OWNERSHIP OF DATA AND THE NEED FOR INFORMATION EXCHANGE

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Abstract-This paper addresses the data ownership and information exchange issues as they relate to operating the power system in the new, restructured environment. The power system liberalization, privatization and deregulation have introduced a new view regarding data ownership. This may now be different from the situation seen in the past where all the entities of the power system (generation, transmission, distribution, and customer services) were under the same "jurisdiction". In the new environment, the data may be owned by the entities that are now independent, and the need for information exchange becomes pretty important. The paper primarily discusses the experience in the USA, but the conclusions may be extended to other countries (regions) and different utility practices as well.

***Index Terms*—Control, Data, Deregulation, Information, Liberalization, Maintenance, Operation, Planning, Privatization, Protection.**

I. Introduction

THIS paper addresses the issues of data ownership and information exchange that have re-surfaced as the various changes in the utility industry, such as liberalization, deregulation, restructuring, and privatization have taken place in recent years. In the "old" days, the utility industry was horizontally and vertically integrated meaning that generation, transmission, distribution, and customer support as well as control, protection, maintenance, planning, and operation where a part of the business carried out under one management and financial umbrella. With the recent changes in the industry, a disintegration process is under way where the traditional organization is being drastically changed. New and independent ownership may now be introduced and practiced for the generation, transmission, distribution, and customer's services. In addition, new market players such as Independent Power Producers, Independent System Operators, Power Marketers and Power Retailers are resuming their unique roles. As a consequence, the traditional control, protection, maintenance, planning and operation functions need to be coordinated in a different way relying on new approaches in integrating the data and exchanging information.

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This paper re-visits the issues of data ownership and information exchange through discussing the new needs and requirements for collecting, storing, and processing the data. The paper reviews how the data was integrated and information exchanged in the past indicating how the recent changes in the utility environment are bound to affect the existing practice. To contrast the previous practice, the paper indicates how the ownership of data as well as the information exchange practices may change as the evolving utility businesses are established.

The first part of the paper explores the recent changes bearing in mind the impacts on data ownership and information exchange. The traditional approaches are reviewed next. Several case studies of the new approaches are presented to illustrate the new needs and solutions. Conclusions and references are given at the end.

II. Recent Changes In The Utility Industry

The way of handling the data integration and information exchange may have an important impact on the way the utility industry operates in the future, including both the time response and reliability of the actions taken. That is why the emphasis has been placed on the issues of data ownership and information exchange as the guiding themes of this paper.

A. Restructuring

Restructuring has been primarily related to two visible trends:

- Breaking up the "vertical" organization of utility business into several separate entities (generation, transmission and distribution, and retail customer service)
- Creating new business entities such as the independent power producers, power marketers, and independent system operators.

By breaking up the existing organizational structure, several traditional functions have been affected. The major emphasis may be on the planning side where the system view is different now since the data describing in detail all the system components (generation, transmission and load centers) may not be readily available to all parties. In terms of the system operation, the traditional control and protection infrastructure has remained, but the way the relaying and control are coordinated has changed due to the need to perform the coordination between different entities now vs doing it inside the same company before.

Introducing the new business entities has created a question of what may be the new data and/or information that the entities may need to perform their tasks. As the new entities are created, their physical location may be quite spread across a wide region or even an entire continent, which emphasizes a particular need for collecting and processing the data locally while exchanging the information remotely.

B. Deregulation/Liberalization

Deregulation and Liberalization are a part of the entire restructuring process resulting in a different way of doing business. Earlier, the utility business has been confined to the “perimeters” of the utility service area, which traditionally meant the geographical area covered by the interconnected system owned by one company. Today, a company may own a business miles away from their traditional service area due to the opportunities of wheeling the power over long distances using someone else’s transmission system. Similarly, a company may be capable of generating the power at various geographical locations far away from their traditional service area through an ownership of independent generating sources. In addition, new market players are introduced allowing independent ownership of power generation, power marketing, and power retailing services. Collecting data from various locations that are not confined to a traditional system boundary and exchanging information among different areas is a common requirement in the new environment.

C. Privatization/Change of Ownership

The emphasis here is on the physical asset ownership. As a result of the new trends, a particular business entity may now own new equipment, or may not own any equipment at all. In that sense, the data ownership may be somewhat decoupled from the ownership of the equipment used to collect the data or the equipment needed for information exchange. Since the information extraction and exchange may be customized to the particular needs of the users that may not even own the data collection equipment, the question remains as to what information should be extracted, where it should be sent and stored, and who should have an access to it. Inevitably, the question of who should bear the cost of collecting, processing, storing, maintaining, and exchanging the data and information will need to be addressed as well.

