RSA-Grid: A Framework for Grid Computing Based Power System Reliability and Security Analysis

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Abstract—Grid computing is an emerging technology for providing the high performance computing capability and collaboration mechanism for solving the collaborated and complex problems while using the existing resources. In this paper, a grid computing based framework is proposed for the probabilistic based power system reliability and security analysis. The suggested name of this computing grid is Reliability and Security Grid (RSA-Grid). Then the architecture of this grid is presented. A prototype system have been built for further development of grid based services for power systems reliability and security assessment based on probabilistic techniques, which require high performance computing and large size of memory. Preliminary results based on prototype of this grid show that RSA-Grid can provide the comprehensive assessment results for real power systems efficiently and economically.

Index Terms—Grid Computing, Power system reliability and security analysis, probabilistic reliability analysis, Monte Carlo simulation

I. INTRODUCTION

With the constant expansion in electric power systems due to increase in energy demand the power systems have become more and more complex. Many uncertainties are raised which demand comprehensive reliability and security assessment [1-2] for constant energy supply. Power engineers have to run thousands of times domain simulations to determine the stability for a set of credible disturbances before dispatching [3]. This is more significant in expansion planning. Further with the deregulation in power industry, the operation control is shifted to many organizations, which demand a collaboration mechanism to evaluate the reliability of overall system. Adequacy analysis is needed in power system planning [1] and can be defined as collaborative tasks. Security analysis is associated with the dynamic response of the power system to various disturbances [2] [4]. It is highly desirable to have real time security assessment especially in the market environment [5]. For example, in Australian National Electricity Market (NEM), the system operator needs to obtain security assessment results within 20 minute immediately after a contingency in order to ensure secure operation of the NEM grid. High performance computing power is also needed in case of power systems reliability assessment. Power industry in many countries is facing these challenges and trying to increase the computational capability to handle the ever increasing data and analytical needs for its operations and planning.

The initial methods used for reliability analysis were deterministic and these methods were not capable in satisfying stochastic nature of power systems [4] [6]. Some new techniques for reliability analysis were proposed but not used because of limitations of computational resources. One such example is the probabilistic technique [7] which is able to consider system uncertainties and provide comprehensive results in both reliability and security assessment. Despite its popularity, it is not used much because of lack of data, low capacity of computing resources [3] [7] and/or lack of realistic reliability techniques [6]. As a result, a power system may be subject to system contingencies in operations and the expansion planning options may be more expensive than necessary.

Grid computing is catching up attentions from power engineering experts as one of the ideal solutions to those computational difficulties power industry is facing [8]. It is an infrastructure that involves the integrated and collaborative use of computers, networks, databases and scientific instruments owned and managed by multiple organizations [9]. Grid computing technology can provide services in all the areas of power system including generation, transmission, distribution and electricity market [10]. It is significant contribution in scientific research, oil and gas fields, banking and education [11]. For these purposes serval grid has been implemented successfully including GridPP [12], Globus [13], GridCC [14], Information Power Grid (IPG) [15] and EUROGRID [16].

A limited research is started on different places to investigate the of grid computing in power systems [8] [17].

The objective of this research is to propose and develop a general framework of computing grid for probabilistic based power system reliability and security assessment. The developed grid services will provide comprehensive results with great efficiency, and ultimately will enhance the existing computing capabilities of power companies in a most
economical way. The significance of this research will be the performance, accuracy, secured data sharing and collaboration and most important capability of power system analysis in a deregulated environment involving complex, large size and huge amount of data which are otherwise impossible without huge investment in computing facilities if not grid computing based.

II. ARCHITECTURE OF RSA-GRID

The architecture of RSA-Grid is proposed in three layers as shown in Fig. 1. The first one is resource layer, which forms the hardware part of this computing grid. The second one is regarded as Grid middleware of this RSA-Grid. It provides access of grid resources to the grid services. For this second layer Globus Toolkit [13] is selected. Globus Toolkit based on OGSA [18] standards, which are considered as the de-facto standards for Grid Architecture [19] [20].

