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Synchronized and Reliable Event Notification System for Power Distribution Systems

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A secure and scalable Web application framework has been developed using SOAP communication for continuous monitoring of power distribution systems and maintenance of outage history information which is required for planning while further expansion. The model is designed to report the status of the power distribution system corresponding to outage and restoration state in a synchronized way. This model enhances the security of operational data of different power sectors in the deregulated environment and protects the history of outage information as the clients are not aware of the location of the operational database. The SOAP communication model uses sharable bean components and Web services to update the power system operators automatically with outage or restoration information due to data changes with respect to the operational status of the power systems. The service that resides in the database server is informed about the new information by triggering a function. The reporting facility is extended to various devices to enhance the reliable communication to avoid abnormalities.

Keywords: Power distribution systems, Outage database, SQL, Event notification systems.

1. Introduction

Over decades, computer network and distributed information processing technologies have seen profound growth. In the meantime, deregulation is starting and will be spreading in the electric power industries. The deregulation of power sectors is bringing about major changes in the utilities, with new players involved in the network and increased quality and profitability requirements. Consequently, customers request low cost power supply and high quality services from the power suppliers. Corresponding to these requirements caused by deregulation, Seki et al (2002) [1] have developed a prototype power systems information delivering system using Internet technologies supplying useful power systems information such as power failures. The purpose of using Internet technologies is to reduce the cost and time to develop applications and integrate them with existing systems. The prototype system consists of an application layer based on a Web browser, an information model layer which reflects the power systems behaviour and a distributed object management layer using CORBA and OS / Network layer. Due to deregulation policies, an electric power company needs to compete with other power companies and hence more efficient operations are required and various services are to be provided to the customers. There will be stiff competition on cost and services associated with supplying power. It is necessary to provide timely power systems operational information to the customer.

Originally the software was designed and built in the EMS / SCADA systems, which was dependent on the hardware since the data had been received from the sensors. Later the EMS / SCADA for power systems have been developed using Internet Protocol (IP) for the Wide Area Network (WAN) connected between the control centres and substations. This system provides information on power failures to customers through the Internet, in addition to the operators of the electric power sector. Moreover, the system is able to supervise the status and failure of both the power transmission systems and the power distribution systems simultaneously. This system detects power failures using the operation

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status and activated status of the switch and the relay. The power systems information delivering system has the following features:

- Power failure monitoring using Web browser
- Reproducing at any time the power systems status in the past
- The integration of the information on power systems configuration and status for the power transmission and the power distribution network
- The integration of power systems information and geographical map information
- The provision of statistical or historical information for offline use, such as calculated blackout time or number of customers affected

Kivikko et al (2003) [2] presented a Web application for viewing customer-specific interruption data. The application is integrated with commercial Distribution Management System (DMS) and it uses the same database as DMS system.

The authors have clearly described about the content of interruption database and the construction of interruption sector. They have proposed a Web application for customer interruption monitoring. The application presents the existing outage data measured and saved by the SCADA and DMS systems on the browser. They have also explored the possibilities of new technologies, which make the development of Web and mobile applications. Microsoft Visual Studio .Net programming tool and C# programming language are used in the implementation of the Web application. They have described a logic how the interruption data is gathered to the DMS database and how the number and durations of interruptions can be searched for a certain customer and illustrated a methodology for construction of interruption sector. The major aim is to develop a Web application, which uses the existing interruption data gathered by other systems and can be integrated with existing commercial data systems.

Yves Chollot and Martine Pauletto (2003) [3] of Schneider Electric Industries have proposed Web based solutions which provide an efficient and reliable sharing of the network information between all the clients and which increase the quality of their services. They have developed a general architecture that describes the system that is Web enabled and designed for medium voltage / low voltage substation monitoring and maintenance. The developed system utilizes Web, GSM and GPRS technologies, which are becoming lesser and lesser expensive and makes it possible to:

- inform the right persons when there is an alarm in a substation via e-mail
- inform through SMS
- display on the Web through a PC with a Web browser
- provide real time information from the substation and also
- provide historical information

Even though Web enabled power system applications provide faster and timely information and collaborate efficiently with other network technologies, they are still facing challenges due to heterogeneous nature and the way they are communicating with each other. transfer. This model faces security challenges because of the introduction of mobile agents. The author uses public key cryptographic algorithm to secure communication using mobile agents, which causes additional overhead to the overall performance of the system.

