Data Warehouse and Analysis Agents

M. Kezunovic, T. Popovic

***Abstract* - The paper discusses automated substation data integration and analysis. Recorded data collected from various substation IEDs is stored into a substation data warehouse that utilizes standardized file formats and database interface. The data warehouse allows different software agents to convert raw data to useful information and represents an interface for functional integration of different applications.**

The paper introduces a framework for application (software agent) integration. The framework allows accessing IED and configuration data, as well as organizing agent reports, and user interfaces. The transparent implementation of the application interfaces enables an open software environment design, an important feature of future automated analysis systems.

Examples of open system implementations are given at the end. First example demonstrates a solution that integrates data from three types of substation IEDs and combines three processing and analysis agents. Second example demonstrates how adding digital protective relay data into an existing solution for automated integration, processing and analysis of DFR data may be done. Finally, the last example demonstrates analysis agent that performs two-end fault location calculation built on the top of the DFR data integration solution.

***Index Terms* — substation measurements, substation automation, power system faults, power system monitoring, substation data warehouse, software agent, fault location**

I. Introduction

The paper discusses an open system approach to performing automated analysis of integrated substation data. A concept of utilizing universal substation data warehouse as a connecting point for different analysis functions is presented in a form of a framework for application integration. The main focus is on the analysis agents that utilize intelligent electronic device (IED) data collected in power system substations. The framework is introduced through its application to a case study. Many different analysis agents from different vendors may be integrated utilizing the proposed framework.

Different functions related to the integration framework are:

- Interfacing to IEDs (retrieving data collected in substations).
- Organizing Data warehouse (creating repositories for IED and configuration data, as well as results/reports.
- Processing and analyzing IED data (implementing different analysis agents).
- Presenting and disseminating results/reports (providing customized user interfaces).

The paper focuses on the data processing and analysis functions. Each analysis function, analysis agent, has to provide interfaces for handling IED data, system configuration information, analysis reports, as well as integration into user interfaces. Each requirement is explained in details through an example. The data warehouse is identified as a "point of connection" between different analysis agents and different functional groups.

The example focuses on two different scenarios. First one when the analysis agents utilize IED data based on the IED type, specifically, digital protective relays, digital fault recorders, circuit breaker recorders, etc. Another scenario is where the analysis agents interact between themselves. For example, if one analysis agent is to perform single-ended fault location calculation, another one might utilize the reports from two ends of the same line to calculate the fault location using two-ended algorithms. The presented concept demonstrates its advantages of an open system design where different analysis agents can work together with their functions being combined.

II. Background

Reasons and requirements for data integration have been discussed earlier [1,2]. While solving the issues of automating data integration and IED file processing engineers are faced with additional requirements such as proper handling of communications, as well as NERC recommendations for protection and control [3], and cyber security [4]. The proposed open system framework is shown in Figure 1.

The concept discussed in this paper is addressing another important angle – analysis agents and their interaction. Each analysis agent can be seen as an individual application that utilizes data from the

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warehouse as an input data and stores its output data back to the warehouse or to a user via user interface. To achieve an open system design, it is absolutely necessary to provide users with a transparent data warehouse solution that can be easily maintained and used by variety of analysis agents. As shown in the Figure 1, the key for the integration is the data ware house. The main building blocks of the open system solution are discussed next.

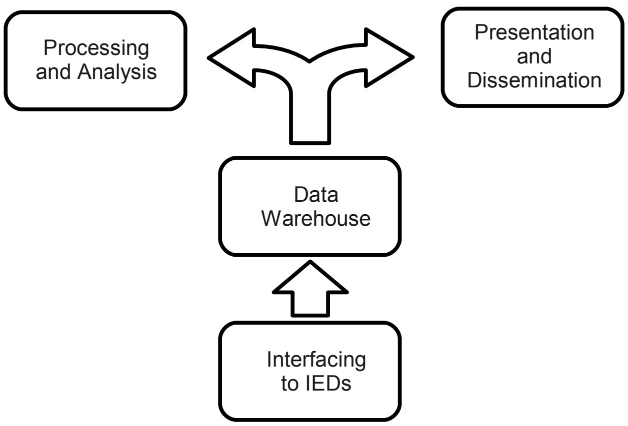

Fig. 1. Concept: Integrating Agents Through Data

A. Interfacing to IEDs

Software modules for data integration provide interfacing to IEDs to allow automated retrieval of newly recorded data. This interfacing is typically implemented by using vendor specific software for data retrieval and then dedicated routines for importing the IED data into the file repository. Sometimes, the interface is implemented by the use of direct communication to IEDs. The key here is automating data format conversion and file format unification. The solutions discussed in this paper provide modules that can interface to variety of IED products from different vendors.