![Fig. 1: RSA-Grid Architecture](image)

The third layer consists of RSA-Grid services, which uses the interface of globus toolkit software and execute the algorithms for power system reliability and security analysis. RSA-Grid will use some mandatory grid services provided by globus toolkit along with a set of additional services for the power system reliability and security analysis

A. Resource Layer

The resource layer of RSA-Grid is consists of the physical architecture of the Grid. All the hardware resources are included in this layer. It consists of
- Computers, workstations, clusters of computers
- Communication media (LAN and Internet)
- Data resource: Grid configurations and log history of the events and
- Databases of the power system data related to generation, transmission and load demand.
- Devices to get real time information of power system

The reason of including these data sources in this layer is to provide the abstraction for the grid users and services.

B. Grid Middleware

This layer provides a link between the grid services and grid resources. It provides the access and information about the grid resources to the grid services in third layer.

This layer consists of Globus Toolkit software 4.0 which is standard OGSA platform and provides standard services [13] as shown in Fig. 2. These services are basic grid services and necessary for Grid development. A few globus grid components proposed for grid framework is listed below:

- Common Runtime Components: It provide GT4 web and pre-web services along with the set of libraries and tools that allows these services to be platform independent, to build on various abstraction layers and to leverage functionality lower in the web services stack.
- Monitoring and Discovery System: MDS is a set of web services, those allow the grid users to monitor and discover resources and services on Grids. It consists of Index Service, Trigger Service, Aggregator Framework and WebMDS. Index Service collects monitoring and discovery information from Grid resources. Trigger Service collects data from resources on the grid and perform various actions according to predefined rules. WebMDS enables end users to view monitoring information via a standard web browser interface.

![Fig. 2: Globus Grid Architecture](image)
single virtual high performance machine.

C. Application Layer

This third layer consists of Grid services. These services are divided into three types: Portal service, RSA-Grid services and Core service. The core services are used to manage the resources, communications authorization and authentications, system monitoring and control. The following first five services are classified as core services followed by the Portal and grid services as shown in following Fig. 3.

![Diagram](image-url)

**Fig. 3. Grid Services Layer**

- **Authorization:** This service will provide the service for the authentication and authorization of the grid users to provide the access to the resources according to policies. WS Authorization and Authentication Service Interface of Globus Toolkit are used in this service.
- **Monitoring:** It discovers the information about RSA-services states and the status of resources availability. GT4 MDS Service is used for this purpose. It also maintains a log of all the resources, services and events in Services and Resources Database. WebMDS provides this information in visual form for the grid administrator/user through portal service.
- **Schedule and Execution Service:** This service controls the execution of the RSA-Grid services in real time or according to the schedule timeframe. Communication Schedular Framework (CSF) provides the interface for this service. It provides the facility for Grid users to submit jobs and advanced job reservations. It finds the resources and services algorithms through monitoring service, allocates the resources for required services and makes the execution plan. It also mange and coordinate the execution of RSA-Service.
- **Registry:** It maintains the information and current status of all the resources and services and priority description status of job submission and response status. This is used for service execution and updates a table for all information at run time.
- **Database Management:** This service is responsible for access of the database in the grid system. This is used for data transfer across the nodes over the whole grid system. GridFTP of the globus toolkit will be used to provide such functionality. OGSA-DAI provides service framework for accessing and integrating data resources of the power systems.

- **Portal:** This service provides the uniform web based interface for grid users due to heterogeneity of the grid system. It also provides the different interfaces for job submission, result presentation and grid monitoring status through WebMDS. It also provides the interface for power system data entry by different organizations.
- **RSA-Grid Services:** This is the set of services for actually performing the reliability and security assessment of the power systems. These will be developed by using C/C++/Visual C++ and Matlab Power System Toolkit Box. The input parameters and out put for each service will be defined.

The Integration and interaction of these components of both layers is shown in Fig. 4. The functionality of these components helps in successful implementation of the RSA-Grid.

![Diagram](image-url)

**Fig. 4. RSA- Grid Services**

III. GRID SERVICES EXECUTION

Each grid node consists of all services suggested at application layer. The following Fig. 5 shows the interaction and execution of all these services for probabilistic reliability assessment.

