An Enhanced Distributed Model for Reliability Evaluation of Power Distribution Systems

P. Anbalagan and V. Ramachandran

Abstract—**Reliability assessment is the most important factor in designing and planning of distribution systems that should operate in an economic manner with minimal interruption of customer loads. The main aim of this paper is to develop interoperable services for power distribution systems reliability evaluation using SOAP communication in which the reliability data is included as attachment within the SOAP message. The proposed XML based SOAP with attachment model is composed of Power System Reliability service provider and Reliability Service Requester. The Power System reliability services are designed to enhance the interoperability based on standards such as HTTP, XML and Simple Object Access Protocol (SOAP). The data pertaining to Power Systems reliability analysis are represented in eXtensible Markup Language (XML) for exchanging the reliability data among the users and service providers. The calling sequences of reliability evaluation services along with required data are configured as SOAP messages. The proposed model for Distribution system reliability evaluation provides flexible loosely coupled as well as high-efficient integration architecture in the deregulating and competitive electric market and has inherent features such as scalable and reliable environment for Power Systems reliability analysis.**

Index Terms—**Distribution systems, Reliability, XML, SOAP, WSDL.**

I. Introduction

The goal of a power system is to supply electricity to its customers in an economical and reliable manner. It is important to plan and maintain reliable power systems because cost of interruptions and power outages can have severe economic impact on the utility and its customers. At present, the deregulated electric power utilities are being restructured and operated as distinct generation, transmission and distribution companies and the responsibility of maintaining reliability of the overall power system is shared by all participating companies instead of by a single electric utility [1].At present, power system operations are to be handled in a heterogeneous environment. Generally, reliability analysis is being carried out during planning stage of power systems. In order to maintain the operational state of the power systems at the required levels and subsequently to meet the load demand satisfactorily, the power system operations such as state estimation, reliability analysis etc., are to be carried out at frequent intervals. Perhaps, the above operations have to be invoked dynamically whenever the power system resumes its operation back after following sudden failure or outage. Reliability analysis has to be carried out at frequent intervals during operating period of power systems in order to monitor the customer requirement satisfaction at desired levels. The reliability evaluation system should be dynamically adaptable to the current operating conditions of the power systems.

Due to the increase in demand of power, the size of the power system grows exponentially large. Private power industries have joined with public sector to cope with the power demand. Power System operations are becoming complex and the data required for analysis have been stored in different formats and are distributed in a heterogeneous environment. The power systems basic operations such as load flow, stability analysis, reliability analysis etc., are being carried out using different power system applications executing in heterogeneous platforms. Integration of responses due to various power system operations is a major task and power system applications should be interoperable even though every system has its own way of representation and implemented using different paradigms.

Integrity can be achieved by modifying the legacy power system applications into interoperable services either by converting the applications developed using different paradigms into a single paradigm or an efficient solution has to be found out to make the existing applications interoperable without modifying the existing system. An effective way is needed to convert the power system applications as services and they can be published over the Web and made easily discoverable. A service oriented open system made up of variety of power system services operating on dissimilar platforms has be to developed so that more extensive data and applications can be shared easily and flexibly [2].

The estimation of reliability indices is essential at the time of planning and expansion. Roy Billinton and Peng Wang had developed a practical technique for distribution system reliability evaluation, which can be used to simplify the procedure for determining the reliability indices of radial distribution systems with branches [3]. X. G. Wei et.al had demonstrated an Automated Distribution System Modeling (ADSM) Tool for analysis [4]. Yeddanapudi et.al developed a Predictive Reliability Assessment Tool to analyze large distribution system using historical data [5]. Fangxing Li et.al had demonstrated an architectural design for a framework, which aims to summarize the commonalities in software design for power distribution systems, including components, topological traverses, and analysis algorithms. This framework also supports the idea of distributed computations [6]. Chen et.al made an attempt to create a completely Web-based, platform-independent, power system simulation package with various analyses distributed in a clustered environment [7]. The InterPSS

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which is an Internet technology based software system for design, analysis, and simulation of power systems has been developed using web services standards. InterPSS has provided with an open and loosely coupled system architecture, wherein the power system components developed by others can be easily plugged into the system [8].

