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Smart Grid – From Generation to Distribution

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Abstract

A decision support system that has been developed to aid electrical utilities in diagnosing, evaluating, and planning repairs of faults during service outages. The system, called the Integrated Distribution Management System (IDMS), provides both a diagnostics component and an easily configurable integration framework. The IDMS is a cost-effective solution for fault management in small to medium sized utilities.

A small scale model of a power grid to represent the Smart Grid concept is introduced. This model composed of Generation, Substation and Distribution units. The goal of the project is to develop, design and build a Smart Grid that demonstrates the most advanced concepts in smart grid technology.

Overview

The major concerns being faced by rural electric utilities in the current more competitive environment are 1) how to affordably and effectively manage outages in the energy distribution networks, given decreasing resources, and 2) how to cost-effectively integrate existing information systems so that they work collectively to support business activities such as diagnosis and repair planning. This paper presents a system we have developed to address these concerns for electrical utilities, called the Integrated Distribution Management System (IDMS). The IDMS integrates several information systems with a diagnostics component called the Outage Restoration Management Server (ORMS). The ORMS employs an advanced diagnostics reasoning algorithm designed specifically for electrical distribution networks to determine the location of faulty components during electrical outages, and presents the diagnostics results to the user in graphical form to aid in planning repair actions. The IDMS includes a flexible integration framework, based on Model Integrated Computing (MIC) technology that provides the integration between the ORMS and several standard Commercial Off The Shelf (COTS) systems commonly used in electrical utilities. These components include an ESRI GIS system, a Lucent Technologies Interactive Voice Response system (IVR / trouble call system), a QEI Supervisory Control And Data Acquisition system (SCADA), and a Customer Information System (CIS) database. We will show that 1) the ORMS provides accurate, relevant, and timely diagnostics results and 2) because of the use of MIC technology, the IDMS can be easily adapted to integrate other information system components used in utilities.

Utility Environment

Utilities tend to have similar concerns with respect to information technology. Most utilities depend upon computer systems for managing their maps (GIS). Many have SCADA systems for remotely managing sub-stations and main switches. Most have Interactive Voice Recognition Systems (IVR) which automatically log the calls of customers reporting outages. The difficulties come when these systems have to work together, for example in the control room during an outage. A dispatcher watches the trouble call and SCADA systems, fields trouble calls, and coordinates the repair actions of linemen. The dispatcher is actually performing much of the work of integrating and fusing information together and, and manually synthesizes the solutions. It is possible to support these tasks with systems designed to perform the integration and fusion automatically. The solution synthesis can also be supported with appropriate tools. However, small utilities do not have the resources available to develop such systems internally. Hiring companies to develop custom solutions to solve these problems is extremely expensive. Not only is initial cost high, but the cost of maintaining, upgrading, and evolving custom software is out of the reach of many small utilities. The result is that many of the processes, such as fault diagnosis, repair coordination, and resource allocation are done manually by experienced staff.

The problems of improving the fault diagnosis capabilities, and in general integrating the available data systems together in support of important decision making processes need to be solved in a cost-effective and general way. Utilities need be able use and maintain these systems more independently and inexpensively, especially in light of the current more competitive environment.

IDMS

A system was developed, called the Integrated Distribution Management System, which is designed to provide diagnostics support, and eventually to integrate with other decision support tools, from small to medium sized utilities. This system addresses two of the major concerns being faced by these utilities, effective diagnostics, and maintainable and evolvable integration.

The goal of the IDMS is to provide both decision support tools and the integration required to make them work in small to medium sized utilities. One underlying requirement for the design was that the components and the integration code itself should be developed with standard, published interfaces. This approach should produce so-called *open systems*, which are much less expensive to integrate, maintain, and evolve. Toward this goal, and to avoid re-inventing the wheel, we were obliged to use as many Commercial Off the Shelf (COTS) components as possible, and concentrate on making the integration code independent of which components were chosen, so that a utility would not become locked into using a particular vendor's solutions because of large integration costs.

The first type of decision support tool we found to be most needed and relevant was a diagnostic system that would provide queues to the operators about where the faulted components are in the electrical network during outages. The requirements of a diagnostics algorithm to be used for utilities are 1) it must function well using reasonable resources (a standard PC or workstation), it should have the ability to detect multiple non-interacting faults within a sub-station circuit within reasonable response time (10s of seconds), it should be able to take advantage of any instrumentation available (SCADA, trouble calls, etc), it should provide accurate results (few false alarms), and it should be able to pinpoint faults at any level in the network (sub-station, feeder, section, lateral, tap) in any type of component (switch, line, fuse).