- **User enters the power system data through portal service, which use Database Management service to get access to power system database.**
- **Authorization service checks the user’s authentication at the time of login and will provide authorization to grid resources and services according to defined policies.**
- **Monitoring Service keeps the track of services status available resources and will maintain a log of all the events happen in the whole Grid. One of its component WebMDS presents the monitoring status to administrator/user through Portal.**
- **Once user enters some request, it goes to Schedule & Execution service. This service gets the status of available resources and the required RSA-Grid service from the Monitoring service. Then it allocates the required resources to that RSA service from the available resources and invokes the required service at schedule time on the available resource in the whole grid.**
Specific RSA-Grid service loads the power system data from the database and performs the reliability analysis and forwards the results to the RSA-results database.

During the RSA-Grid service execution the Registry service maintains the information at run time of jobs submission, completion status and status of assigned resources to each job. After the completion of the job the Schedule and Execution service presents the results to the user through Portal service.

- RSA-Grid service for small system stability analysis: This service performs the analysis according assigned number of iterations from the master system.
- Resource Monitoring Agent: This is an agent service, notifies the master server of its existence for the whole of its lifetime period.
- Portal: This is desktop application deployed on each system so that request can be generated from any system. One computer system also serves as master server and has an additional role. Two core services are implemented initially on this master server.
- Resource monitoring service: It keeps the track of all available processors on the prototype grid.
- Task distribution and scheduling service: It accepts any request for power system analysis, and distributes the task to available resource with load balancing mechanism.

At this stage any system included in prototype grid and having CPU usage less than 10% is considered as available resource. All processing nodes perform the assigned task and send the results back to master server for merging.

The data of power system configuration including the nodal loads and generation outputs is stored on the master server, which is accessible to the services running on all processing nodes. Visual C++ is used along with WinSock library for development of prototype grid and Matlab is used in grid service for power system analysis support.

Asynchronous mode of communication is used by implementing the UDP protocol. This communication-mode helps in logically plug-in and plug-out the computer systems from the grid without any prior hand shaking mechanism. Once the processing node activates in the grid, the resource monitoring and service monitor their life time through its running agent on that node.

IV. PROTOTYPE OF RSA-GRID

To demonstrate the function of this RSA-Grid and to prove the capability of providing the high performance computing (HPC) power through combine use of large size of memory a prototype system is designed. Small signal stability assessment using the Monte Carlo simulation is selected as a reliability analysis case for our experiment. This assessment requires HPC and large size of memory in order to provide the comprehensive results. A Grid service was developed for this case as first milestone in our research. This service reveals the oscillation modes and damping conditions in detail and in limited time.

Physical Architecture and Grid services

This prototype system is developed in power system research lab with consisting of 15 computers (Pentium –IV with 2.8 GHz, 512 MB Physical memory and Window XP operating system). All computers are connected to each other over the local area network with bandwidth 100Mbps.

The architecture of this prototype is given in Fig. 6. All computer systems serve as processing nodes. Two services are deployed on each computer system included in the prototype grid along with Portal as grid interface.

- RSA-Grid Service for small signal stability analysis
- Task distribution and scheduling service
- Desktop Portal
- Resource Monitoring service
- Resource Monitoring agent
- RSA-Grid Service for small signal stability analysis
- Resource Monitoring agent
- Desktop Portal
- ...
processing efficiency in grid based environment. Second experiment is carried out on New England system [21], [22], which is larger one with 10 generators and 39 busses and also observed the increase in computing performance and accuracy by collaboration of more systems in the processing as shown in Fig. 7. In these experiments, the prototype computing grid has shown excellent performance of computational accuracy and stability without interruptions of the computing process.

A. Case Study 1

For small system, this analysis takes 38 minutes and 20 seconds approximately on single computer, while the same task is completed in 3 minutes and 24 seconds approximately by collaboration of 10 computers. This is observed that, by increasing the \( k \) number of machines in the processing collaboratively, the efficiency in processing speed is achieved more than \( k \) times. This is because of task distribution and availability of more processing power and large size of memory. With single computer the array is generated for all iterations i.e. 10000 and this occupied most of the physical memory, due to which efficiency is decreased. While with the use of \( k \) computers, the generated array was approximately \( k \) times smaller than the previous one, through which more physical memory was available for computing and this factor influenced positively on processing speed.