Wang Xin Fang et al (2003) [4] had applied XML and SOAP in transformer substation management information system for communication between client and server and for providing data exchange with other electric utilities. They have made possible that transformer substation can exchange data with other power utilities through firewalls. Cao Hou-ji et al (2007) [5] have described how transmission substations exchange large quantity of outage data among the heterogeneous platforms by using SOAP message in a predefined format with strong firewall passing ability and without the need for additional installation of special software to receive them.

Kannammal et al (2006) [6] have proposed a secure model based on the concept of shared objects and mobile agents to secure the business database present in the e-business environment. The models have been implemented that would control the direct access to the business database while maintaining synchronized data Pasteur et al (2007) [7] have proposed to utilize SOAP based Industrial Messaging Specification (SIMS) to exchange power plant process data with increased real time performance. The proposed SIMS messaging is based on two components: a client and a server. The server component is a data provider, which provides read, write and subscribe Web services. The client component is the data consumer and it aims to invoke services and provides call-back functions. These call-back functions are also Web services used by the server to notify the client that new data are available. They have designed the messaging server to have an access to any type of data sources and capable of providing these data if its Web services are invoked.

The Messaging server provides two Web services read() and write() that can be called by the client to write or read current values. Also client can subscribe to some data in order to be notified if any of the attributes of this data changed. If data changes are made, a notification is created and stored in a buffer and the client will be intimated using 'notify' message that new values are available for the data to which it has subscribed. The authors have demonstrated this SIMS messaging based on Web services to exchange data between a hydraulic power plant and a telecontrol center.

The SIMS messaging was first used in SCADA application to telecontrol 15,000 MW hydro power plants from four dispatching Centre's (Laurent Bacon and Cedric Bellec 2006) [8]. Three levels tele-control architecture was defined to ensure the robustness of the control systems. First level concerns about the power unit control, the second level called as plant local control deals with power distribution among all power units and the third level called as dispatching center deals with control, modification and supervision of generation schedules. SIMS is used as the communication protocol between a dispatching center and hundreds of local control plants. Open connectivity unified architectures are evolving based on service oriented architecture to have effective message based communication. Standard specifications are emerging to define a base set of generic services to browse and query namespaces, read / write data and publish / subscribe events and data changes.

Jeongje Park et al (2010) [9] have developed Web based on-line real time reliability integrated information system for monitoring reliability of electrical energy supply including wind turbine generator. In order to supply information about the quality, reliability and security of the electric service, several techniques and methodologies have been adapted that include traditional operation planning, real time control functions and a redesign of control system hardware and software architectures. As the utilization of renewable resources has been receiving considerable attention in recent years, the information system requirement is increased. The reliability information system is more important for implementing the smart grid. The proposed integrated information system not only supplies the information about the reliability indices of the power system but also the estimation of CO_2 emission.