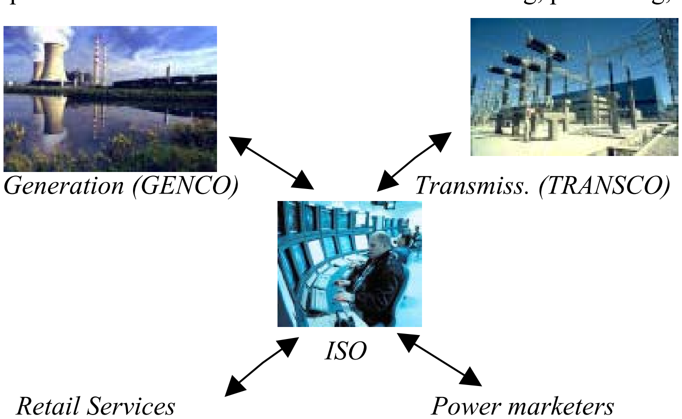

Figure 1. Restructured Utility Environment

To summarize the situation, Figure 1 gives a typical arrangement for the various entities in the new business environment.

III. The traditional Approaches

This section gives a very brief overview of the traditional approaches to data ownership and information exchange. This section serves as a reference for emphasizing the changes that may have to be made in the new utility environment.

A. Planning

Traditionally, this function is based on the data and information about the overall system including details on the generation capacity and scheduling as well as the load allocation and forecasting. Obviously, if the system is broken down into different owners of the transmission and generation, their planning function is now dependent on the information exchange, which in turn is dependent on the availability of data owned by different business entities that may even have a competing relationship.

B. Operations

The real-time field data is used to control the system, manage the outages and define the system restoration strategies. This data is traditionally collected by the Supervisory Control and Data Acquisition (SCADA) systems and utilized by the Energy Management System (EMS) functions. The data may still be collected the same way in the new environment except the owners of data and the potential users of information may not be the same entities. Who does the required information processing for the end-user is an issue of interest in the case the owners of data and users of information are different.

C. Maintenance

The traditional approach is to have an enterprise-wide database that contains all the maintenance information. In the case of a single system, a software management package, such as the Reliability Centered Maintenance solution [1], may be used to integrate the data and exchange the information. Being a part of the same enterprise computer system, the issues of data security, user authorization, and database access may not be as complex as if the same functions are implemented across multiple enterprise systems that have quite different design properties.

D. Customer Retail Services

In the “old” times, the customer retail services were a part of the traditional utility business infrastructure. In the new environment, this function may be provided as an independent service that may even not be regulated at all. As such, the new business entity may still have to rely on the customer data that a utility may own, but the relationship to the owner of the data may have to be “at arms length”, in particular if the owner is the “old” company that the customer service originally was a part of and then branched off as a different business.

IV. Case Studies: New Needs And Solutions

This section gives a few examples how the ownership of data and information exchange may be implemented in the new utility environment. The examples concentrate on a specific function implementation that may have to be quite different from the traditional approach used prior to the recent changes.

A. Generation Maintenance Scheduling - Mobile Agent Approach [2]

1) Background

A typical maintenance scheduling procedure in deregulated environments involves the planning, submitting and approving steps [3]. At first, an asset owner makes a tentative schedule/plan for the maintenance, and then the initial schedule is submitted to another entity, usually ISO, for approving. The ISO checks the submitted schedule against the system constraints to decide its feasibility. If it is not feasible, the entity will be asked to modify its maintenance schedule. The whole process may be tedious and very complicated when more than two parties are involved.

The authors in [3] applied Benders decomposition method to deal with the new maintenance scheduling issues in the deregulated environments. The basic idea is to de-couple the whole scheduling problem into one master problem and several sub-problems. The master problem is solved at the assets owner's side, whereas each sub-problem represents a set of constraints imposed by a third entity. An iterative process is usually needed until the solution converges or no solution conclusion is reached. Exchanging the information on paper and involving human beings to create the input and output may be time consuming and error-prone.

The agent is a natural concept for representing an entity. By integrating some gaming strategies into an agent, it can represent the client doing the time-consuming negotiation work, especially when some conflicts need resolving or other types of negotiation are needed. Intelligent agents with heuristic experience captured from human experts may become very useful. In [4], the agent technology has been considered as a promising approach to construct the third generation EMS systems.