B. Organizing Data Warehouse

Being identified as a central block in the solution it is critical that the data warehouse is implemented to be easily utilized by both the users and application agent developers. The database functions should be implemented using as standardized as possible database engines. A good approach is using standard SQL database engine with an instructions subset that is common across SQL database implementations. The files should be stored in manageable file repositories to allow an easy access and maintenance of the data files.

C. Processing and Analyzing IED Data

The simplest model of the processing and analysis functions (core functions) is that a module reads data from the repository, creates an output without corrupting the original data, and the output results are stored back into the repository into location predefined for the processing results. In some instances, processing and analysis functions may have their own data repositories and/or databases that may be decoupled from the integrated data. The processing and analysis functions are typically implemented as stand-alone programs and provide fully automated mode of operation. The key feature of the open system design is the ability to integrate software agents from different vendors.

D. Presenting and Disseminating Results/reports

When creating a solution by integrating different applications several user interfaces may be created. An example is shown I Figure 2.

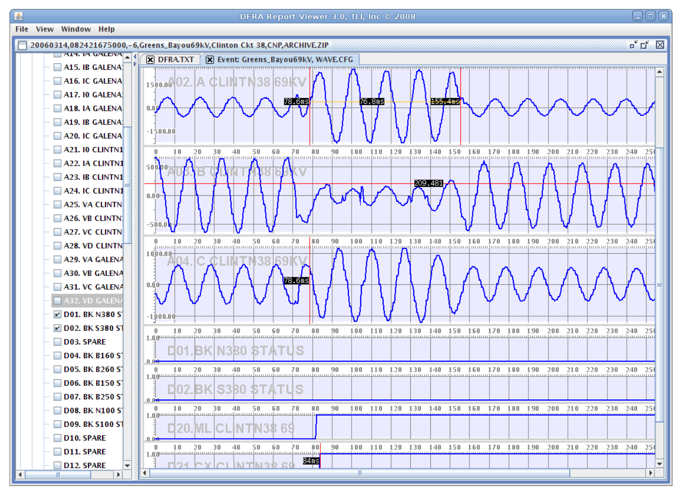

Fig. 2. DFR Assistant™ Event Data and Report Viewer [5]

While each core application may have its own user interface, a universal approach may also be feasible. Main functions of a universal user interface are:

- Event browser: enabling navigation through event tables
- Event viewer: displaying event waveforms and reports
- Configuration editor: providing tools for editing and creating configuration setup.
- Top level user interface (web portal): directing user to specific applications

- Dissemination: accessing data via Graphical User Interface (GUI) and/or utilizing automated notifications (pager, email, printer, fax).

III. Data Warehouse Example

The example of the substation data warehouse design shown in Figure 3 combines the use of a file repository and a database engine in attempt to get the best from both worlds. The file repository is used to store the following:

- IED data
- Configuration data (IED, substation, agents)
- Analysis reports/results

A. IED Data

- Proper time synchronization, most commonly through GPS or NTP [6,7].
- Use of unified data format (COMTRADE, IEEE Std C37.111-1999) [8-10].
- Utilization of file naming convention (modified IEEE recommendation C37.232-2007 [11]).

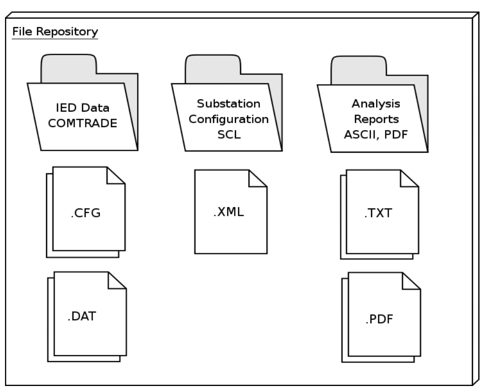

Fig. 3. Data Warehouse Example – File Repository

B. Configuration Data (IED, substation, agents)

- Providing universal substation configuration in XML file format (SCL) [12].
- Keeping the configuration history (to be able to retrieve configuration for the given time stamp).
- Enabling import/export of configuration data to core applications.

C. Analysis Reports/Results

- Analysis reports to be kept in ASCII, XML, PDF (preferably all). Use of widely accepted standard formats makes the system more open and easy to interface with third party programs, which provides more flexibility for the users.
- Utilization of proper file naming convention (same as used for IED data files with an optional field to identify report type)

D. Additional Considerations

- Automatic synchronization of all the new IED event data to appear in the repository in a timely matter.
- Use of "read only" format for the repository data when accessed by the applications. Applications using database should not modify original IED data created in the integration layer.
- Allowing addition of new data types in the file repositories. It is anticipated that additional data may be artificially created (by agents) "virtual IED data".