The proposed SOAP communication model in the form of document style will provide a common computational environment for interaction between various power system clients and reliability service providers. The document style messages are "self-contained documents" that cannot be mapped directly to an object. Usually some pre-processing of the document must be done first when the message is received. This model represents asynchronous reliability data exchange and allows plugging in new services or upgrading existing services in a granular fashion to address the new requirements. Analytical techniques for distribution system reliability assessment can be effectively used to evaluate the wide range of system reliability indices.

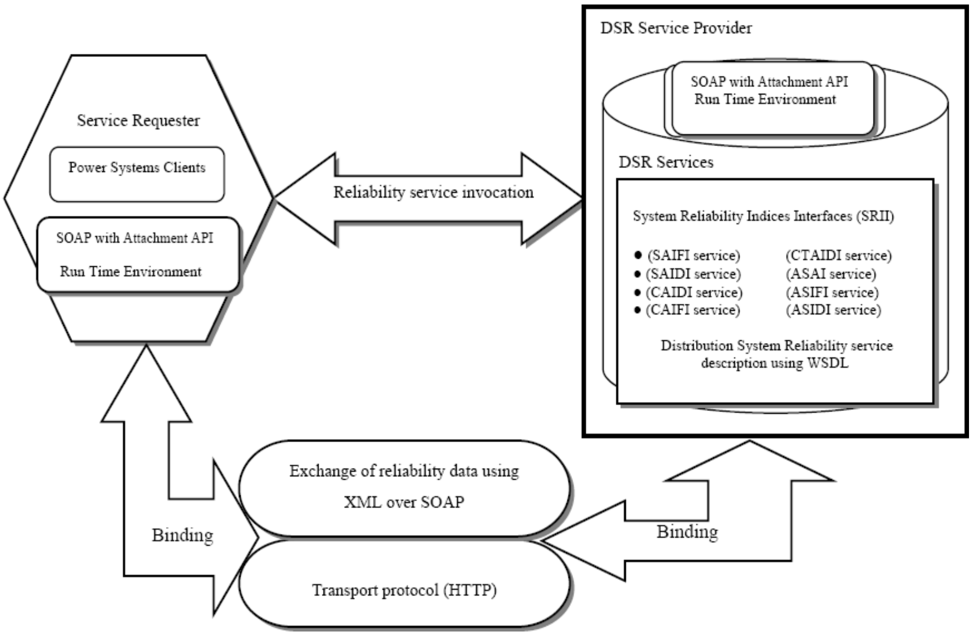

Fig.1. SOAP Communication Model for Distribution System Reliability Analysis

II. .SOAP COMMUNICATION MODEL FOR DISTRIBUTION SYSTEM RELIABILITY ANALYSIS

The major components of the proposed SOAP communication model are Distribution System Reliability (DSR) Service Provider and the Service Requester. The main aim is to represent the estimation of distribution system reliability indices as a service and to exchange the required data using XML over SOAP. The SOAP communication model for distribution system reliability analysis is shown in Figure 1.

The DSR services are categorized into estimation of Interruption Indices such as System Average Interruption Frequency Index (SAIFI), the System Average Interruption Duration Index (SAIDI), the Customer Average Interruption Frequency Index (CAIFI), the Customer Average Interruption Duration Index (CAIDI), Customer Total Average Interruption Duration Index (CTAIDI), the Average Service Availability Index (ASAI), the Average System Interruption Frequency Index (ASIFI), Average System Interruption Duration Index (ASIDI) and estimation of energy indices such as the Energy Not Supplied (ENS) and the Average Energy Not Supplied (AENS).

The DSR Service provider offers the above services and describes the services to its clients using Web Services Description Language (WSDL). Since the described services are Distribution System Reliability Services, the WSDL file is named as DSRS-WSDL, Which is in XML format. A service is a reusable function that can be invoked by another component through a well-defined interface. Services are loosely coupled, that is, they hide their implementation details and only expose their interfaces. In this manner, the power system client need not be aware of any underlying technology or the programming paradigm which the service is using. The loose coupling between services allows for a quicker response to changes than the existing conventional applications for power system operations. This results in a much faster adoption to the need of power system industries.