2) Problem formulation

The problem given in [3] is a Mixed-Integer Programming (MIP) problem. The number of generation units is usually not very big, so the problem generally can be solved efficiently. But, the system constraints are usually not available to a GENCO in a deregulated environment, which means a trial schedule without system constraints must be defined at first and then be submitted to the ISO for approbation. The ISO will check the feasibility of the schedule, and either approve it or deny it. When a proposed schedule is denied, the GENCO would prefer if the ISO could feed back some information on how to modify the initial schedule to meet the system constraints.

For the generation unit maintenance problem given in [3], Benders decomposition method can be used to decompose it into a GENCO master problem and an ISO sub-problem. The master problem is solved without system constraints at first to get the decision x_{it} variables. Once those variables are fixed, the ISO sub-problem can be solved with system constraints. If the initial trail schedule is not feasible, a Benders cut is generated. The cut is added into the master problem in the next iteration. The whole process is depicted in Figure 2.

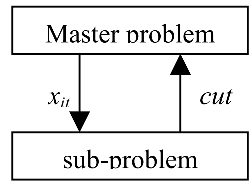

Figure 2. Iteration of the solution process

3) Solution:Benders Decomposition: [3]

To make the illustration more clear, the mixed-integer problem of [3] is rewritten as the following form:

$$\begin{aligned} Min \quad & c^T x + f(y) \\ S.T. \quad & Ax + F(y) \ge b \\ & x \ge 0 \\ & y \in Z \end{aligned} \tag{1}$$

Where:

A: constraint matrix

x: continuous variable vector

y: integer variable vector

If values of ***y*** are fixed at first by choosing:

$$y \in R = \{ y \mid Ax \ge b - F(y), x \ge 0 \} \tag{2}$$

Then (1) is linear in ***x***, and it can be written as:

$$\min\{ f(y) + \min\{ c^T x \mid Ax \ge b - F(y), x \ge 0 \} \} \tag{3}$$

Based on the duality theory, the set R in (2) may be rewritten as:

$$R = \{ y \mid (b - F(y))^T u_i^{\,r}, i = 1 \ldots n_r \} \tag{4}$$

Where u_i^r is the extreme point vector which belongs to a cone C = $\{\boldsymbol{u} \mid \mathbf{A}^T \boldsymbol{u} \le 0,\ \boldsymbol{u} \ge 0\}$, and n_r is number of extreme points of the cone C. The inner minimization in (3) can be rewritten as follows:

$$\begin{aligned} Min \quad & c^T x \\ S.T. \quad & Ax \ge b - F(y) \\ & x \ge 0 \end{aligned} \tag{5}$$

Its dual problem is:

$$\begin{aligned} Max \quad & (b - F(y))^T u \\ S.T. \quad & A^T u \le c \\ & u \ge 0 \end{aligned} \tag{6}$$

Substituting (6) into (3) yields a new form of (1):

$$\min\{ f(y) + \max\{ (b - F(y))^T u \mid A^T u \le c, u \ge 0 \} \} \tag{7}$$

Expression (7) is equivalent to the following procedure:

$$\begin{aligned} &Min \quad z \\ &S.T. \quad z \geq f(y) + (b - F(y))^T u_i^p, \quad i = 1..n_p \qquad (8) \\ &\qquad (b - F(y))^T u_i^r \leq 0, \quad i = 1..n_r \end{aligned}$$

Where u_i^p is an extreme point of P = $\{\boldsymbol{u} \mid \mathbf{A}^T\boldsymbol{u} \leq c,\ \boldsymbol{u} \geq 0\}$. The Problem (8) is equivalent to the problem (1) with an integer variable y. Problem (8) has one constraint for each extreme point that translates into an enormous number of constraints even in a problem with moderate dimensions. However, only a small fraction of constraints will be binding at an optimal solution. Therefore, we begin with a few constraints and solve (8), which is the master problem. The sub-problem (5) or (6) is used to see if this solution satisfies the remaining constraints.

4) Requirements for Implementation:

The solution method mentioned above requires an implementation with the following features:

- It shall work on heterogeneous hardware platforms and operating systems. The iteration process involves different entities, such as the GENCO and ISO, which may have different hardware and software environments.
- It shall be able to authenticate and authorize the users.
- It shall provide secure communicate channels in the cases that the public network is used to connect the GENCO and ISO.
- It shall integrate with the existing systems well.