In this example the focus is on the triggered data captured by Digital Fault Recorders (DFRs) or Digital Protective Relays (DPRs) The solution may be expanded to provide for storage of periodic or log type data (such as generated by PMUs or PQ meters) or agent generated data (merging substation IED data into "virtual IED" or "virtual substation" data).

IV. Framework for Application Integration

Data warehouse has been identified as a main connecting point for analysis agents and other applications. In order to enable functional integration of different applications the framework for applications implementation has been developed as depicted in Figure. 3.

The framework for application integration is focusing on implementing four interfacing components:

- IED data import/export.
- Configuration data import/export.
- Report import/export.
- GUI integration (optional).

First three interfaces are a direct connection to the warehouse. These should be implemented universally and transparently for different application agents. The optional GUI integration is only to enable user to directly communicate with and configure the analysis agent.

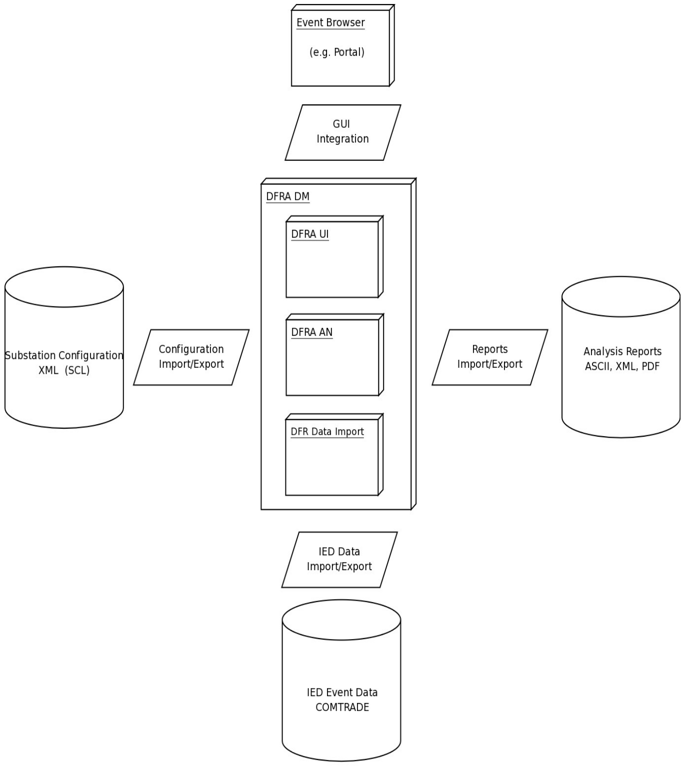

Fig 4. Typical Processing and Analysis Agent

DFR Assistant™ agent (Fig. 4) processes newly downloaded DFR records [5]. The analysis uses both the converted DFR data (COMTRADE file) and system configuration data to create an analysis report.

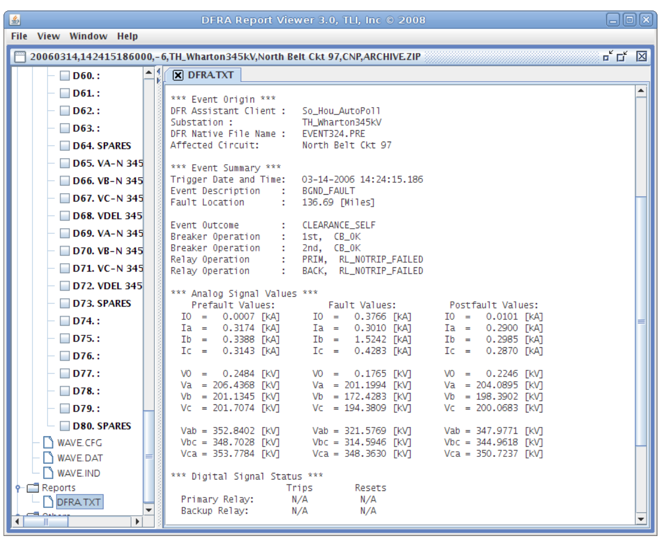

Fig 5. DFR Assistant™ Agent – Analysis Report [5]

The analysis reports are stored back to the data warehouse and available for both the users and other agents.

V. Example Implementations

This section provides examples of an open system design and its uses in building different solutions. The examples are related to on-going deployment projects at FirstEnergy, CenterPoint Energy, and New York Power Authority.