III. IMPLEMENTATION OF PROPOSED MODEL

A radial feeder test system is considered for reliability evaluation using the proposed model. Synchronous SOAP request-response model is proposed in which the request payload encapsulates service invocation details and reliability data in XML format and the SOAP response messages represent System Reliability Indices (SRI), which are also in document style format. The various stages involved in the implementation of the proposed SOAP Communication Model for Distribution System Reliability analysis are XML data representation, reliability service interface, service configuration, description, service mapping, service binding and service invocation. The detailed implementation and deployment of these services are explained in the following section

A. Reliability evaluation of radial distribution feeder test system – case study

The development of a service oriented model for predictive reliability assessment of radial distribution feeder system using Failure Modes and Effects Analysis (FMEA) is presented. The radial feeder can be represented as an interconnection of components whose failure characteristics can be used to predict the system behavior. The predictive methods are commonly used to predict the distribution system reliability. The test system, which is shown in Fig 2. Consists of a switching station and a typical radial distribution feeder arrangement.

The test feeder consists of five load points L1, L2, L3, L4, and L5 and four customers at load points C1, C2 C3 and C4 with capacities as shown. It is assumed that the customers experience an outage of 4 hours. Fuses and substation breakers are the protective devices and are shown as F1, F2, F3 and M1, M2, M3 respectively. It is assumed that the switches are 100% reliable and the average switching time of each switch (S1, S2, and S3) is 0.5 hours [9].

B. XML Representation of Distribution System Reliability Data

Power System industries are now increasingly becoming privatized and hence the system data is becoming increasingly distributed, with more constrained and complex operational and control requirements. Because of the complex physical connectivity of the power systems, all levels of industry like generation, transmission, distribution and market need proper operational and equipment data. As expected, the data to be shared between different power system applications are huge and hence it is vital to have an efficient and reliable data generation model to reduce human efforts and to have the data in a secure and compatible form. Both operational and equipment data of the power systems need to be exchanged for proper operation of the power systems. Power system operations are becoming complex and the data required for analysis have been stored in different formats and are distributed in a heterogeneous environment. The data exchange needs to be reliable, error-free and adaptable to different types of software used for power system applications. The data exchange must have a protocol that makes the data meaningful for each power system operation. The exchange of power system data using XML offers trouble-free integration with the Web and Intranet / Internet based Power System applications.

The power system reliability analysis needs huge volume of failure data which are heterogeneous in nature. The growing attention on power system reliability related problems has prompted the need to share reliability data between power utilities. A convenient data representation model is required to enhance the interoperability between heterogeneous applications. IEEE Reliability Test System data (RTS-96) format was implemented in 1996 by an IEEE Task force committee. IEEE recommended common data format for exchanging power system reliability data is limited to static data and not suitable for storing dynamic information. Rapidly growing power sector environment changes their data structure or adds new data structure whenever new participants join in the power network.

As there are many proprietary formats, it is highly inefficient and inconvenient to implement application dependent interfaces, and considerable efforts have to be taken to maintain these software and data. The situation becomes daunting if the formats are subjected to frequent changes. It is obvious that there is a need to have a common standard format universally accepted by all. The exchange of data needs to be reliable, error-free and adaptable to different types of software used for power system planning and operations in the related power system industries.