The system developed by them is used to evaluate probabilistic production energy with reduction in production cost and to obtain CO_2 emission by inserting renewable energy to the power systems. Probabilistic reliability indices have been used extensively for generation expansion planning. The basic reliability indices, namely the loss of load expectation (LOLE), the expected energy not supplied (EENS) and the energy index of reliability (EIR) can be calculated using effective load duration curve. From these reliability indices, probabilistic production energy, production cost, capacity factor and CO_2 emission can be obtained. The proposed on-line reliability information system is successfully established and applied to Jeju Island Power System in South Korea. The functioning of this system can be viewed in the Web site, http://worris.gsnu.ac.kr/PraWin. The users of this system are the system operators, decision makes and information seekers and they will access the system with browser via the Web. Jaeseok Choi et al (2010) [10] have extended the above work for grid constrained probabilistic reliability evaluation of power systems including wind turbine generators. They have developed a multi-state model for composite power system reliability evaluation based on the composite power system effective load model in order to consider wind turbine generators. The proposed work is integrated with the information system developed by Jeongje Park (2010) [12]. Anbalagan et al (2012) have proposed SOA model for generation system reliability analysis makes the service provider and the power systems client to exist in a loosely coupled heterogeneous environment. The SOA model has been designed to include or plug in new power system planning and expansion services without modifying the existing environment.

In order to enhance the security of operational data of different power sectors in the deregulated environment and to protect the history of outage information, a new SOAP based communication model is proposed using remotely accessible shared objects between the messaging server and client. The proposed model ensures synchronized communication between the operations monitoring service providers like SCADA applications and the power system operators to enhance reliable notification of failure events and other operational data required for decision making to keep the capacity reserve at the required levels to meet the demand and to avoid catastrophic events.

The proposed model uses remote sharable bean components and Web services to update the power system operators automatically with new information due to data changes with respect to the operational status of the power systems. The service that resides in the database server is informed about the new information by triggering a function. Then the Web service updates the bean with the recent outage information by invoking a remote method. This sharable component is accessed by another Web service on the client side, which sends the information to the decision makers and information seekers. This approach improves security, as clients are not aware of the location of the outage history database and makes power system events notification application more scalable by deploying Web services.

2. Securing Outage History Database for Power System Applications

While integrating power system applications with the Internet offers potentially unlimited opportunities for increasing efficiency and reducing cost, it also offers potentially unlimited risk. In the automation of power system operations, the system parameters are maintained consistently in a database. The outage history thus logged in the database throughout the operation of power systems reflects the quality of power system maintenance. In the deregulated environment, the power utilities should keep their operational data secure especially the outage history table. Critical decisions have been made based on the operational data and based on the outage history table. A knowledgeable and malicious client or even the system operator can execute unauthorized procedures or SQL queries inside the outage history database.

An unauthenticated user with browser access to a Web server hosting the power system application can exploit the database. This activity will lead to unwanted decisions, which will pose a false hope to the planners as well as consumers and create a negative impact on the quality of service of the system. If an unauthorized user voluntarily records a false outage data to the outage history table even when the power system operation is in line with the normal and stable operating conditions, it will cast an illusion of poor maintenance of power system. The risk of exposure to power system operational data as well as outage history database is high, as any client with browser access and specialized knowledge can exploit these vulnerabilities. At the same time, the occurrence of the critical events should be notified to the system operators in a synchronized manner without any information loss or omission in order to take timely decisions.

A Web service model has been proposed for event notification system to improve scalability and a concept of remotely accessible sharable bean component is introduced to improve the security of Web applications. This sharable bean component named as shared object is used not only to improve the security, but also to enable synchronized and reliable communication between server side applications. Using the recently stored contents of the sharable bean component, the Web service updates the operators and decision makers automatically with new information.

The Web service associated with the database server is informed about the new information by triggering a function. This information is copied onto the static sharable bean component, which is accessed by another Web service, which will forward the same to the system operators and to the clients. The block diagram representation of the architectural design of synchronized event notification system is shown in figure. 1 Power system utilities maintain data about the various outages occurring in the system, especially in distribution systems. The outage data includes failure histories which comprise details of fault occurrence times, fault restoration times, feeder information and interruption type.