5) Implementation

The maintenance scheduling system is implemented using the Concordia mobile agent software [5]. Two computers have been setup to represent the GENCO and the ISO respectively. Both computers have the Concordia server running. The mobile agent travels between those two servers and calls some local services provided by the servers. The services may be provided by other Java software, or exported from legacy systems using Java Native Interface (JNI) or Common Object Request Broker Architecture (CORBA) [6].

When solving maintenance scheduling problems, the mobile agent architecture provides the following advantages:

- The mobile agents can be authenticated when they arrive at an entity (GENCO or ISO) to determine their identity.
- An entity can control the information the mobile agents can access according to their identification.
- An entity can expose its services to mobile agents and the entity can control the accessibility to the services.
- The software structure becomes more flexible by decoupling the overall negotiation process and the local problem solving processes (at GENCO or ISO). For example, the GENCO may use totally different methods to generate the maintenance schedule, and may use different data format of the schedule. As long as the service interfaces are not changed, the whole system structure will not be affected.

B. Automated Fault and Substation Operation Analysis: Expert System Application [7]

1) Background

This example illustrates how the substation data related to fault clearing and operation can be gathered and exchanged among all the interested parties through automatic means. In this example, a discussion is centered on using the digital fault recorder (DFR) infrastructure [8]. The same concept may be extended to other substation intelligent electronic devices (IEDs) such as protective relays, circuit breaker monitors, sequence of event (SOE) recorders, etc. Further discussion is emphasizing what type of information may be extracted and how the information may be exchanged.

2) Problem Formulation

The utilities employ DFRs to monitor state of the electric power system and its elements. Typically, DFR data records are uploaded to a master station computer, using DFR master station software. The viewing, analysis and classification of DFR records are performed manually. This leads to the following shortcomings:

- DFR records cannot be efficiently analyzed manually due to an overwhelming number of records obtained in a moderately sized system.
- Use of different master station programs increases training costs since the master station software from different vendors have distinctively different features as well as the look and feel.
- Slow response (i.e. DFR data analysis takes time) is an impediment if several records supplied by different DFRs for the same event must be uploaded and analyzed.
- Highly-skilled people devote a lot of time to routine tasks because DFR systems provide redundant information on system events and most of the records may just verify the proper operation of the protection or.
- Non-selectivity (i.e. DFR records are not event prioritized) is an issue if the operator must sort out the records for the analysis purposes.
- Inefficient data archival and retrieval due to rather primitive means of storing and retrieving the data.
- Lack of ability to integrate data coming from different DFR types is evident when one attempts to integrate the different DFR systems and services.

3) Solution: Open System Communication Architecture

A general solution is to have a flexible access to data acquisition, storage, integration and processing so that several groups needing the information can get either the data or information in an online and timely manner. This would allow the operations, engineering, planning and maintenance groups to utilize the same infrastructure while the access to data and information may be restricted and guided according to specific rules established ahead of the time. A general solution that demonstrates the mentioned requirements is as follows [7]:

- File format filters – modules for converting native DFR data files into COMTRADE file format.

- Expert system – module for analysis, classification and fault calculation.
- DFR Communication – optional module for direct interfacing to DFRs (without master station).
- Broadcaster – module that provide services for dissemination of both DFR data and analysis reports (fax, email, print, page, web).
- Database – centralized database for archival of DFR data, analysis reports, system configuration.
- System Analysis – module for more elaborate substation and system-wide analysis.
- GUI – set of user interface applications.
- Web Server – centralized web-based application for Intranet access to DFR data and reports via corporate network

4) Requirements for Implementation

First big step towards integration in the field of DFR systems was the introduction of the COMTRADE file format [10]. DFR vendors are gradually accepting a new format opening a door for easier data integration. Most of the vendors are still keeping their own native DFR file formats or developing new ones and just providing additional utility programs or commands for exporting data in COMTRADE file format. Unfortunately, this export-to-COMTRADE feature, in most cases, is not configurable for automated operation. Also, the COMTRADE format specification allows freedom, to some extent, on how to provide information inside the files. This leads to situations where different software packages supporting COMTRADE file format cannot exchange data among themselves due to the lack of standardized descriptions of the files and signals inside. In addition to original COMTRADE standard specification [10], there are the latest IEEE revision [11] and IEC version [12]. Having the three versions currently being used increases a possibility not to be able to exchange DFR data among different types of software packages due to inconsistencies between different versions.