It was noted that the algorithms currently in use were lacking in the ability to provide accurate and relevant results. One algorithm we evaluated that was in use in a small utility was a tracing algorithm designed to identify a single fault per sub-station circuit, and was not able to take advantage of SCADA measurements, which can prove extremely useful in utility network diagnosis, as will be shown. No diagnostic systems we found would perform the functionality required with the resources available. The IDMS was designed around the need for improved diagnostics capabilities, and the flexible, extensible integration to support it. Figure 1 illustrates the overall operation of an electric utility.

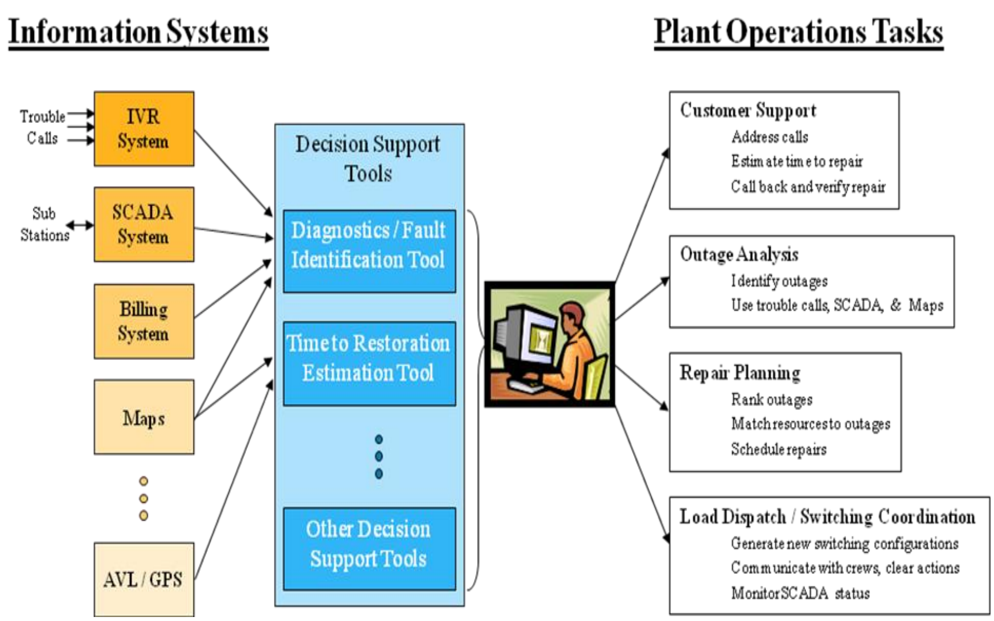

Figure 1. The overall operation of an electric utility.

System Architecture

GIS & FM and Data Systems

These systems are usually present in utilities, in varying forms. A GIS system contains a model of the circuit topology (where components are, how they are inter-connected, and some service, or customer information). Since a major goal was to promote open systems concepts, the IDMS integration framework was designed to work with GIS systems which store the circuit topology information in a standard format, such as a commercially available database (SQL Server, Oracle, SyBase, etc), or in files with either a published format or with standard access drivers available (OLEDB, ODBC, etc). Facility Management (FM) systems are used to design, maintain, control, and generally manage the network. Examples of these are work order management systems, which are used to update the GIS model as the circuit is extended and maintained, and load analysis packages such as CymDist.

The Data Systems provide additional information about the network configuration, the customers, and the health and fault status of the circuit. The status information can be thought of as instrumentation of the circuit. For example, a SCADA system will provide remote monitoring of currents, voltages, and switch positions of various remote circuit components (direct measurements). An IVR (trouble call) system will field customer phone calls and log service outages (observations of customers). A customer information database contains address and contact information of customers, service location, and billing information (additional information about the network and customers) that can be used in matching phone numbers of trouble calls to locations in the electrical network.

ORMS

The ORMS diagnostics algorithm is implemented by as a Microsoft OLE/DCOM component, and is controlled via a simple graphical user interface. This is called the ORMS Client, and it allows the user to initialize and update the ORMS, and run the diagnosis algorithm, and view the outages that have been diagnosed. The ORMS Client is also capable of displaying the faulted components and the affected customers on the GIS map. Currently, the implementation supports this functionality only for the ESRI ArcFM GIS software. However, extending this capability is straightforward.