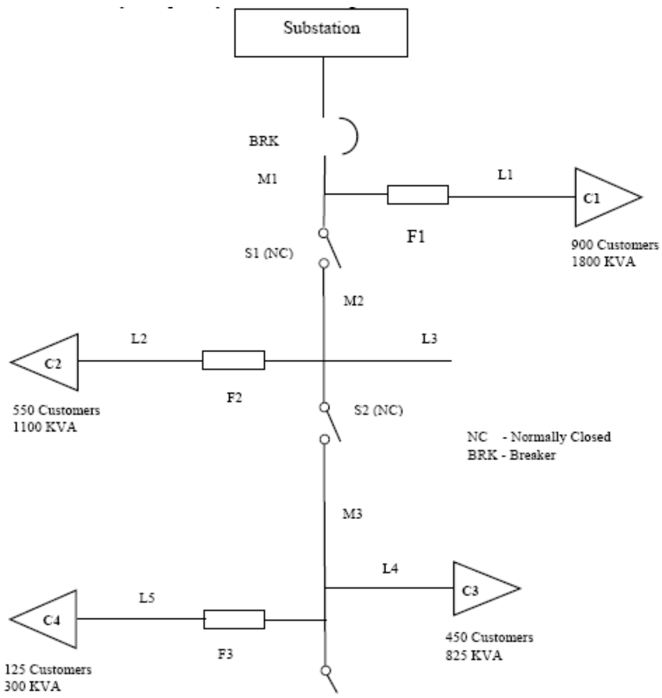

Fig 2. Radial distribution Feeder System Configuration

In power systems, data can be output of one process while being input for another [10]. In reliability analysis, huge amount of data are being exchanged among interconnected systems. The exchange of power system data using XML offers trouble-free integration with the Web and Intranet / Internet applications. In order to compute the power system reliability indices, utilities often use large databases where outage histories are maintained often termed as Outage Management Systems (OMS) [5]. These databases include details of the location, date / time of the event, the component involved and the number of customers interrupted due to each outage. Also recorded are the entities like the time taken to restore service to the affected customers, the time to repair / replace the failed component and more importantly the cause of the interruption. Events where service was restored in stages due to switching actions or reconfiguration of the system are also recorded. Put together, these databases provide information on each and every event that happens on distribution system. The history of outages is needed for calculating the indices of Distribution System Reliability(DSR). The outage data consist of number of customers, components failure data, repair data and forced outage data. The XML data representation of Distribution System Reliability is as follows:

The XMLised representation of power system data offers reliable data exchange between legacy power system applications. The XML data representation ensures interoperability between various power system applications in a heterogeneous environment.

C. Reliability Service Interfaces

The service interface provides the contract between the power system client and reliability service provider as shown in Figure 3. The service interface is responsible for all of the implementation details needed to perform the communication between the clients and service provider. In this proposed model, eight interfaces are created for the representation of various reliability indices estimation services such as System Average Interruption Frequency Index estimation, System Average Interruption Duration Index estimation, Customer Average Interruption Duration Index estimation etc., as shown in the figure 3.

Decoupling the service interface from the service implementation enables the system to deploy two codebases on separate tiers, potentially increasing the deployment flexibility. The service interface for computing System Average Interruption Frequency Index is as follows:

```
Package reliability;
Public interface saifi extends Remote
{
Public String estimateSAIFI() throws RemoteException ;
}
```

The service interface encapsulates all aspects of the network protocol used for communication between clients and service provider. All other interfaces are described similarly. The implementation of the service is modified without affecting the user who consumes that service.

D. Configuring Reliability Services

The services related to computing of power distribution system reliability indices are configured as follows:

```
<service name="reliabilityservice"
            targetNamespace="urn:Reliability"
            typeNamespace="urn:Reliability"
            packageName="reliability">
                <interface name="reliability.saifi"/>
                <interface name="reliability.saidi"/>
                <interface name="reliability.caifi"/>
                <interface name="reliability.caidi"/>
            .........................
            <interface name="reliability.asidi"/>
</service>
```

The above XML document contains the information and details about the deployed distribution system reliability services (SAIFI, SAIDI etc.,) and metadata such as their service name (reliabilityservice) and namespace (Reliability).

E. Reliability Service Descriptors (RSDs)

A service description is document-based that defines or references the information needed to use, deploy, manage and control reliability services. The service descriptor includes the information and behavior models associated with a service to define the service interface. The purpose of service descriptor is to facilitate interaction and visibility, particularly when the providers and participants are in different ownership domains. By providing descriptions, it makes it possible for potential participants to construct systems that use services and even offer compatible services.

