a CC, the alternate settings are active if a CC configured for 'alternate settings' is closed; otherwise, the normal settings are active.

Instantaneous and RMS Oscillography
Two sets of oscillography data are stored in memory each time the DFM detects either a high impedance fault or an overcurrent fault, or when an external contact triggers oscillography. The first set of data consists of the instantaneous voltage and current values for up to 200 cycles of data. The memory for this data can be configured for the most recent one 200-cycle, two

100-cycle, four 50-cycle, or eight 25-cycle events. The second set of data consists of the two-cycle RMS values for the voltage and current for 5400 samples (3 minutes). The configuration of this data is tied directly to the instantaneous Oscillography configuration, with the one, two, four, and eight mapped to 5400-sample, 2700-sample, 1350-sample, and 675-sample events, respectively.

Password Protection

Three different passwords provide security when uploading and viewing stored data, when performing control actions, and when changing settings via a serial port. Each password has a default which is stored in memory as shipped from the factory. These defaults must be changed when the DFM is placed in operation. The three passwords may be viewed in their encrypted form on the local MMI. They may be changed through a serial port.

Power-On Self-Tests

The most comprehensive testing of the DFM is performed during a power-up. Since the DFM is not performing any monitoring activities at that time, tests that would be disruptive to run-time processing may be performed. The power-on self-tests attempt to verify the DFM's hardware components (EPROM, local RAM, interrupt controller, timer chip, serial ports, DMA channels, nonvolatile memory, analog and digital 1/0 circuitry, MMI hardware, etc.).

Run-Time Self-Tests

The DFM's run-time self-test diagnostics are executed on a regular basis during online operation. These self-tests are intended to diagnose possible real-time failures due to component aging, premature component failure, etc. Tests that are run verify DFM memory cell integrity and bus connections without disturbing ongoing algorithmic and communication processes.

Serial Communications

Two RS-232 serial ports are provided on the DFM, one on the front panel and one on the rear panel.

Time Synchronization

The DFM includes a clock that can run freely from the internal oscillator or be synchronized from an external signal. Three different external time synchronization signals are possible. If available, an unmodulated IRIG-B signal connected to the IRIG-B BNC connector on the DFM's back panel is used to synchronize the clock. If the DFM is connected to the host computer of a G-NET substation information and control system, then the DFM receives a time synchronization pulse via pin 25 of PL-1 on the DFM's back panel. A time reference can also be supplied to the DFM from a PC connected via a serial port.

Strategies for Assessment and Test

The DFM is one of many new digital devices for protection and monitoring made available to the utility industry over the last ten years. While digital technology has been accepted by many utilities, each new device is generally evaluated on its own merits. To facilitate the acceptance of such new devices GE has initiated the concept of an Advisory Committee of Experts (ACE). The DFM ACE Team consists of approximately thirty participating utility members and fifteen associate members. The ACE Team acts as an ongoing forum for both application issues and collective performance assessment.