Diagnostics Approach

The approach taken by the ORMS algorithm does not make the single fault assumption of simple tracing algorithms. It automates the manual analysis usually performed by the dispatchers, and considers the possibility that in the presence of *N* trouble calls, the number of faults could be 1, 2, *up to and including N.* The algorithm constructs fault hypothesis sets containing *N* or fewer components that 1) could completely explain the *N* trouble calls observed, and 2) contain a minimal set of components, in that if any component were removed from the set, it would no longer completely explain the observed trouble calls. The fault hypothesis sets are then ranked, and the highest-ranking set is chosen. The difficult tasks in the fore mentioned approach are 1) finding an efficiently programmable mathematical formalism to use in generating the hypothesis sets, 2) dealing with the combinatorial size of the hypothesis space, and 3) evaluating the relative "likelihoods" of the resulting hypothesis sets.

The IDMS Integration Framework

The IDMS employs Model Integrated Computing (MIC) technology, namely the Mutigraph Architecture (MGA) to create a flexible, reconfiguration, and extensible framework with which the data from the GIS system and the Data Sources are integrated with the ORMS. The Integration Framework can also provide integration for other decision support tools.

Diagnostic Capabilities

The ORMS diagnostic engine is capable of efficiently diagnosing faults in energy distribution networks. The following capabilities make this system unique:

- It can locate not only a single fault, but also multiple faults (non-interacting faults within a single feeder)
- It is able to locate and identify any faulty electrical components, including conductors.
- Because of the BDD technique described above, the diagnosis is fast and accurate. It can process multiple outages in matter of seconds. The scalability issue is resolved by using the hierarchical structure of the feeder circuits and the fast BDD method.
- The system is accurate and reliable because the algorithm takes advantage of all available data. It considers the component properties, their relationship and associations, their locations, and the weather conditions when ranking the fault hypothesis. It also uses historical knowledge of component failures in the decision making process. These properties make the diagnostics approach more realistic and applicable to real-world utility networks.
- Component properties, their relationship and association, and their locations are considered in component ranking.

Integration

The use of MIC in the Integration Framework has produced a flexible, extensible, and easy to manage integration between ORMS, the data source, and the GIS system.

The approach has proven to achieve almost effortless integration, and reconfiguration. Although currently the IF has been used only with the ORMS, we believe that it is capable of supporting the data integration needs of many decision support applications.

Case Study

A team of students under direction of a faculty advisor created the Smart Grid Project to assist in understand the real world problems and challenges. This study was intended to present the detailed specifications, operation procedures, and significant functions of this project. The main goal is to promote excellence and importance in both Cal Poly Pomona's power program and its Electrical and Computer Engineering department research in smart grid technology. Figure 2 illustrates the small scale smart grid.

Figure 2. The small scale smart grid for power utility

A decision was made on the fact that a grid must involve a real-time update of grid to computer communications. A refresh rate of 100ms was implemented to handle near instantaneous updates on the GUI. In addition, since it was decided to completely scrap the idea of using analog circuitry, such as flip flops and MUXs, the data was received directly from the house sources. This provided with a more precise evaluation of our grid. For the main fault detection system, all of the logic was based within the micro-controllers. The use of simple transistors along with the micro-controllers provided a simple fault detection layout, and an overall improvement in design. The use of transformers have also been translated into the project as well, however, it was designed in such a way that certain transformers will act as upstream transformers. This enabled the simple cascading system of older type power grids.

As for added and enhanced features, a carbon neutral, repowering neighborhood, a primary alternate feeder with breaker system, and a dynamic contingency plan was employed. Now these features are very modern systems which involved much more research and development. The integration of these systems will provide an association of real world systems which benefit many different customers, such as residential, commercial, and the critical care customers. Figure 3 illustrated the completed model of smart grid illuminated in dark.

Figure 3. The completed model of smart grid illuminated in dark.

Conclusions

This paper will present an integrated fault management system designed and developed for power distribution networks. The diagnostics component, the ORMS, is capable of efficiently identifying faulty components during power outages. The ORMS algorithm was successfully implemented, and has been integrated with several standard Commercials Off The Shelf (COTS) systems commonly used in electrical utilities. The COTS systems provide useful information to the diagnostic engine, including SCADA measurements, customer information, and customer calls. The diagnostic engine uses this data in localizing faulty components.

References:

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