The RSDs describe how the service provider and client communicate with each other. WSDL is capable of describing services that are implemented using any language and deployed on any platform. It represents information about the interface and semantics of how to invoke a service. It also provides the information about the data type, binding and address information for invoking the services from the service provider. The SAIFI service is described as
Follows:

```
<definitionsname=”reliabilityservice”targetNamespace="urn:Reliability
">
    <Types>
                <schema targetNamespace="urn:Reliability"
                xmlns:tns="urn:Reliability"xmlns:
                        soap11enc="http://schemas.xmlsoap.org/soap/e
ncoding/" ….>
              <doubleType name="estimateSAIFI">
                </doubleType>
                <element name="estimateSAIFIResponse" type
="string"/>
    </types>
    <message name="SAIFI_estimateSAIFI">
    <portType name="saifi">
           <operation name="estimateSAIFI">
              <input message="tns: SAIFI_estimateSAIFI"/
    <output message="tns:
saifi_estimateSAIFIResponse"/></operation>                    </portTy
pe>
    <binding name="saifiBinding" type="tns: saifi">
              <soap:binding
transport="http://schemas.xmlsoap.org/soap/http"
           style="document"/><operation  name="estimateSAIFI">
              <soap:operation soapAction=""/
              <soap:body use="literal"/></operation>
     </binding>
              <service name="reliabilityservice">
              <port name="saifiPort" binding="tns: saifiBinding">
              <soap:address location=" http://loacalhost:8080/reliability"/>
              </service>
```

The RSD document consists of seven key structural elements for describing reliability services. The <definitions> element defines the name of the service as ‘reliabilityservice’ and declares the namespace as ‘Reliability’. The <types> element defines the data types that would be used to describe the distribution system reliability data. The <message> element represents a logical definition of the data being transmitted between the client and the service provider. The <port Type> element provides the abstract definition of the operation (estimateSAIFI) of the service. The <binding> element specifies a concrete protocol (SOAP) used for representing messages. The <service> element represents the service to be invoked over multiple bindings. The <port> element specifies an address (saifiPort) for binding to the service.

F. Mapping the Services

In the traditional distributed environment paradigm such as RMI, the method call and the associated parameters are marshaled (i.e.) converted into a wire format while clients try to invoke a remote method. At the server end, the marshalled data has been unmarshalled (i.e.) converted back to original method call and parameters. Marshalling and unmarshalling will be applicable only to Java paradigm and confine to RMI framework. Since the existing power system applications are implemented in different language paradigms, they need a common serialization / de-serialization of information for invoking the remote services. The common format has to be flexible and interoperable in a heterogeneous environment. In this proposed SOAP communication model, all the reliability service objects are translated and mapped into XML for interoperability in a heterogeneous environment. The mapping file describes how the Java objects like package, type, port, method, and endpoint are mapped into XML and vice versa. While invoking the reliability service, the method call and its parameters are mapped into XML and sent through SOAP communication protocol. When received at the client or server end, the request / response parameters must be mapped from XML to their proper types or objects to make interoperability inherently.

G. Reliability Service Binding

The power system clients communicate with the Distribution System Reliability service provider using SOAP messages. The XML form of distribution system reliability data is The power system clients communicate with the Distribution System Reliability service provider using SOAP messages. The XML form of distribution system reliability data is attached as an input parameter in the SOAP Body. SOAP uses HTTP POST method for request and response in the form of messages. SOAP messages are configured for reliability service invocation and response. The request message consists of IP address of the service provider and the required power system data in XML form. The following code segment delineates how distribution system reliability data has been attached to the SOAP message.

The power system clients communicate with the Distribution System Reliability service provider using SOAP messages. The XML form of distribution system reliability data is attached as an input parameter in the SOAP Body. SOAP uses HTTP POST method for request and response in the form of messages. SOAP messages are configured for reliability service invocation and response. The request message consists of IP address of the service provider and the required power system data in XML form. The following code segment delineates how distribution system reliability data has been attached to the SOAP message.

```
MessageFactory messageFactory= MessageFactory.newInstance();
SOAPMessage message  = messageFactory.createMessage();
SOAPPart soapPart = message.getSOAPPart();
SOAPEnvelope envelope = soapPart.getEnvelope();
SOAPBody body = envelope.getBody();
SOAPElement bodyElement =
body.addChildElement(envelope.createName(operation, "", urn));
FileInputStream fs=new
FileInputStream("distributionsystemdata.xml");
AttachmentPart
attachment=Message.createAttachmentPart(xmldata,"text/plain");
attachment.setContentId("distributionsystemldata");
message.addAttachmentPart(attachment);
```

A binding describes how the SOAP request and response messages have been sent through the transport protocol.