A. Data Integration (Multiple IED Types)

In the data integration deployment example the concept is being implemented in a two-substation setup. The setup requirements are:

- One Digital Fault Recorder (DFR), five Digital Protective Relays (DPRs), and ten Circuit Breaker Recorders (CBRs) in the first substation.
- Radio modem communication from CBRs to the control house.
- One DFR and two DPRs in adjacent substation (for collecting two-end transmission line records).
- Data warehouse
- Processing agents for the three IED types.
- User interfaces (web based)

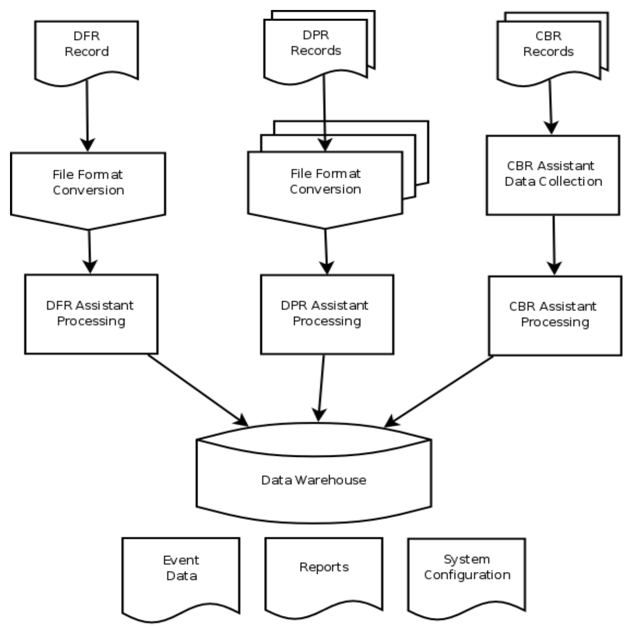

Fig. 6. Data Integration Solution

The data from three different types of IEDs is being integrated and automatically processed by individual IED-based processing agents (Fig. 4). All the data coming from digital fault recorders (DFR), digital protective relays (DPR), and new device called circuit breaker recorder (CBR) is collected and stored in the data warehouse. The processing and analysis agents make sure that the data file formats are being unified (COMTRADE, proper file naming). DFR Assistant™ agent provides detailed analysis and fault location calculation based on DFR data. DPR Assistant creates the packages with event data (oscillography) and reports obtained from relays.

Circuit breaker recorder device monitors the signals inside the control circuit of circuit breakers [12]. CBR Assistant™ agent creates reports based on extracted signal features and status changes relevant to the trip and close operations of circuit breakers.

All the IED data is integrated into universal data warehouse and accessible through web-based user interface, also implemented as an application agent.

B. Adding Digital Relay Data to DFR System

Existing system with DFR data integration and analysis solution based on the DFR Assistant™ Agent is being expanded with digital relay data. The setup requirements are:

- ~50 substations
- ~50 DFRs, one DFR vendor, different vintages (old and new models)
- Two master stations
- Data Warehouse
- DFR data processing agent
- User interfaces (web and desktop)

Primary focus in this example is to expand the DFR solution to include the relay data coming from digital protective relays in the transmission system. Initially, a small number of relays is being added into the picture with a goal of covering different vendors and models in the future. The main features are:

- Two major relay vendors
- Distance and current differential relays
- File format conversion, proper file naming
- Relay data processing agent

The primary issue in this example is utilizing universal presentation layer for all the data, as well as the results/reports.. Both the web-based and desktop-based user interface versions utilize transparent access to the data in the warehouse for different purposes. The events are listed and accessed the same way regardless of the IED type, model, or vintage. An example of the solution is shown in Figure 7.

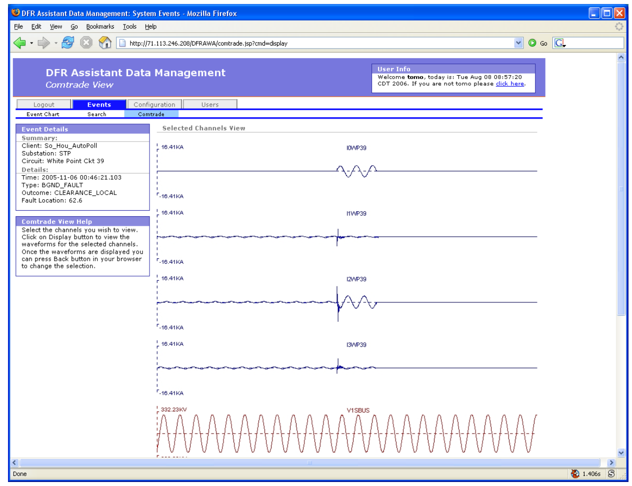

Fig. 7. DFR Assistant™ Web-based Interface

C. Two-End Fault Location Calculation Agent

This example covers an implementation of a DFR data integration and analysis solution enhanced with two-ended fault location [13]. The main setup requirements are:

- ~20 substations
- ~20 DFRs, two vendors, different vintages
- ~20 master station setups (in each substation)
- Data Warehouse
- DFR data processing agent
- User interfaces (web and desktop)
- Two-end fault location calculation agent

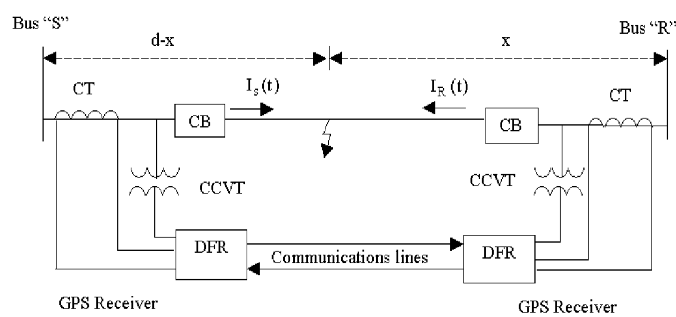

Fig. 8. Two ended fault location setup

The two-end fault location agent in this example is being implemented to work off of the data from the data warehouse that combines records from two ends of a transmission line. The configuration of the two-end Fault location algorithm deployment is shown in Figure 8. The agent interfaces into the repository and scans the newly stored event data looking for pairs of DFR records that correspond to two ends of the same transmission line and same fault event. The actual operation of the agent is triggered by occurrence of a DFR data record and report created by analysis agent from one end. The biggest challenge in this case is obtaining "good" test data as the DFR records have to be time synchronized and there is not much historical data available. For the purpose of initial setup and evaluation the two-end fault location algorithm is being tested with in-house simulated faults.

VI. Conclusions

The paper presents a framework for an open system design allowing integration application. The goal was to:

- Enable coexistence and cooperation of different analysis agents as well as user interface applications through transparent interfacing. Several deployment examples to illustrate this approach are provided.
- Implement universal access to substation data warehouse. An example of a data warehouse is presented. The data warehouse utilizes both file repository and standard SQL database engine.
- Provide solution upgrade path that will allow future application agents to be added. Each of the example deployment projects has limited requirements now that are expected to grow in the future

VII. Acknowledgments

Authors would like to thank several individuals involved in current solution deployment projects:

Mr. Scott Sternfeld and Mr. Robert Foster from FirstEnergy, Akron, Ohio;

Ms. Edvina Uzunovic from New York Power Authority, White Plains, New York;

Mr. Don Sevcik and Mr. Robert Lunsford from CenterPoint Energy, Houston, Texas;

Mr. Aty Edris from Electric Power Research Institute (EPRI).

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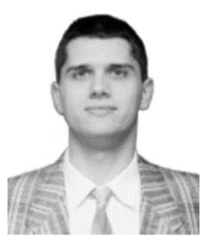
IX. Biographies

Mladen Kezunovic (S'77, M'80, SM'85, F'99) received his Dipl. Ing. Degree from the University of Sarajevo, the MS and PhD degrees from the University of Kansas, all in electrical engineering, in 1974, 1977 and 1980, respectively.

He has been with Texas A&M University since 1987 where he is the Eugene E. Webb Professor and Site Director of Power Engineering Research Center (PSerc), and NSF I/UCRC. His main research interests are digital simulators and simulation methods for equipment evaluation and testing as well as application of intelligent methods to control, protection and power system monitoring. Dr. Kezunovic is a registered professional engineer in Texas and a Fellow of the IEEE.



Tomo Popovic (M'99, S'06) received his BS degree in electrical engineering in 1994 from University of Novi Sad, Serbia and his MS degree from Texas A&M University, USA.

He has been with Test Laboratories International Inc. since 1998 where he is a Sr. Systems Engineer. His prior positions were with NIS-GAS, part of Petroleum Industry of Serbia, and University of Novi Sad, both in Novi Sad, Serbia. His main professional interest is developing and implementing software and hardware solutions for industrial applications, especially in the field of electric power system engineering: substation automation, analysis of fault records, transient testing of protective relays and digital simulators. Mr. Popovic is Senior Member of the IEEE.