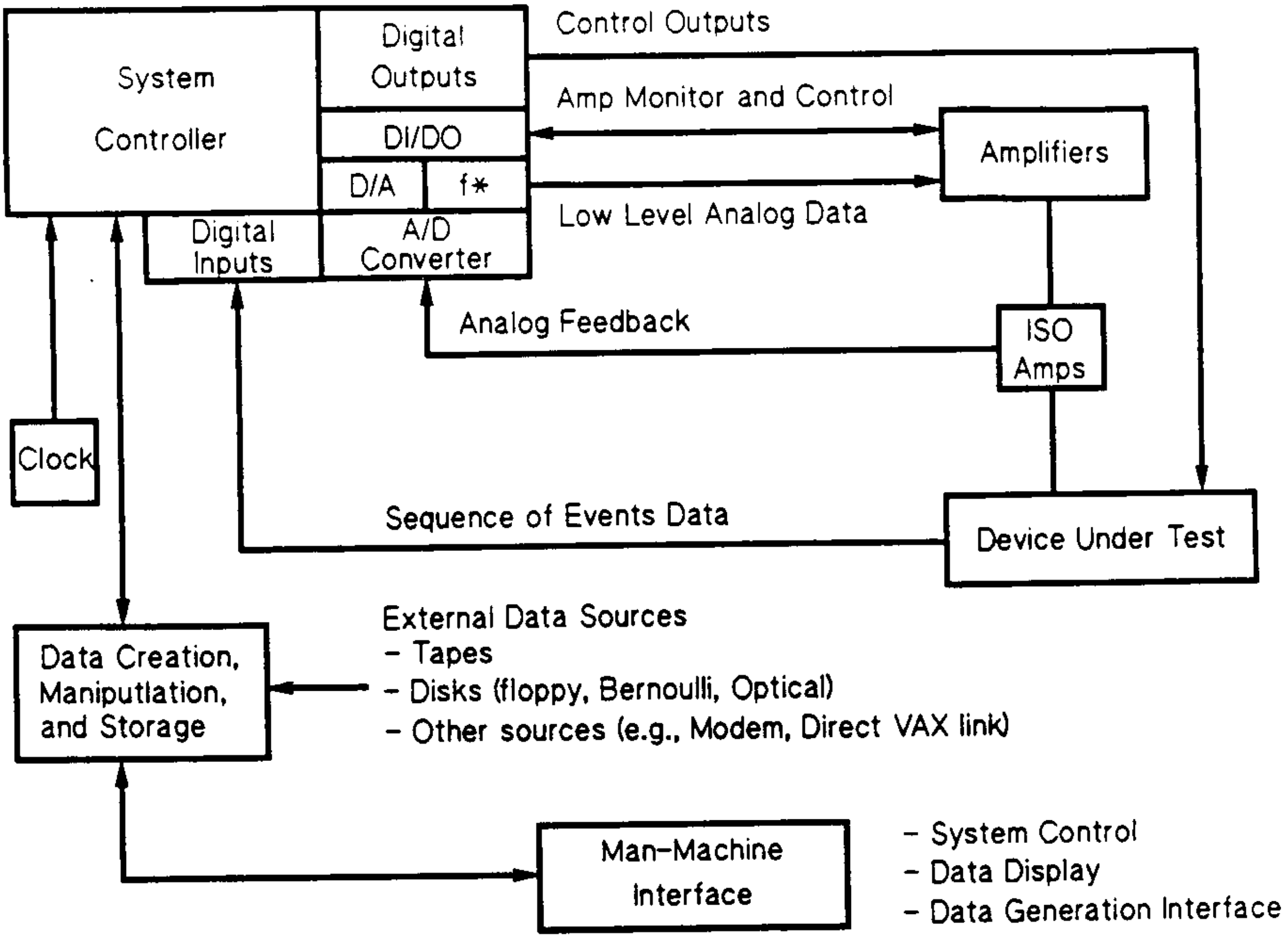
Many of the DFM's algorithms analyze higher order harmonic and non-harmonic frequencies which are beyond the capabilities of most analog simulators typically used for testing protective relay performance. However, the newer digitally-generated simulators, which use the output from EMTP studies or actual DFR recordings as inputs to linear amplifiers the outputs of which are applied to the device under test, are quite capable of the required frequency response. Figure 5 shows a simplified block diagram of the digital model power system (DMPS) located in GE's Malvern Technology Center.

An extensive digital data base of actual power system high impedance faults, as well as non-fault operating transients has already been accumulated. Much of this data was recorded at Texas A&M University's Downed Conductor Test Facility. This data base is currently being expanded by recording staged events on actual utility feeders located on the power systems of various ACE Team members.

At the present time, pre-production DFM units are being tested on the GE DMPS and are being installed on actual feeders by ACE Team members to gain actual in-service experience. A primary goal of the ACE Team concept is that this shared experience accumulated over a relatively short period of time be accepted by the industry in place of the more traditional two to three years of in-service experience (on some other power system) required before a new device is accepted. The sharing of field experience in various environments can provide a much higher confidence level than would be possible with individual utility experience.

Both the DMPS testing and field installation exposure are intended to show that the high impedance fault detection is secure and dependable. The other goals are to prove out the monitoring functions and to show that, as designed, the DFM can survive in the harsh environments encountered at distribution substations.

An ongoing task f or GE and the ACE Team members is to determine the best way to field test the continuing viability of the high impedance fault detection after the DFM has been placed in service. The need for periodic testing of digital protective relays has been discussed extensively over the last ten years. While digital devices generally provide extensive self-test



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Digital Model Power System Simplified Block Diagram

Figure 5

capability, self-testing cannot generally detect a failure in all components. For instance, most digital devices including the DFM use small magnetic CTs and VTs packaged inside the device's case to condition the current and voltage inputs for use by the analog-to-digital converter circuitry. These magnetic CTs and VTs may fail and not be detected by the device's self-test feature. Routine periodic testing is advisable. The question with a digital device is how extensive should this periodic testing be

Many utilities continue to perform periodic tests on digital protective relays in a manner identical to that used for electromechanical and static analog relays. This means that the functioning of the various measurement functions are checked by applying 60 Hz values of test current and voltage required to operate that function at its pickup setting. If a similar tact is taken with the DFM's high impedance fault detection function, then the application of 60 Hz quantities is not adequate. More sophisticated field test equipment will have to be used to obtain the required higher harmonic and non-harmonic frequencies. Whether periodic field testing of the DFM using only injected 60 Hz currents and voltages will be acceptable has not yet been determined.

Conclusions

The lingering problem of not being able to reliably detect high impedance faults and downed conductors has yielded to more than a decade of research and the availability of high performance microprocessors. The accumulated observations of Texas A&M researchers have been distilled into multiple algorithms to permit the detection of a large percentage of high impedance faults with excellent security. Even with these substantial improvements, a few unsafe conditions will never provide measurable parameters, and they will evade detection. The DFM which embodies this technology has been designed to fit the panel cutout of IAC relays to facilitate retrofits where one of the two or three existing phase overcurrent relays is to be replaced with the DFM, Close cooperation between the users and manufacturer in the assessment and application of the DFM is intended to benefit all parties including the general public.

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