H. SOAP Request and Response for Reliability Services

The power system clients are capable of invoking the required reliability services as given in the SOAP message at the specified port and the work flow of invocation is shown in Figure 4

The reliability service descriptor represents information about the interface and semantics of how to invoke a reliability service. The power system client has to establish the SOAP connection using SOAP Connection Factory for invoking the desired services. The SOAP message is created using Message Factory reference to an Endpoint Interface.

The method call and its parameters are mapped into XML and sent through SOAP communication protocol. Whenreceived at the client or server end, the request / response parameters must be mapped from XML to their proper types or objects. The following code segment delineates how the SAIFI service is being invoked by the power system clients

The SOAP request with the attachments of power distribution system reliability data for invoking the reliability estimation services is shown below:

```
<SOAP-ENV:Envelope
xmlns:SOAP-
ENV="http://schemas.xmlsoap.org/soap/envelope/>
<SOAP-
ENV:encodingStyle="http://schemas.xmlsoap.org/soap/encoding
/"><SOAP-ENV:header/>
<SOAP-ENV:Body><compute xmlns="urn:dis"/>
</SOAP-ENV:Body></SOAP-ENV:Envelope>

<distribution_system_reliability_data>
        <general>
          <cust>900</cust>
          <clr type="kva">1800</clr>
        </general>
        <loadpoint_data>
           <loadpoint_customer_ one="c1">
                <failuremode_device_name brk="m1">
                        <frd>0.10</frd>
                        <mttr type="hour">4</mttr>
                        <for>0.40</for>
                </failuremode_device_name brk="m1">
                <failuremode_device_name brk="m2">
                        <frd>0.25</frd>
                        <mttr
type="hour">0.50</mttr>
                        <for>0.125</for>
                </failuremode_device_name brk="m2">
                </loadpoint_customer>
        </loadpoint_data>
```

The SOAP response for SAIFI and SAIDI services obtained using the proposed model is shown below:

```
<env:envelope xmlns:env="http://schemas.xmlsoap.org/soap/envelope/"
xmlns:enc="http://schemas.xmlsoap.org/soap/encoding/"
xmlns:ns0="urn:reliability"
xmlns:xsd="http://www.w3.org/2001/xmlschema"
xmlns:xsi="http://www.w3.org/2001/xmlschema-instance">
<env:body>
<ns:computeresponse>
<result>
        <distribution_system_evaluation>
                <dsrindices>
                        <saifi>1.04999</saifi>
                        <saidi>2.02257</saidi>
                        -------------------------
                </dsrindices>
        </distribution _system _evaluation>
</result>
</ns:computeresponse>
</env:body>
</env:envelope>
```

In the proposed SOAP communication model, the various reliability services can be invoked by the clients without any limitations. It has been proven that the proposed model is capable of representing the power system problems in heterogeneous environments. The data required for distribution system reliability evaluation are attached in the SOAP body. SOAP based communications are asynchronous in nature when an action is invoked on a service. The provider sends an entire document rather than sending a set of parameters to the clients. However, RPC mechanisms are based on synchronous communication, which has been proven to be much less scalable than an asynchronous pattern, especially in the presence of complex power system processes where many operations with variable response times run concurrently. Hence, the proposed SOAP communication model for reliability analysis makes the distribution system reliability service provider and client to exist in a loosely coupled environment.

IV. Conclusion

An effective XML based SOAP Communication model has been developed to evaluate the reliability of power distribution systems. The implementation of this approach suggested in this paper has been tested for a radial feeder configuration and wide range of reliability indices is evaluated. The proposed model is scalable for any number of power system clients and the reliability services can be invoked without any limitations. The other power system services can also be plugged into this model and the services are made available anytime and anywhere for the power system planning and operations.

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