One step further was the introduction of the standardized IEEE file naming convention for time sequence data [13]. The proposed convention defines coded schema for naming the data files. Such file names can enable easier handling of large volume of files as well as unique file identification since the file name should contain unique information about the event: date, time, station, company, duration, location etc. Benefits of using this standardized file-naming schema should encourage DFR and related software vendors to provide the support, which is not a common feature today.

There is still a lack of standardized approach to communication protocols for DFRs and convention for providing information on parameters that describe system objects (signals and associated application arrangements) monitored by DFRs.

Having a standardized communication protocols would allow much easier integration of DFR systems and enable interchangeability of one type of DFRs with another. Future DFR systems may utilize standards like the one proposed by IEC [14]. Unfortunately, at present, we may be far from that possibility.

5) Implementation

One possible approach is the centralization of all system functions. This configuration is normally implemented for systems consisting of multiple DFRs and master stations provided by different vendors. Computer hosting applications is usually a dedicated one and data downloading is done using separate master station computers that make DFR data files available through LAN connection [15]. This configuration can be implemented with the single computer, too. Figure 3 illustrates the architecture of this type of solution. In this system, both client and server software components are installed on the computer at the central location (e.g. in the central office). This type of the system is characterized by the two-tier analysis. First, the Expert System module carries out the analysis centered on the faulted transmission line in a substation. Second, the System Analysis module performs more elaborate, substation- and system-wide analysis.

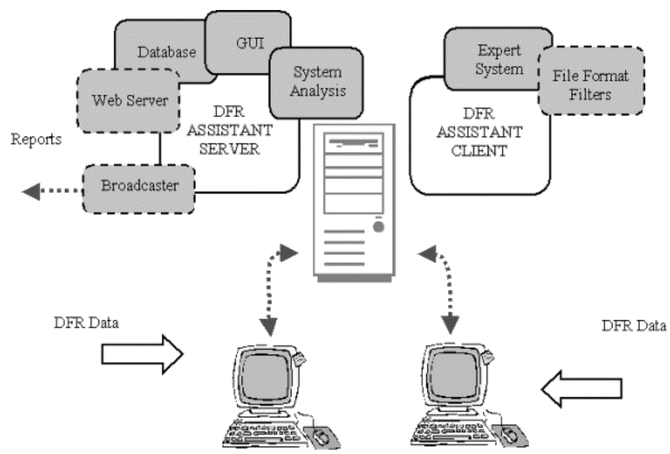

Fig. 3. Architecture of the Centralized Configuration

C. Power Quality Monitoring : Tools for Automated Assessments [16]

1) Background

With the increased use of sensitive electronic circuitry, customers become more concerned about the electric power quality (PQ). In the new open-access and competitive power market, electricity consumers are in a unique position to demand a higher quality of service. The utilities or other power providers have to ensure a high quality of their service to remain competitive and retain/attract the customers. Efficient power quality tools are needed to help achieve this goal [17].

2) Problem Formulation

PQ assessment is a complex subject and may include diverse aspects such as power system and equipment modeling, PQ problem mitigation and optimization, and data analysis [18]. Among various PQ phenomena, PQ disturbances like voltage sags, swells, and switching transients are of particular interest. This section is focusing on automated assessment of PQ disturbances that may facilitate the overall PQ assessment.

3) Solution: Modeling, Simulation and Replaying

The flowchart of the proposed solution for event detection and classification is shown in Fig. 4.

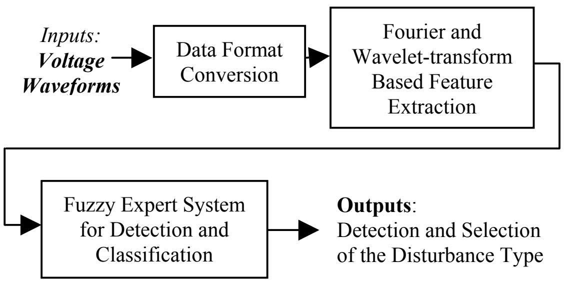

Fig. 4. Detection and classification flowchart

The sub-module "Data Format Conversion" converts the inputs from a specific recording device or simulation package format into a common data format comprehensible to other modules of the software. The "Fourier and Wavelet-transform Based Feature Extraction" module obtains unique features pertinent to specific events and "Fuzzy Expert System for Detection and Classification" module reaches a decision regarding detection and classification, as discussed next [18].