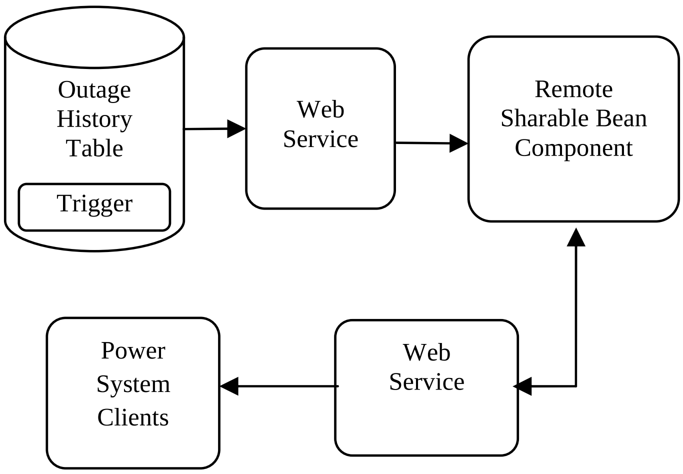

Fig. 1 Block Diagram Representation of the Event Notification System

A radial system with 2 feeders (F1 and F2) having an outage history as shown in Table I has been considered (IEEE Guide, 2003) to illustrate the event notification system. Assuming Feeder 1 has a total of 900 customers along with a load of 1800 kVA and Feeder 2 has 1850 customers with a load of 3700 kVA, the total number of customers in the system is: 900+1800=2700 while the total load connected to the system is: 1900+1125= 4025 kVA. An interruption is loss of power supply to the customer and its effect is variable, which is classified as sustained and momentary based on the duration of failures.

The interruption types ‘S’ and ‘M’ stand for sustained and momentary respectively.

The notification system includes one or more system operators and service consumers to whom the failure events are to be informed in time to take appropriate actions. Figure. 2 depicts the architecture of the proposed secure, reliable and synchronized event notification system. The power system operators and decision makers have to continuously enquire the database server by sending requests to the client side Web service. The database server has to send responses to all the requestors only during occurrence of new events in the system.

Web services have been deployed to act as intermediaries between the database server and the remotely accessible sharable bean and between the sharable bean and the power system clients respectively. The sharable bean component contains fields to hold the information present in the outage history database due to insertion of new failure event information or due to update of existing outage data. And also it has a flag to indicate whether the recent contents are consumed by the power system clients or not. The Web services access the sharable bean using a middleware component, which is common to both forwarding and notification services. The middleware application in turn uses the RMI framework to access the sharable bean component. The sharable bean component has been declared as static within the remote object to enable sharing of data between services.

Table 1: Historical Outage Data for a Radial Feeder System

Date	Time of fault	Time of restoration	Feeder	No.of Customers	Load kVA	Interruption type
23 March	12:02:20	12:20:30	F1	900	1800	S
15 April	16:13:56	16:14:26	F1	550	1100	M
5 May	00:23:10	01:34:29	F1	450	825	S
12 June	23:17:00	23:47:14	F2	400	800	S
6 July	09:30:10	09:31:10	F2	1850	3700	M
20 August	15:45:39	20:12:50	F1	450	825	S
31 August	08:20:00	10:20:00	F2	900	1800	S
3September	17:10:00	17:20:00	F2	950	1900	S
2 October	10:15:00	10:55:00	F2	1850	3700	S
31 October	01:47:25	03:35:15	F2	900	2600	S
23 November	15:00:05	15:20:00	F1	550	1100	S
13 December	09:05:10	09:06:15	F2	1850	3700	M

The outage history information as shown in Table I is stored in a relational database using a table name “power”.

The table has been associated with the following trigger, which has to be initiated while inserting new outage record or updating the contents of the existing record.

```
/*An insert or update trigger, which invokes in turn a Web Service to forward the outage
information*/ create or replace
trigger message_send after insert or update on power for each row
declare
    fault_occurrence_time date;
    restoration_time date;
    feederno varchcar2(10);
    interruption_type varchar2(2);
    newdata varchar2(36);
```

```
    mobile_no varchar2(15);
    email_id varchar2(30);
  begin
    fault_occurrence_time := :new.intime;
    restoration_time := :new.restorationtime;
    feederno := :new.feedernumber;
    interruption_type := :new.interruptiontype;
    mobile_no := :new.mobileno;
    email_id := :new.emailid;
    newdata:= 'Outage Data '|| to_char(fault_occurrence_time,'hh:mi:ssam') ||
    to_char(restoration_time,'hh:mi:ssam') || feederno ||    interruption_type;
    communicationService(newdata, mobile_no, email_id);
    end;
```