B. Case Study 2

Second case also confirms the increase in computing performance by performing analysis on prototype grid as shown in Fig. 7. With 5 computers, the analysis is completed in 63 minutes and 6 seconds approximately. The same task is completed in 26 minutes and 52 seconds with 10 computers and with 15 computers this task was completed in about 16 minutes and 41 seconds approximately.

In graph the minimum number of computers showed for second case is 4. This experiment is also attempted with 3 computers but was unsuccessful in getting the result in reasonable time span, as this was completed in took 22 hours 2 minutes and 20 seconds. This was due to gradual increase in arrays size and limited size of physical memory, due to which the execution became slow.

C. Communication Overhead

These experiments were performed on local area network with high bandwidth. But this is believed that by expanding this prototype grid over the Internet and running this service on remote location will not affect the overall computing performance as much as compare the efficiency is achieved by using the grid technology. Because with the advancement in communication technology, the communication delay over the Internet is very much negligible. In order to prove this, round trip delay is measured by pinging one server over the LAN and two remote servers over the Internet, whose results are given in following Table I.

<table>
<thead>
<tr>
<th>System</th>
<th>Approximate round trip times in milliseconds</th>
</tr>
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<tbody>
<tr>
<td>Local Gateway server</td>
<td>Min.</td>
</tr>
<tr>
<td>[130.102.67.254]</td>
<td>1</td>
</tr>
<tr>
<td><a href="http://www.bbc.net.uk">www.bbc.net.uk</a> [212.58.240.33]</td>
<td>266</td>
</tr>
</tbody>
</table>

Table shows that the round trip delay for a server in USA from Australia is on the average 269 milliseconds, while for the server in UK, this is 281 milliseconds. By running this service over the Internet will add in the cumulative processing time equal to one round trip delay in overall processing time, which is less than half second in given results.

D. Analysis and Discussion

At this stage two experiments were conducted for assessing the probabilistic small signal stability over the prototype grid consisted of 15 computers with two different configurations of power systems as given in case studies. The results show that Grid computing technology is the future technology [23] for meeting the computing demands for power systems analysis. It provides high performance computing through combining the processing power of ordinary computers with accuracy and stability. Grid computing provides loosely coupling mechanism for adding the computer systems for the grid and handling resources dynamically. By adding more computers in the grid, more efficiency can be achieved. At this stage, we are now able to explore more scenarios for the power system analysis in further research.

VI. CONCLUSION AND FUTURE SCOPE

A. Conclusion

Grid computing is an emerging technology with providing significant contribution in providing high performance
computing (HPC) with existing IT infrastructure. In this paper, a computing grid based framework was proposed for meeting the computational demands of HPC and large size of memory for the probabilistic based reliability and security analysis. Grid computing with its characteristics provides economical and efficient solution to provide the required computational needs for getting fast and comprehensive results of very large and complex systems. This framework also provides the infrastructure for secured data sharing and mechanism of collaboration between the different entities of the electricity market.

B. Future Development

Research is continued in our research lab by the collaboration of computer scientists and electrical engineers in investigating the computational needs in power systems and finding their solutions. The framework proposed here gives a clear vision about the future development of utilizing grid computing technique into power systems computations. In our going research a computing grid will be developed based on this proposed framework. It will provide access to the grid users of different organizations of the electricity market including generation and transmission companies and ISO. The heterogeneous resources will be used belonging to different organizations with different kind of access rights. The distributed databases will be used for secured data sharing for market operations related to overall reliability and security assessment of whole power systems. It is also planned to deploy 2-3 nodes of this computing grid at remote locations over the Internet in order the make it more effective over vast area.

VII. REFERENCES

[12] GridPP, UK Computing for Particle Physics, [http://www.gridpp.ac.uk]