The following eight distinct features inherent to different types of power quality events have been identified: the Fundamental Component (V_n), Phase Angle Shift (α_n), Total Harmonic Distortion (THD_n), Number of Peaks of the Wavelet Coefficients (N_n), Energy of the Wavelet Coefficients (EW_n), Oscillation Number of the Missing Voltage (OS_n), Lower Harmonic Distortion (TS_n), and Oscillation Number of the rms Variations (RN). The formulae for computing these features are referred to in [18].

The output for the detection part is the variable "Detect" whose value reflects the credibility that certain disturbance exists. The outputs for the classification parts are fuzzy variables "Flicker", "Impulse", "Interruption", "Swell", "Sag", "Notch", "Transient", and "Harmonic" whose values represent the degree to which the event belongs to each of these categories. The type of the event selected will be the one with the largest membership. In cases where two or more types of disturbances have the same largest membership value, all of them will be selected for further analysis.

4) Requirements for Implementation

The main requirements are:

- PQ data needs to be brought to the user from the location where the PQ meters reside
- The recordings of PQ disturbances may be captured at one side of the meter (utility or customer), while the other side may wish to perform the assessment.
- The data relating to system or device models, which may be proprietary to the particular owner, is required to complete the assessment
- The information relevant for the assessment needs to be extracted automatically to enable an efficient analysis

5) Implementation

Examination of how sag parameters affect the equipment behavior is emphasized next. Through equipment sensitivity study, the software can explain why a specific load failed during a sag event, or predict how well a load will perform during an actual sag event.

The overall structure for evaluating the equipment behavior under voltage sag events is depicted in Fig. 5. The inputs are the voltage sag waveforms that can either be recorded in the field or generated by specific simulation packages. The outputs are the operating characteristics of the equipment during the specified sag events. The block "Voltage Sag Characterization" computes various sag parameters. The block "Sag Parameter Tuning" allows the user to tune or edit the sag parameters, obtained from the block "Voltage Sag Characterization", to certain values. The "Recorded Voltage Sag Waveforms" provide us with a set of initial sag parameters based on which further tuning can be made. The recorded waveforms are optional and if they are unavailable, the user can input any desired initial sag parameter and then tune them for testing. In either case, by tuning the sag parameters such as the sag magnitude, sag duration, phase angle shift, etc., the software allows the user to observe and study how specific sag parameters affect the operating characteristics of the equipment under test. This is what we call the equipment sensitivity study. The block "Voltage Sag Generator" reconstructs the voltage sag waveforms based on the selected sag parameters. The constructed voltage waveforms serve as the voltage source for testing the equipment. The voltage sources can either be one phase or three phase depending on the equipment being evaluated. The "Equipment Model" allows development of mathematical models for the equipment. Equipment sensitivity study during other types of disturbances can be performed similarly.

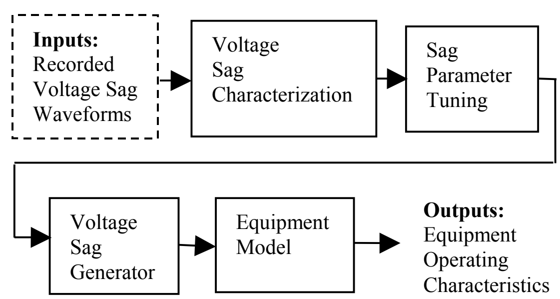

Fig. 5. The structure for equipment behavior evaluation

VI. Conclusion

Based on the discussion and case studies given in the paper, the following conclusion may be drawn:

- Data ownership and information exchange may be quite different in the new, restructured utility environment
- Due to the change in ownership of the equipment assets need for delivery of power as well as in the ownership of the related infrastructure for data collection, storage and processing, the data and information may not be readily available to all interested parties

- Making provisions for enabling some level of data integration and information exchange is critical for doing the business both in the area of power trading and in the area of system control, protection, maintenance, and operation

- Ability to exchange data and information may be facilitated through the use of mobile agent software technology due to the flexibility in making the different operating systems, databases, and user interfaces transparent to the user (application)

- Open System Communication Architecture is a prerequisite for enabling different users to have access to diverse data and information

- The need for data about component and equipment models as well as the use of the simulated and field recorded data may be essential when delivering some customer services

- Investigating the issues of data ownership and integration as well as information processing and exchange may be rather important when deciding how the particular business entity may perform its new role in the restructured environment.

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VIII. BIOGRAPHIES

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