The trigger has to invoke the SQL procedure, “communicationService” to forward the outage data or restoration data to the Web service associated with the database server. The Web service in turn invokes a remote method, “storeData()” to copy the outage information in the static sharable bean component and sets the flag in the bean as ‘true’. The procedure for “communicationService” is given in Appendix A. The “communicationService” will access the JAX-RPC based Web service using the endpoint reference, “http://localhost:8080/power/ForwardingService?WSDL”

When there is an information update, the database server sends the recent outage information to the Web service logically named as “ForwardingService” through the “message_send” trigger. The “ForwardingService” checks the flag attribute of sharable component to find out whether the information provided by previous ‘update’ or ‘insert’ has been consumed or not by the Web service on the client side, logically named as “NotificationService”. If the flag is set to ‘false’ by the notification service, it means that the previous information is consumed, and then the forwarding service updates the outage information attributes of the sharable bean by invoking the remote method “storeData()”. Also, the flag attribute of the bean is set to ‘true’ to indicate that new information is available for the notification service to consume. The “NotificationService” has been implemented using SOAP communication in AXIS2 platform.

The notification service on the client side continuously monitors the remotely accessible sharable bean for the availability of new outage information. When the flag attribute is ‘true’ then it means that the new information is available, and hence notification service retrieves the information and sets the flag to ‘false’, to indicate that the information is consumed. The flag field is updated accordingly in order to ensure synchronized and reliable data transfer between the database server and the clients. The power system clients have to contact the notification service continuously by sending request messages for any information update. The clients need not contact the database server for the information. Also, the location of sharable bean and the database server are hidden from the clients. By this approach, the outage history database is made secure by avoiding direct access to the database server. Since the forwarding and notification services are deployed as Web services, they are inherently scalable and will respond to a large number of clients who are sending request messages for updated information.

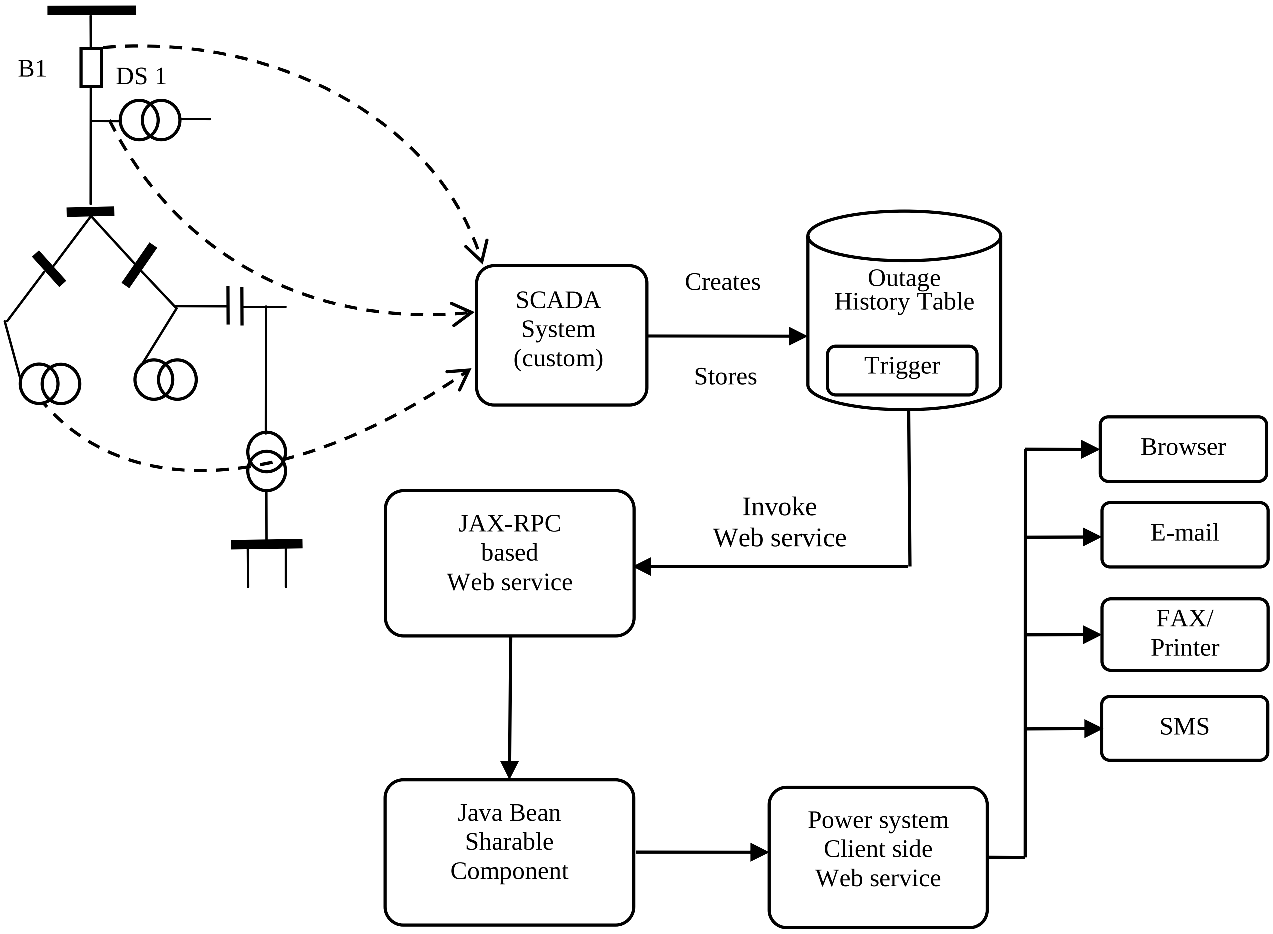

Fig. 2 Secure and Reliable Synchronized Event Notification System

As the system is designed to notify the fault events during power systems operations, it is not sufficient to have only scalable and synchronized services but also reliable services are required to notify the system events to the power system operators at appropriate time to enable them to take effective decisions. The reporting facility is extended to various devices to enhance the reliable communication. The notification service has been developed to report the consumed information from the sharable bean component to the power system operators using various modes of communication such as PC, Web browser, printer or fax, SMS using a mobile device or sending the outage information via e-mail.

This model enhances the security of operational data of different power sectors in the deregulated environment and protects the history of outage information as the clients are completely detached from the location of the operational database. A common middleware component connects the forwarding service and the notification service, which in turn uses an RMI framework to access the static sharable bean component. The reliability of notification system is enhanced by providing the information to various devices simultaneously.

3. Conclusion

A secure and scalable Web application framework has been developed using SOAP communication for continuous monitoring of power distribution systems and maintenance of outage history information which is required for planning while further expansion. The model is designed to report the status of the power distribution system corresponding to outage and restoration state in a synchronized way. This model enhances the security of operational data of different power sectors in the deregulated environment and protects the history of outage information as the clients are not aware of the location of the operational database. The SOAP communication model uses sharable bean components and Web services to update the power system operators automatically with outage or restoration information due to data changes with respect to the operational status of the power systems. The service that resides in the database server is informed about the new information by triggering a function. The reporting facility is extended to various devices such as PC, Fax and other electronic gadgets to enhance the reliable communication to avoid abnormalities. The developed notification model is scalable as the forwarding and notification services are designed as Web services and the critical events are notified to the operators as well as to the decision makers instantly in a synchronized way, which enables them to take appropriate actions in time to improve the quality of service and maintenance.

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